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ARTIFICIAL INTELLIGENCE AND PRODUCTIVITY: CHALLENGES AND OPPORTUNITIES

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7th International Scientific Conference: Economics of Digital Transformation

ARTIFICIAL INTELLIGENCE AND PRODUCTIVITY: CHALLENGES AND OPPORTUNITIES

Conference Proceedings

FOREWORD

Welcome to the proceedings of the 7th International Scientific Conference on the Economics of Digital Transformation, held in Opatija, Croatia, from June 19 to 22, 2024. This year's conference focused on the captivating topic of "Artificial Intelligence and Productivity - Challenges and Opportunities". The integration of artificial intelligence (AI) into various sectors of the economy presents both unprecedented opportunities and significant challenges in the rapidly evolving landscape of digital transformation. This conference brought together leading researchers, industry experts, policy makers and practitioners exploring the diverse impact of AI on productivity, the workforce and the wider economy.

We would like to thank all our keynote speakers: Peter Nijkamp and Tomasz Kozluk for their speech on the impact of AI and Carlos Moreno, Carlo Ratti, Karima Kourtit and Peter Nijkamp for their speech on the X-Minute City. We would also like to thank all the panelists: Christian Ketels, Peter Nijkamp, Catherine Gall and Lara Jelenc for "Reimagining Economics: What Next?", Carlos Moreno, Carlo Ratti and Nicos Komninos for "Decoding Resilience, Sustainability and Efficiency"; Carlo Sessa, Jelena Stanković and Saša Čegar for "Empowering Long-Term Urban Resilience and Prosperity: Fostering A Regenerative Economy in European Cities", and B. J. Fletcher, Ivan Gržeta, Edward (Ned) Hill, Predrag Pale and Dragan Vukmirović for "The Impact of AI Technology on Government, Industry and Science". These contributions have enriched this conference and advanced our collective understanding of the economic dynamics of AI. We would also like to thank our sponsors and organizing committee, whose efforts contributed to the success of this event. We extend our heartfelt thanks to Alan F. Unger and the Unger Foundation for their generous support through the Unger Panel and the Unger Program, which made the organization of this conference possible. Finally, we are also very grateful to all our contributors, reviewers, program and organizing committee members, partner universities and sponsors. A special thanks goes to those students, whose knowledge, professionalism and hospitality were warmly commended by our guests. The best papers from the conference have been selected for publication in the international journal Proceedings of Rijeka Faculty of Economics-Journal of Economics and Business (Vol. 42, No. 2, 2024).

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INTRODUCTION

Artificial intelligence is no longer just a distant concept for the future but a present reality influencing industries and economies worldwide. As AI continues to advance, its role in increasing productivity and transforming the world of work is becoming ever more important. This conference proceedings summarizes the wealth of shared knowledge and the key findings of the 7th International Scientific Conference on the Economics of Digital Transformation. Our distinguished speakers and contributors have provided invaluable perspectives on the benefits and risks of AI adoption. From improving production efficiency and personalizing customer experiences to the economic impact and ethical considerations, these contributions reflect a comprehensive examination of the impact of AI. Our aim is to provide a deeper understanding of how AI can increase productivity by exploring related challenges such as job displacement, inequality and ethical concerns. By fostering an interdisciplinary dialog and collaboration, we aim to contribute to the development of sustainable and inclusive strategies for the use of AI in the digital economy.

The first series of articles deals with digital transformation and the use of AI in public administration and regulation. The recent CJEU ruling in the SCHUFA (scoring) case highlights the challenges and opportunities of using AI-supported automated decision making to increase productivity but, at the same time, also raises critical questions about data protection and employee rights under EU labour law. The use of AI in eHealth and personalised medicine increases productivity by enabling tailored therapies based on genetic profiles but its use carries significant technical, legal and ethical challenges that need to be addressed to ensure the protection and appropriate regulation of genetic data and biobanks. AI-powered analytics could effectively assess and enhance public sector efficiency by increasing productivity through e-government systems and demonstrate how public sector digitization increases productivity and economic growth by streamlining processes, reducing corruption and encouraging private sector investment. AI-enabled digitalization in public administration, particularly under the EU's Next Generation initiative, highlights the potential for productivity gains through algorithmic processes while addressing the need for adequate training and coordination of civil servants to uphold constitutional principles and ensure efficient service delivery.

The second series of articles refers to the impact of digitalization and innovation on economic development. In this sense, our authors emphasize the crucial role of external knowledge from sources such as customers, universities, suppliers and consultants in increasing productivity and innovation in companies. The phenomenon of virtual influencers in digital marketing highlights the opportunities and challenges for companies using AI-driven influencers to increase productivity and reach younger generations who value authenticity, ethics and product quality in their interactions and purchasing decisions. In addition, by using natural language processing (NLP) and sentiment analysis to examine customer reviews and feature descriptions, companies can uncover important themes and insights about user satisfaction to develop AI-driven marketing strategies and increase productivity.

The third series of articles refers to topics related to artificial intelligence and Industry 4.0. Advances in AI, such as machine learning and predictive analytics, are revolutionizing financial sector tasks including risk management, fraud detection and investment strategies, thus highlighting the transformative potential, challenges and opportunities of AI for the financial

industry. By systematically analyzing high-quality sources from large databases, our authors identify key research topics and gaps that focus on challenges related to the integration of AI, the current attitudes towards AI and its trustworthiness in the public sector. This should guide future research towards a more nuanced understanding of the impact of AI on public administration and governance practices. Furthermore, our authors discuss the financing of cleantech innovation by assessing the role of crowdfunding as a viable alternative to traditional financing mechanisms. By examining EU equity crowdfunding platforms for cleantech projects, critical success factors such as the number of investors, the promised internal rate of return (IRR) and the investment horizon are identified.

The final set of contributions explores topics related to modern management, organization and marketing, focusing on how digitalization and emerging project management approaches are set to reshape the role of the project manager in the future. Research shows that the traditional role may be transformed due to the emergence of self-organized teams and agile practices, and suggests implications for leadership development, curricula and strategic planning in project management. Another contribution in this area advances the understanding of lean implementation within the context of Industry 4.0 by presenting a novel model that connects key success factors and challenges identified in the literature. This model not only expands the theoretical framework for lean practices, but also provides practical guidance for applications in education and business improvement. By using computational techniques such as the Newton's method to solve nonlinear equations in a duopoly scenario, one of the articles provides a detailed understanding of the interplay between offensive and defensive marketing efforts. This approach not only bridges the gap between theoretical knowledge and practical applications, but also emphasizes the importance of using advanced computational tools for strategic decision making to increase productivity and gain competitive advantages in dynamic markets.

We are confident that these scientific contributions will offer our readers valuable insights and fresh perspectives. We trust you will find the authors' work both provoking and engaging. As we conclude, we warmly invite you to join us at our next conference, where we will continue to expore and share groundbreaking ideas.

Automated Decision-Making and Algorithmic Management: Implications of the CJEU's *SCHUFA (Scoring)* Case for the EU Labour Law

Adrijana Martinović[1]

ABSTRACT

Praised by many as a landmark ruling with wider impact on AI-powered automated decision-making systems across sectors, and equally criticised for creating systemic fissures in the GDPR framework, the recent judgment by the Court of Justice of the European Union in SCHUFA (scoring) case (C-634/21) concerning the interpretation of Article 22(1) GDPR deserves to be scrutinised in light of its potential implications for the EU labour law and the regulation of algorithmic management practices. Employers increasingly rely on automated systems to support or fully automate their management decisions. The use of automated decision-making systems in the recruitment and/or employment context largely falls back on the general data protection rules. However, there are limits, ambiguities, and potential gaps regarding their application that could undermine the workers' protection, and bring into question regulatory compliance. The emerging EU legislation, such as the proposed Platform Work Directive (COM (2021) 762), aims to provide specific obligations concerning algorithmic management. Even if this legislation is passed, it will apply only in the context of platform work, and not in "traditional" employment, which could result in different levels of protection. The question about the nature and scope of Article 22 GDPR in the employment context therefore remains relevant. This paper will critically evaluate the findings from the SCHUFA (scoring) case and explore their impact on the current and future regulation of algorithmic management. The aim is to propose workable solutions that harness the benefits of legitimate algorithmic management practices, while safeguarding the workers' rights in the AI-driven world of work.

Key words: *algorithmic management, automated decision-making, EU labour law, Artificial Intelligence Act, Platform Work Directive*

JEL classification: *J81, K31*

1 Introduction

In the AI-driven and digitalised world of work, the intersection between labour law and data protection law is inevitable. This is especially true in view of increasingly used algorithmic management practices. Algorithmic management can be defined in technical terms as "the use of computer-programmed procedures for the coordination of labour input in an organisation" (Baiocco et al., 2022). In other words, it means a delegation of managerial functions to automated systems (Jarrahi et al., 2021). It involves a set of tools and "workplace practices that

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rely on digital devices or software to either partially or totally automate functions traditionally exercised by managers and supervisors" (Aloisi and Potocka-Sionek, 2022). In more practical terms, the definition highlights the algorithmic management's potential to automate "the full range of traditional employer functions, from hiring workers and managing the day-to-day operation of the enterprise through to the termination of the employment relationship" (Adams-Prassl et al., 2022).

It is not a "new thing", but a *"continuation of very long historical trends of rationalisation or bureaucratisation of economic activity and the organisation of work"* (Baiocco et al., 2022). However, it has an enormous disruptive potential, as it combines technological development and the ability to collect, store, process and built the massive amounts of data into organisational and work processes, thus reshaping the power balances at workplace (Baiocco et al., 2022).

Algorithmic management has outgrown the boundaries of its original deployment in the context of platform work,[2] transitioning seemingly effortlessly into the conventional labour arrangements (see Aloisi and Potocka-Sionek, 2022; Adams-Prassl et al., 2022). Algorithmic management practices, such as work allocation, direction, real-time monitoring, evaluation, "nudging", etc. are increasingly used in the traditional or conventional work setting (Wood, 2021). The use of artificial intelligence (AI) tools that can boost these practices is growing in human resources management (see De Stefano and Wouters, 2022; Lechardoy, López Forés and Codagnone, 2023), as evident from the overview of available literature (Palos-Sánchez et al., 2022). As rightly claimed, the regulation of algorithmic management falls under multiple legal domains (Abraha, 2023). Where labour law currently fails to offer adequate protections to workers, data protection law, as well as anti-discrimination law, or occupational health and safety law should step in to cover the gaps, if possible. This paper aims to identify and analyse the interplay of the various existing and emerging EU rules on the protection of workers in the context of algorithmic management practices.

In the following section, we will briefly outline the subtleties of the key terms used (2), and proceed with analysing the existing and emerging EU legislation concerning algorithmic management practices. We will first focus on the prohibition of automated individual decision-making under the GDPR, based on the recent interpretation of Article 22(1) GDPR by the Court of Justice of the EU (CJEU) (2.1). We will then turn to the proposal of the Draft Platform Work Directive (DPWD), which aims to regulate algorithmic management in platform work (2.2). The third part of our analysis will explore the algorithmic management from a different angle: the regulation of AI systems deployed in this context by the freshly adopted AI Act[3] (2.3). We will then test the coherence between these instruments on a hypothetical example (3), and conclude by offering some perspectives for further development (4).

The methodology is based on desk research and analysis of academic literature, legal sources and case law.

[2] "Platform work" usually describes the form of work performance characterised by a multi-sided market where services are provided "on-demand", and online platforms act as intermediaries between platform workers and clients (see Bodiroga-Vukobrat and Martinović, 2019; Grgurev and Bjelinski Radić, 2023).

[3] At the time this paper was completed, the AI Act was adopted by the European Parliament. However, the legislative procedure is still not finalised, as the Act will have to go through the lawyer-linguist check before final endorsement in the Council. Since the completion of this process and publication in the Official Journal is expected after submission of this paper, it will refer to the latest publicly available version of the text which was subject to vote in the European Parliament, see European Parliament (2024b), available at: <https://www.europarl.europa.eu/doceo/document/TA-9-2024-0138_EN.html>. A reference to particular provision of the AI Act in this paper will therefore rely on the numeration of its provisions from the above document, and refer to the "Draft AI Act".

2 Algorithmic management and automated decision-making

Algorithmic management and automated decision-making should not be used as completely synonymous terms (see to the contrary, Abraha, 2023). Algorithmic management implies a symbiosis between technological and social forces (Jarrahi et al., 2021), and equalising it with automated decision-making puts too much emphasis on the technological part, overlooking some of its important features. First, the level of automation and human intervention in algorithmic management may vary (Baiocco et al., 2022; Wood, 2021). Algorithmic management relies on data and metrics, as well as diverse technological and computing tools, but there are various degrees in which they feed into and influence the final decision affecting the workers' position (various degrees of automation, from full to supportive). Especially in the conventional work setting, the role of human actors might be more pronounced than in the context of platform work. On top of that, there is a risk that automated decision-making might be assimilated with *solely* automated decision-making, which is not correct either.

Second, automated decision-making may have a distinct legal meaning in various legal contexts (see Rodríguez de las Heras Ballell, 2022; Hofmann, 2023), whereas algorithmic management (still) does not (see infra 2.2.). Automated decision-making does not necessarily involve personal data processing either. But when it does, we talk about distinct legal rules for automated processing and solely automated processing in the field of data protection, notably about the automated individual decision-making within the meaning of Article 22(1) of the General Data Protection Regulation (GDPR), which is prohibited unless exceptions apply.

2.1 Automated decision-making and GDPR

In data protection law, the GDPR is relevant for automated processing of personal data, for example in the context of profiling and automated individual decision-making. Under GDPR, profiling is a specific technique which relies on automated processing of personal data with the objective to evaluate certain personal aspects, such as predicting performance at work, creditworthiness, etc. (Article 4(4), GDPR). It is important to highlight that there is no general ban on profiling: data processing for the purpose of profiling is permitted (Recital 71 GDPR; Paal, 2023). Profiling does not exclude human input (Bygrave, 2020b). However, when a profiling result is the basis for a *solely* automated decision-making, Article 22(1) GDPR kicks in. Solely automated decision-making refers to the ability to make decisions by technological means without human involvement (WP29, 2018). This means that automated decision-making may partially overlap or result from profiling, and that they can, but do not necessarily have to be, different activities (WP29, 2018).

In the context of automated individual decision-making, an individual has the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her (Article 22(1), GDPR). The theoretical disagreement whether this right is a qualified prohibition, protecting data subjects from being *"mere objects of algorithmic-based decision"* (Paal, 2023), or a right that has to be effectively exercised by data subject (Bygrave, 2020a; Sancho, 2020), has been resolved by the CJEU in the *SCHUFA (scoring)*[4] (C-643/21) case in favour of the former:

[4] For simplicity, the case will be referred to hereinafter only as *"SCHUFA"*. The case should not be confused with another case involving Schufa Holding AG as intervener, concerning the interpretation of other provisions of GDPR (see Joined Cases C-

Article 22(1) GDPR *"lays down a prohibition in principle, the infringement of which does not need to be invoked individually by such a person"* (*SCHUFA* judgment: para. 52). The exception from this provision applies if the decision (a) is necessary for entering into, or performance of, a contract between the data subject and a data controller; (b) is authorised by Union or Member State law to which the controller is subject and which also lays down suitable measures to safeguard the data subject's rights and freedoms and legitimate interests; or (c) is based on the data subject's explicit consent (Article 22(2), GDPR), with the obligation of data controller in the cases referred to in points (a) and (c), to implement suitable measures to safeguard the data subject's rights and freedoms and legitimate interests, at least the right to obtain human intervention on the part of the controller, to express his or her point of view and to contest the decision (Article 22(3), GDPR). All three alternative conditions require further interpretation, and may be problematic from the labour law perspective. For example, the imbalance of power, which characterises employment relationships, challenges the assumption that explicit consent by the data subject (employee) is provided freely and with thorough understanding of its implications (EDPB, 2020; Adams-Prassl et. al., 2022). Stricter rules for justification of decisions based on special categories of personal data (referred to in Article 9(1), GDPR; such as data revealing racial or ethnic origin, etc.) apply (Article 22(4), GDPR).

As with other personal data, data subject has the right to obtain information from the controller whether his or her personal data is being processed, and to access the personal data and information prescribed under Article 15 GDPR. This includes the information on the existence of automated decision-making, including profiling, referred to in Article 22(1) and (4) GDPR and, at least in those cases, meaningful information about the logic involved, as well as the significance and the envisaged consequences of such processing for the data subject (Article 15(1)(h), GDPR) (on the effective exercise of the right to information under GDPR in general see Wachter, Mittelstadt and Russell, 2018).

This framework is relevant for the context of algorithmic management. Evidence from the EU Member States shows increasing importance and interconnectedness between labour law and data protection law concerning the impact of automated decision-making practices at work (Barros Vale and Zanfir-Fortuna, 2022). National courts and data protection agencies tend to recognise the complexity of legal and factual considerations associated with the application of GDPR provisions and principles on automated decision-making in the field of labour law, but interpretations of the relevant legal framework are divergent (Hiessl, 2023). This is why it is important to have at least some guidance from the CJEU. However, the first time that the CJEU had the opportunity to clarify and interpret Article 22(1) GDPR was in December 2023, in the case *SCHUFA* (C-643/21). This interpretation is liable to have an important impact for algorithmic management and the application of automated monitoring and decision-making systems at work, even though its factual background involves automated decision-making and scoring in the context of loan applications.

2.1.1 The *SCHUFA* case: the scoring result as a decision within the meaning of Article 22(1) GDPR

The *SCHUFA* case originates from a dispute involving the applicant, OQ, and the German Land Hesse, whose appointed Data Protection Officer refused to order Schufa Holding AG to grant

26/22 and C-64/22, *SCHUFA Holding (Discharge from remaining debts)*, ECLI:EU:C:2023:958), and which was decided by the Court on the same day as the *SCHUFA (scoring)* case.

OQ access to and erasure of her personal data. Schufa is a credit scoring company that provides its partners with information on the creditworthiness of third parties, consumers in particular. Schufa establishes its prognosis on the probability of a future behaviour (score), such as a repayment of a loan, based on certain characteristics of that person, and applying mathematical and statistical procedures. The outcome of such "scoring" is based on the assumption that by assigning a person to a group of other persons with comparable characteristics who have behaved in a certain way, similar behaviour can be predicted. Relying on a negative scoring provided by Schufa, a bank refused to grant a loan to OQ. So, the underlying question here was whether the establishment of a probability value, such as the credit scoring in the case at hand, constitutes an automated individual decision-making under Article 22(1) GDPR, and if so, does it cover the activity of a company such as Schufa, which does not grant loans itself. The referring national court (*Verwaltungsgericht* Wiesbaden) describes a strong reliance of the bank on the scoring results, and highlights a very realistic risk of a gap in legal protection, if Article 22(1) GDPR would not be applicable until the third party (a bank) takes a decision with regard to data subject (i.e., to grant or refuse a loan). If that were the case, data subject would be left entirely without protection, because first, Schufa would not be obliged to grant the right of access by the data subject to the personal data and information about the logic of automated decision-making under Article 15(1)(h) GDPR, and second, a third party (e.g. a bank refusing a loan) would not be able to provide the data subject such information, simply because it does not have it. Against this factual and legal background, the Court chose to adopt a broad reading of Article 22(1) GDPR, and interpreted the concept of "automated individual decision-making" from that provision to include the automated establishment of a probability value based on personal data, where a third party draws strongly on that probability value to establish, implement or terminate a contractual relationship with that person.

This reasoning is supported by the literal, contextual and teleological interpretation. According to the Court, the wording of this provision clearly entails three cumulative conditions for its application: there must be a "decision" that is based "solely on automated processing, including profiling", which "produces legal effects concerning [a person] or similarly significantly affects him or her". Although the concept of "decision" is not defined in GDPR, it is apparent from its wording that it is very broad, capable of including various acts affecting data subject in many ways. Examples of "decisions", as evident from Recital 71 GDPR, include automatic refusal of an online credit application, or e-recruiting practices without any human intervention. Concerning the second condition, it was common ground in this particular case that the activity performed by Schufa is profiling, within the meaning of the definition from Article 4(4) GDPR. As regards the third condition, the factual finding of the referring court, namely that a third party "draws strongly" on the probability value established by Schufa, where an insufficient probability value leads, in almost all cases, to the refusal to grant a loan, is a viable indication that the probability value itself affects the data subject significantly. This is further corroborated by the context and the objectives and the purpose of GDPR. Article 22(1) GDPR gives data subject the right not to be subject solely to automated decision making, including processing. The Court adheres to the widely accepted doctrinal position (see Paal, 2023) that this is a prohibition in principle, which does not have to be invoked individually by each person. A combined reading of Article 22(1) and Recital 71 GDPR allows the adoption of a decision based solely on automated processing only in cases referred to in Article 22(2) GDPR, i.e. where a decision is necessary for entering into or performance of a contract, where it is authorised by an EU or Member State law, or where data subject provides explicit consent. Such exceptions should be accompanied by suitable measures to safeguard data subject's rights and freedoms and legitimate interests, at least including the right to obtain human intervention, to express data subject's view, and to contest a decision. These enhanced requirements for lawfulness of

automated decision making are explained by the purpose of Article 22 GDPR, which is to protect the individuals against risks to their rights and freedoms posed by such activities. Therefore, a restrictive interpretation of Article 22 GDPR, whereby the establishment of a probability value would be considered merely as a preparatory act, and only the act of a third party as a "decision" within the meaning of this provision, would risk circumventing this guarantee and creating a gap in legal protection. As highlighted by AG Pikamäe, when the final decision is purely formal because "a score established by a credit information agency and transmitted to a financial institution generally tends to predetermine the financial institution's decision to grant or refuse to grant credit to the data subject", the score itself must be regarded as a "decision" within the meaning of Article 22(1) GDPR (Opinion of AG Pikamäe, 2023).

2.1.2 Implications of the *SCHUFA* judgment for labour law and algorithmic management

The *SCHUFA* judgment brought an important clarification of Article 22(1) GDPR, but this is just the beginning. What we know after *SCHUFA* is that the concept of "a decision based solely on automated processing" from that provision is broad enough to encompass a credit scoring, because it is capable of affecting the data subject when the final decision "draws strongly" on it. Therefore, it is a broad concept, encompassing a *"number of acts which may affect data subject in many ways"* (*SCHUFA* judgment: para. 46). There is also instruction on how to assess whether the national legal rules on profiling could be deemed as an exception from the prohibition of individual automated decision-making. Given that the Court was constrained by the facts of the case, other important concepts are still in need of clarification, despite the guidance offered by Article 29 Data Protection Working Party on automated individual decision-making and profiling (WP29, 2018). What we do not know in great many detail is to what extent a human involvement affects the status of "solely automated" decisions; and what, if any, legal weight should be ascribed to "legal effects" produced by the solely automated individual decisions, as opposed to "similarly significant" effects of such decisions. Should these two concepts always be viewed jointly, as the judgment seems to suggest (*SHUFA* judgment: para. 50). What characterises a "significant" effect? Could it, in the context of employment relations, be taken to mean any decision which significantly affects the core interests of workers, i.e. work opportunities and wages, as already emerging from interpretations by some national courts (Hiessl, 2023)? How can one interpret exceptions from the prohibition, provided in Article 22(2) GDPR, especially concerning data subject's consent? This is not just a theoretical debate, as evidence from the national jurisdictions shows that national courts do struggle with these concepts, especially in the context of (platform) work (Hiessl, 2023). This will be especially pertinent for algorithmic management practices in platform work, because that business model heavily relies on automated decisions based on data processing and taken in real time, and human involvement and monitoring of these decisions is in many cases either technically impossible, or just a formality, at best. A way to overcome this, as Adams Prassl et al. (2023) suggest is not just by simply banning fully automated practices (human in the loop), but also by providing for a human involvement at other stages of a decision-making process (review, information and consultation, and impact assessment). In any case, the scope of Article 22(1) GDPR will affect any such consideration (see Martini, 2020).

In terms of GDPR and consumer protection, some authors point to inconsistencies in adopting a broad interpretation of "decision" in *SCHUFA* judgment, by concentrating on the specific relations between credit institutions and credit scoring companies. It is argued that the gap in protection ensuing from a stricter interpretation of Article 22(1) GDPR could be filled by a

more proactive role of credit institutions to ensure that customers have access to the relevant information on the processing of their data, through contractual relations with credit scoring companies, if necessary (Paal, 2023). It is also argued that it makes more sense for the customers to apply and obtain the relevant information from the credit institution, without having to go through the credit scoring company first, which partly contradicts the consumer protection guarantees (Paal, 2023). While it is true that many such objections make sense, it is necessary to turn to the broader implications of this decision. Its impact reaches beyond the data protection law and consumer protection considerations, and is especially relevant in the context of AI applications for algorithmic management and automated decision-making. For example, AI recruiting tools have become omnipresent (see Kelly, 2023). They work in a similar manner: think of the programme going through hundreds of CVs to suggest the most suitable candidates for a job. It will automatically exclude certain job applications, and by doing so, it will do more than just match the applicant's skill with the job description. The inner programming is the tricky part, and AI empowered technology goes beyond keywords matching and into the deep learning techniques, resulting in transparency and explainability issues (Abuladze and Hasimi, 2022; Hunkenschroer and Luetge, 2022). Even if it is claimed that human makes the ultimate decision regarding, for example, whether and whom to call to a job interview, "suggestions" made by the automated system could be considered as "decisions" in the light of Article 22(1) GDPR and *SCHUFA* judgment, whether they are transmitted to the employer by a third party, or whether the employer applies a system bought from and developed by a third party or not (see similarly, Aloisi and De Stefano, 2022). Issues could also arise in connection with the assessment of the degree of significance of effect of the screening decisions on some applicants (Parviainen, 2022). Consider automated worker monitoring systems that track worker's productivity and assign tasks or consequences based on this input: is a human truly actively involved in considering the results of monitoring, or merely serving as a passive and formal "vessel" for the ultimate decision driven primarily by automation? This becomes even more critical in real-time worker-customer matching and work allocation decisions in platform work.

2.2 Automated decision-making in employment and the regulation of platform work

As explained, apart from the mentioned Article 22(1) GDPR, there is currently no specific provision of EU labour law directly protecting the workers from automated decision-making. The Directive 2019/1152 on transparent and predictable working conditions prescribes minimum requirements concerning the workers right to safe and transparent working conditions in view of adaptation of the labour market to the digital innovation. Assurances provided in the Directive, especially concerning predictability of the work schedule and work patterns, will have to be taken into account in the context of algorithmic management and automated decision-making. However, pending the adoption of the proposed Directive of the European Parliament and of the Council on improving working conditions in platform work (European Commission, 2021a); the Draft Platform Work Directive or DPWD), there is currently no specific legal regime applicable for highly automatized work relations, such as those concerning platform work.

The Draft Platform Work Directive is currently in the legislative process. Drawing on specific legal challenges identified in practice (see, e.g. Agosti et al., 2023; Hauben et al., 2021), it will prescribe obligations for digital labour platforms in connection with the automated monitoring and decision-making systems. Its general objective is to improve the working conditions and the social rights of people working through platforms, whereas ensuring fairness, transparency

and accountability in algorithmic management in the platform work context is one of its specific objectives. This includes protection from harm arising from algorithmic management practices, in view of its impact on income and working conditions, models of control and subordination, transparency and access to information and remedies, as well as its potential for gender bias and discrimination. The Commission's proposal refers specifically to "algorithmic management", which is the first time that this term will be used as such in the legislation. It is important to mention, however, that "algorithmic management" in the proposed Draft Platform Work Directive is understood in the narrow terms, confined to elements inherent to digital labour platform's business models. There is no legal definition in the text itself, but the explanatory memorandum makes it clear that it refers to the *"use of automated systems to match supply and demand for work"* (European Commission, 2021a). Although many of the initially proposed provisions will probably be altered as a result of the negotiation process, it is useful to take a look and briefly analyse the provision of Chapter III of DPWD entitled "Algorithmic management". In the initial Commission's proposal this Chapter is comprised of five articles (Articles 6 – 10, DPWD), which regulate the obligations of digital labour platforms to ensure transparency in the use of automated monitoring and decision-making systems, human monitoring of automated systems and their decisions, human review of significant decisions, including the corresponding right for platform workers to obtain an explanation from the digital labour platform for any such decision, to inform and consult with platform workers' representatives or themselves on algorithmic management decisions, as well as appropriate safeguards for genuinely self-employed platform workers in connection with automated systems. Additional guarantees were inserted in this Chapter during interinstitutional negotiations, along with amendments of the existing provisions, such as clearer limitations regarding the type of personal data to be processed by means of automated decision-making systems, and express reference to data protection impact assessment pursuant to Article 35 GDPR (European Parliament, 2024a).[5]

As evident, these are all crucial aspects of the digital platforms' business model, where important safeguards of workers' rights at EU level are currently inadequate. The explanatory memorandum particularly highlights the difficulty to "draw the line between algorithmic decisions that do or do not affect workers in a sufficiently "significant way", and the ensuing difficulties in guaranteeing efficient legal protection (European Commission, 2021a). In that sense, the Draft Platform Work Directive should be compatible and does not prejudice the rights and obligations under the GDPR. The GDPR itself provides for the possibility to enact specific rules to ensure the protection of workers' personal data in the context of employment, including the organisation of work (Article 88, GDPR), and in relation to platform work this will, ultimately, be provided in the context of the Draft Platform Work Directive (for a critique of this solution see Ponce del Castillo, 2023). There are three obligations for digital labour platforms that are particularly relevant in the context of automated decision-making. The first concerns the transparency and information obligations, which are specific to the digital platform context (Article 6, DPWD), and add to those guaranteed under the Directive on transparent and predictable working conditions. The second is the obligation to ensure regular human monitoring and evaluation of individual decisions taken or supported by automated monitoring and decision-making systems on working conditions, including the guarantee of sufficient, trained, and competent human resources with the authority for the performance of this task, and protection against dismissal and other negative consequences in case they override automated decisions (Article 7, DPWD). The third is the human review of significant decisions, which

[5] The text of the Provisional Agreement resulting from interinstitutional negotiations of 11 March 2024 is available at: <https://oeil.secure.europarl.europa.eu/oeil/popups/ficheprocedure.do?reference=2021/0414(COD)&l=en>. For the sake of simplicity, this paper will refer to the Articles from the initial Commission's proposal of the directive.

establishes the right for platform workers to obtain an explanation from the digital labour platform for a decision taken or supported by automated systems that significantly affects their working conditions (Article 8, DPWD; European Commission, 2021a). This includes the possibility to discuss and clarify the facts, circumstances and reasons for such decisions with a human contact person at the digital labour platform, the obligation of platforms to provide a written statement of reasons for any decision to restrict, suspend or terminate the platform worker's account, to refuse the remuneration for work performed by the platform worker, or affecting the platform worker's contractual status, as well as further reassurances (substantiated reply, rectification of decision, compensation in case of infringement of worker's rights).

While the proposed regulation of algorithmic management in the Draft Platform Work Directive is mostly welcome, many authors warn about the potential for abuse which could undermine the original aims of the directive (Veale et al., 2023; Ponce del Castillo and Naranjo, 2022). The Draft Platform Work Directive will hopefully close the gap in protection, which arises with certain automated decisions, that do not result from personal data processing. For example, AI-powered demand predictions (taking into account, e.g. time of year, day, season, events nearby, weather forecasts, etc.) can shape the working patterns and inform decisions on working schedules. In such cases, GDPR would not apply, but the decision could nevertheless have a significant effect on the worker's status. Nevertheless, the same would not apply in conventional working arrangements, which are outside of the scope of the Draft Platform Work Directive. The only EU legal instrument that offers some reassurance for the conventional working arrangements in such case would be the Directive 2019/1152 on transparent and predictable working conditions, but only to a very limited extent.

Algorithmic management and automated decision-making thrive with the development of AI-powered systems. The potential harms of such applications are recognised in the freshly adopted AI Act, the first binding legal instrument for the regulation of AI systems in the world. We now change the perspective and take a look at another avenue for safeguarding the workers' rights before any individual automated decision has been made at all: it implies ensuring the use of trustworthy AI systems in employment and workers management.

2.3 Automated decision-making in employment and the AI Act: (High-risk) AI systems used in employment and workers management?

Aside from the protections in relation to the automated decision-making in the context of algorithmic management itself, in the near future, with the adoption of the AI Act, the AI systems used in the context of algorithmic management will be subject to a set of rules for high-risk AI systems. Under the Draft AI Act (European Parliament, 2024b; European Commission, 2021b) it is made clear that data subjects continue to enjoy all the rights and guarantees awarded under GDPR, including the rights related to solely automated individual decision-making, including profiling (Recital (10), Draft AI Act). In that sense, the harmonised rules for the placing on the market, the putting into service and the use of AI systems under the proposed AI Act should facilitate the effective implementation and enable the exercise of the data subjects' rights and other remedies guaranteed under Union law on the protection of personal data and of other fundamental rights.

The AI system under the AI Act is defined as *"a machine-based system designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs*

such as predictions, content, recommendations, or decisions that can influence physical or virtual environments" (Article 3(1), Draft AI Act). It is important to highlight that a key characteristic of AI systems falling under the AI Act is their *capability to infer*, which poses particular privacy harms (see Solove, 2024; Keats Citron and Solove, 2021). This particular feature distinguishes them *"from simpler traditional software systems or programming approaches"*, and that notion should therefore *"not cover systems that are based on the rules defined solely by natural persons to automatically execute operations"* (Recital (12), Draft AI Act). It is imaginable, therefore, that some technological tools and programs used in algorithmic management practices might not fit the definition of an "AI system", rendering the AI Act inapplicable. The AI Act adopts a proportionate risk-based approach, differentiating between uses of AI that create an unacceptable risk, which are prohibited; a high risk, which are subject to *ex ante* impact and conformity assessments; limited risk, which entail certain transparency obligations, and minimal risk, which are left to voluntary industry standards (see more in Pošćić and Martinović, 2022).

The general criteria for high-risk AI systems are prescribed under Article 6(1) of the Draft AI Act, and include standalone systems, as well as product components. Apart from this general reference, which is capable to encompass a wide variety of AI systems, certain AI systems which are numerated in Annex III are always considered as high-risk systems because of their function or field of usage (Article 6(2), Draft AI Act). They include, among others, AI systems *"in the field of employment, workers management and access to self-employment, which are (a) intended to be used for recruitment or selection of natural persons, notably to place targeted job advertisements, to analyse and filter job applications, and to evaluate candidates; or (b) intended to be used to make decisions affecting terms of the work related relationships, promotion and termination of work-related contractual relationships, to allocate tasks based on individual behaviour or personal traits or characteristics and to monitor and evaluate performance and behaviour of persons in such relationships"* (Recital (57) and Annex III(4), Draft AI Act). The risks associated with the use of such systems include discrimination, and violation of fundamental right to data protection and privacy, and should therefore be subject to the strict(er) legal regime. Although there is a derogation prescribed in Article 6(3) of the Draft AI Act, whereby AI system will not be considered as high-risk if one or more prescribed criteria are fulfilled, it is expressly provided that an AI system that performs profiling is always considered as high-risk and cannot be subject to derogation. This leads us back to the definition of "profiling" under the GDPR, since the AI Act itself refers to profiling as "any form of automated processing of personal data as defined in point (4) of Article 4 of Regulation (EU) 2016/679 (…)" (Article 3(52), Draft AI Act). As explained above (supra 2.1.) profiling and automated-decision making may, but do not necessarily overlap.

What does this mean for the application of automated decision-making and profiling involving AI systems, as defined in the AI Act, in the context of employment relationships? It means that all such systems will fall in the high-risk category, but some of them (those not involving profiling) will be able to rely on the derogation prescribed under 6(3) Draft AI Act and will be subject to more lenient conditions for the placing on the market and use. For example, the automated task assignment and scheduling might involve profiling or not: is the task assigned to a worker in relation to whom the system predicts that will be the most suitable to perform the task based on his or her personal aspects (includes profiling); or is the task assigned to any available worker (without profiling)? In anticipation of the potential legal issues (see, e.g. Kiesow Cortez and Maslej, 2022), it should be emphasised that high-risk AI systems will have to comply with a range of specific obligations before they can be put on the market, and this will fall mostly on the providers. These obligations include the establishment of a risk

management system, ensuring the quality of training data and data governance, technical documentation, automatic logging of activity to ensure traceability, ensuring sufficiently transparent information for deployers, human oversight, guarantee of accuracy, robustness and security, implementing the quality management systems, etc. Harmonised standards, common specifications and conformity assessments will be crucial for effective implementation of these obligations (see Chapter III, Section 2, Draft AI Act). There is a specific obligation for deployers[6] of high-risk AI systems who are employers to inform workers representatives and the affected workers that they will be subject to the system prior to putting such system into service or use at the workplace (Recital (92); Article 26(7), Draft AI Act). This information shall be provided, where applicable, in accordance with the rules and procedures laid down in Union and national law and practice on information of workers and their representatives. The performance of a fundamental rights impact assessment is required from deployers that are bodies governed by public law or private entities providing public services, as well as operators deploying certain types of high-risk systems (Article 27, Draft AI Act). Compared to the initial proposal of the AI Act, the final version seems to address some of the concerns in relation to the protection of fundamental rights of workers (Cefaliello and Kullmann, 2022), under the assumption that the possibility of derogation does not become a standard rule in practice.

Concerning its relation to GDPR, the AI Act makes it clear that it does not, by any means, displace the GDPR and other instruments aimed at the protection of personal data and other fundamental rights (Recital (10); Article 2(7), Draft AI Act). Specifically, data subjects continue to be protected against solely automated individual decision-making, including profiling, under that legal framework. There is an inherent presumption that the use of AI makes it more likely that a decision is based solely on automated processing (Sartor and Lagioia, 2020). The underlying idea is that the AI Act's harmonised rules for the placing on the market, the putting into service and the use of AI systems compliment and facilitate the effective implementation and exercise of the data subjects' rights guaranteed under Union law on the protection of personal data and of other fundamental rights. General obligations of data controllers (e.g. employers) under GDPR, such as data protection by design and by default (Article 25, GDPR), and data protection impact assessments (Article 35, GDPR) apply regardless and in addition to any obligation for AI systems under the AI Act.

3 Testing the coherence: Different levels and gaps in protection?

The underlying aim of this paper was to explore the impact of the existing EU legislation on automated decision-making, as interpreted by the CJEU, in the context of algorithmic management. A comparison with the emerging and freshly adopted legal instruments has revealed areas that require further attention and consideration to prevent different levels of workers' protection in the context of algorithmic management practices, depending whether the work is performed on digital labour platforms or within a (more or less) conventional setting.

For example, despite the broad reading of the term "decision" from *SCHUFA*, the GDPR will not be able to solve all issues in connection with the automated decision-making which affects the worker's position in the employment relationship. GDPR rules cannot protect workers from automated decision-making that does not involve the processing of personal data, and/or

[6] Deployer means any natural or legal person, public authority, agency or other body using an AI system under its authority except where the AI system is used in the course of a personal non-professional activity (Article 3(4), Draft AI Act).

profiling. Even if personal data processing is involved, exceptions, such as contractual necessity, legally prescribed authorisations, and consent can circumvent the application of Article 22(1) GDPR, as can the simple fact that many management decisions are not fully automated (Abraha, 2023; Lukács and Váradi, 2023; Parviainen, 2022; Solove, 2024). Outside of Article 22 GDPR, there is no general regime for automated decisions (Sancho, 2020), meaning that other GDPR provisions and personal data processing principles apply (for data processing at work see WP29, 2017).

Let us look at the following scenario: the manager (a human being) of a retail store decides to switch shifts, or otherwise change the working time arrangements, or even terminate the employment contracts for some workers based on predictions of customer or labour demand (see e.g. Wood, 2021). This automated prediction is not based on the processing of personal data. The ultimate decision to change the worker's working time patterns, or to dismiss the worker is made by a human. However, that prediction plays a determining role for the manager's decision. The manager may not even know how the prediction works (as long as it is accurate!) – the company relies on the system developed by a third party. So if a worker needs information as to how the prediction was formed, i.e. concerning the logic involved and the scope of its impact on the worker's position, in order to challenge the employer's decision to reschedule the working patterns or to terminate the contract, he or she will not have access to that information pursuant to GDPR: there was no automated processing of personal data involved. There is limited protection in terms of predictability of work patterns and the right to redress under Directive 2019/1152 on transparent and predictable working conditions, but it will depend on contract terms how the work pattern was agreed upon in the first place.

If we take a look at the same scenario, but in the context of platform work and the proposed Draft Platform Work Directive, it seems to accord a higher level of protection, because it does not require that automated decisions result from the processing of personal data, but solely that they concern an individual worker (see supra 2.2.). Consequently, there will be an evident discrepancy in the protection between "platform" and "conventional" workers in view of automated decision-making and algorithmic management practices, once the Draft Platform Work Directive is adopted. Admittedly, automated decision-making is an essential characteristic of platform work, which requires tailored solutions. Ultimately, however, there is not much difference between the nature and effect of the automated decision-making and algorithmic management, whether they take place in the context of platform work or conventional work. There should be no differences in workers' protection either (see, similarly, concerning the relation between DPWD and AI Act: Aloisi and Potocka-Sionek, 2022).

If we change the presumption of this scenario, and include profiling or any other processing of personal data in the prediction, thus rendering Article 22 GDPR applicable, the classification of a decision as fully automated one could only be avoided by a "meaningful" human involvement. According to the explanations of the Article 29 Working Party, a meaningful human involvement implies a meaningful oversight of the decision, "rather than just a token gesture" (WP29, 2018). An interesting interpretation of a "meaningful human involvement" comes from the Netherlands, where the Amsterdam Appeals Court interpreted it to mean involvement of a human who is sufficiently qualified, informed, and competent to make a decision (see Hiessl, 2023). The manager is expected to be qualified and competent but is he/she "informed" about the inner workings of an automated system is a matter of debate. The *SCHUFA* Judgment provides limited guidance for this issue since the facts of that case were rather straightforward and human intervention boiled down to accepting negative scoring in practically all situations. That might not always be the case. In any case, a human involvement

cannot be “fabricated” by pure formal acceptance of the results of automated decision-making (WP29, 2018).

Let us broaden the above consideration to the requirements for AI systems used in the field of employment, workers management and access to self-employment. The requirements under the AI Act for high-risk AI systems would apply, if the system of customer prediction is an AI system as defined under the AI Act. According to Article 6(2) and Annex III(4) of the Draft AI Act, an AI system intended to be used to make decisions affecting terms of the work-related relationships, promotion, and termination of work-related contractual relationships, to allocate tasks based on individual behaviour or personal traits or characteristics and to monitor and evaluate performance and behaviour of persons in such relationships is considered a high-risk AI system. However, under the derogation prescribed in Article 6(3) of the Draft AI Act, an AI system will not be considered as high-risk, if one or more of the following criteria are fulfilled: (a) the AI system is intended to perform a narrow procedural task; (b) the AI system is intended to improve the result of a previously completed human activity; (c) the AI system is intended to detect decision-making patterns or deviations from prior decision-making patterns and is not meant to replace or influence the previously completed human assessment, without proper human review; or (d) the AI system is intended to perform a preparatory task to an assessment relevant for the purpose of the use of, inter alia, the mentioned AI systems in the field of employment, workers management and access to self-employment. This derogation cannot be applied to profiling, but there is no profiling involved in the first version of our example. So, either way, there would be no protection for the worker against a decision which relies on automated decision-making and algorithmic management practice, because GDPR would not apply and thus the worker cannot get an insight into how the prediction was made to challenge the employer’s decision. On the other side, the AI system itself might escape the stricter regime for high-risk AI systems, with obligatory conformity assessments and other prescribed obligations for the operators of those systems, that could, at least to a certain extent, guarantee the trustworthiness of the AI system and ensure the protection of fundamental rights. An alternative version of this scenario which includes (some) profiling or other processing of personal data, e.g. where the prediction of customer demand would incorporate the profiling or evaluation of capability or efficiency of a worker for the performance of a certain shift or job would render both the GDPR and the AI Act applicable, and completely change the legal assessment.

4 Concluding considerations

As the world of work is becoming increasingly digitalised and powered by AI, the existing legal framework is trying to keep up with the new challenges. The adoption of the AI Act and the negotiations for the adoption of the Draft Platform Work Directive are certainly a step in the right direction. However, until they enter into force and are able to show their full potential, we will have to rely on the existing legal instruments, notably in the field of data protection, and adapt them to considerations specific for labour relations. However, this may not be enough. It is sometimes questioned whether new rules for automated decision-making are necessary, and suggested that other bodies of law, primarily in the field of data protection, non-discrimination, and human rights suffice, provided that they are effectively supervised and enforced (see, e.g. Mackenzie-Gray Scott and Abrusci, 2023). We cannot agree with such proposition. As our previous analysis shows, there is room for improvement and adaptation of the legal framework, particularly in view of algorithmic management practices that have spread beyond the platform work into all types of work relations. This requires careful calibration of the existing and

emerging EU rules to avoid overlapping and conflicting solutions, with clear delineation between different instruments and a comprehensive approach with the aim of understanding their individual and combined impact on workers' protection.

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Circulation and Protection of Genetic Data and Biobanks: Legal Challenges and Regulatory Perspectives

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ABSTRACT

Globalisation and the so-called information society are having a growing impact on the lives and activities of citizens. From this perspective, e-health takes on a particular importance in the context of digitalisation processes, and indeed a considerable amount of data has been collected in the health sector in recent years. In particular, with regard to genetic data, the use of ITC and AI, inter alia, are revolutionising the field of personalised medicine, making it possible to customise medical therapies based on a patient's genetic profile. However, there are numerous technical and legal challenges in this area, as well as ethical issues that require careful consideration. The first part of the paper focuses specifically on genetic data and biobanks, their multi-layered legal regime, with particular reference to the collection of that data, their circulation and protection. The second part aims to draw a picture of the state of the art of biobanks, focusing on the recent Italian experience (the SharDna case), showing new demands affecting fundamental rights, that regulators and legislators are called to handle and regulate. The paper concludes that a market in genetic data and biobanks is legally inconceivable, but makes some suggestions on how to address and manage new challenges posed by the circulation of data. Configuration of genetic data and biobanks as global commons or genetic commons could be a solution as they affect human dignity and cannot be considered a marketable commodity.

Key words: *E-health, Genetic data regulation, Biobanks regulation, Secondary uses of biobanks, Circulation of genetic data, SharDna*

JEL classification: *K23, K24, K32, K36, K38*

1 Public administrations and the third revolution: the e-Health sector

A third revolution is taking place in public administration. After the first, which was the liberal revolution (1848/61-1865-1889), and the second, the constitutional revolution (1948-1990), we are now in the third revolution, which is known as the artificial intelligence, machine learning and neural networks revolution: it is the digital revolution of the public administration (Cavallo Perin, 2021). It is a revolution in the truest sense of the word, affecting both the structure of the republic and the way in which public administrations operate, whether it is the exercise of public functions or services, the management of databases or the manifestation of a science (Cavallo Perin, 2021). Globalisation and the so-called e-society (or information society or knowledge

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society) have an ever-increasing impact on the lives and activities of citizens (Alpa, 2019). An impact that goes beyond the computerisation or digitalisation or automation of acts, offices and administrative activities (Cavallo Perin, 2021; Balaguer Callejon, 2023). In this new scientific revolution (that of information, the fourth in human history, after those marked by the discoveries of Copernicus, Darwin and Freud, as pointed out by Floridi, 2017), "information" is configured as *"a precondition for the implementation of the principles proper to the democratic state*[3]*"* and *"data is now a central asset in the digital society"* (EU Commission, 2018a).

A digital transition is underway and involves all the latest multi-level policies. The EU is implementing strong approaches in high performance computing, data analytics and artificial intelligence with the aim of, inter alia, helping to design and test new healthcare products, provide faster diagnosis and better treatments (EU Commission, 2018b). However, as pointed out by the European Commission, the success of these efforts depends on the availability of large amounts of high-quality data and an appropriate regulatory framework that protects the rights of individuals and the society as a whole and also stimulates innovation (EU Commission, 2018b). This is why in 2022, the European Commission launched a proposal to establish a European Health Data Space with the aim of "ensuring that natural persons in the EU have more control in practice over their electronic health data" and *"ensuring a legal framework consisting of trustworthy EU and Member State governance mechanisms and a secure processing environment"* (EU Commission, 2022). The new regulation is intended to be consistent with the currently applicable legal framework (in particular with the provisions of the EU General Data Protection Regulation of 2016 - GDPR) (Rufo, 2023), as the Commission clarifies (EU Commission, 2022: point 1 of the Explanatory Memorandum, under "Consistency with existing policy provisions in the policy area"), although risks and interpretation issues arising from the new health data governance system cannot be excluded a priori (see Scialoia, 2023), as we will see *infra*.

In such a scenario, the e-health sector is of paramount importance (see Ducato, 2016). Health data can be used both by medical science to analyse patients' conditions and by other subjects/bodies/organisations, including public administrations (Christ, 2018). The use of health-related technologies is intended to improve the quality of medical care, reduce medical costs and promote independent living, also in remote areas (EU Commission, 2010) and enable universal access to healthcare for all individuals (EU Commission, 2008). Artificial intelligence will also play a fundamental role in the health sector and in the field of genomics (Maqsood et al., 2024; Shao et al., 2023). In fact, as stated in the Italian National Strategy for AI 2020 (currently under revision), AI can revolutionise the entire chain, from research and development for more effective therapeutic and preventive drugs to medical engineering that allows the identification of the most appropriate treatment for each patient (Italian National Strategy for AI, 2020). In recent years, a considerable amount of data has been collected in the health sector. This has led - also due to the growth of the world population - to new forms of personalised medical solutions, including predictive approaches based on computer modelling, simulations and artificial intelligence (EU Commission, 2018b).

In this perspective, some scholars have outlined that *"appropriate analysis of big health data can help predict epidemics, cures and diseases as well as improve the quality of life and avoid preventable deaths"* (Hashem et al., 2016, see also Pentland et al., 2013). The availability of

[3] In Italian: "*informazione"* is understood as "condizione preliminare per l'attuazione dei principi propri dello Stato democratico". See Italian Constitutional Court, judgment 12 April 2005, No. 151. Similarly, see Italian Constitutional Court, judgment 15 October 2003, No. 312, as well as Italian Constitutional Court, judgment 12 February 1996, No. 29.

health or medical information can help patients to make medical decisions in a more effective and informed way through a better understanding of clinical history, medical and health data (Sarrión Esteve, 2018).

In this context, the European Health Data Space will play a crucial role, which will, on the one hand, *"enable researchers, innovators, policy makers and regulators at EU and Member State level to access relevant electronic health data to promote better diagnosis, treatment and well-being of natural persons and lead to better and well-informed policies"* and, on the other hand, *"contribute to a true single market for digital health products and services by harmonising rules, thereby increasing the efficiency of healthcare systems"* (EU Commission, 2022). However, the full implementation of eHealth is fundamentally a political decision[4] and therefore largely depends on the choices that states (including EU states) are willing to make in this area. To date, there is no specific legal framework for e-Health in Italy. The European Commission, for its part, first adopted the Union's strategy to promote the use of ICT in healthcare by publishing the e-Health Action Plan 2012-2020 (EU Commission, 2012), which aims to address and remove the barriers that remain after the adoption of the first Action Plan drawn up by the European Commission in 2004 and the subsequent legislative acts issued in the following years. The objective set by the EU Commission with the 2012 Action Plan is to reap all the benefits of a fully mature and interoperable e-Health system in Europe. More recently, the Commission published a communication on the digital transformation of health and care with the aim of empowering citizens and building a healthier society (EU Commission, 2018b).

The communication on the digital transformation of health and care identifies three priorities: a) citizens' secure access to their health data, also across borders, enabling citizens to access their health data across the EU; b) personalised medicine through a shared European data infrastructure, enabling researchers and other professionals to pool resources (data, expertise, computing, processing and storage capacity) across the EU; c) empowering citizens with digital tools for user feedback and person-centred care using digital tools to empower people to take care of their health, stimulate prevention and enable feedback and interaction between users and healthcare providers (European Commission, 2018c). It is clear that data is a key enabler for digital transformation in the health sector (European Commission, 2018b). Patients can benefit from the use of technologies in the health sector but, at the same time, many challenges and risks can be identified: digital divide, Internet use, access to electronic health records[5]; professional liability (regarding AI and robotics, see Faccioli, 2022, as well as in interdisciplinary terms, see Ruffolo and Gabbrielli, 2023; regarding telemedicine, see European Commission, 2008); market fragmentation and lack of interoperability between national health systems (European Commission, 2018b); complex ethical issues related to the treatment of patients; problems related to the updating of software in the case of essential medical applications (such as robotic prostheses); situations where the application manufacturer goes bankrupt or otherwise decides to leave the market; cybersecurity risks (as defined in Article 2a of Regulation (EU) 2019/881[6]), the possibility of hacking, deactivation or memory wiping of

[4] Similarly, the establishment of biobanks is an expression of a political choice (Macilotti, 2013).

[5] According to the latest data published by the European Commission (DESI, 2023), only 45.60% of Italians have basic digital skills (compared to Finland with 79.18%). Italy is the third last country in this particular ranking, better only than Bulgaria and Poland, both around 30%. The data show that Italy is developing access to eHealth systems (i.e. online access services for citizens to their electronic health record data (via a patient portal or a mobile patient app) and other services). Moreover, the Internet usage indicator shows that Italy needs to improve the current percentage (82.94%) to enable citizens to fully benefit from the e-Health system.

[6] According to Article 2a of Regulation (EU) 2019/881, cyber security "means the activities necessary to protect network and information systems, the users of such systems and other persons affected by cyber threats". As such, cybersecurity is to be seen in the context of a more general commitment of political power to ensuring a disciplining of information technology that

PSCs integrated into the human body, given that this can endanger health or, in extreme cases, even human life (EU Parliament, 2017, see also Pentland et al., 2013; Bifulco, 2018).

It is important to note that in 2020 alone, cyber-attacks on health systems in the European Union increased by 47% compared to 2019 (Verizon, 2021); as well as there being critical profiles in terms of human dignity, protection of fundamental rights and confidentiality of collected data (Cippitani, 2018b; Pizzetti, 2017; Pentland, et al., 2013; European Economic and Social Committee, 2017; Bifulco, 2018; Selita, 2019), and in addition the issue of health data as an economic commodity (Sarrión Esteve, 2018). Hence the need for intervention by national legislators, as to the organisation and delivery of health and social care is the responsibility of the Member States (see Articles 6a and 168 of the Treaty on the Functioning of the European Union) (EU Commission, 2018b; see also De Pasquale, 2020; Scialoia, 2023). They are called upon to provide for those aspects, including those of tangible and intangible infrastructures, which, as the European Parliament and the European Commission have stated, enable equal access for all citizens to such innovations, tools and technological interventions (EU Commission, 2018b; EU Parliament, 2017).

2 Genetic data and biobanks: some definitions

As mentioned above, data is a key enabler of digital transformation in the health sector, not only for diagnostic and therapeutic reasons, but also for predictive purposes (Arnold and Arnold, 2018). One area of great interest is genetic data and biobanks (see the comprehensive work by Arnold et al., 2018). However, before analysing the profiles of biobanks and, in particular, the legal regime governing the circulation of biobanks and the data they contain, it is necessary to consider the definition and classification of biobanks and genetic data. The purpose of this analysis is to clarify the legal nature of biobanks, which in turn affects the rules applicable to them. Identifying the discipline applicable to biobanks is a particularly complex exercise, as there is no organic regulation on the subject, either at a national or international level (for the debate on the international regime on genetic data and databases, see Christ, 2018). The absence of a precise regulation of this phenomenon means that it is necessary to refer to the principles and rules governing the different activities carried out in biobanks (collection of biological samples, storage and use of data, etc.).

In terms of definition, it should be noted that there is a precise legal definition of genetic data. Indeed, pursuant to Article 4, No. 13 of EU Regulation No. 679/2016 (GDPR), genetic data is described as "*personal data relating to the inherited or acquired genetic characteristics of a natural person which give unique information about the physiology or the health of that natural person and which result, in particular, from an analysis of a biological sample from the natural person in question"*. Moreover, whereas 34 of the GDPR clarifies that "Genetic data should be defined as personal data relating to the inherited or acquired genetic characteristics of a natural person which result from the analysis of a biological sample from the natural person in question, in particular chromosomal, deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) analysis, or from the analysis of another element enabling equivalent information to be obtained." This specific category of data is regulated in Article 9 of the GDPR.

guarantees compliance with the democratic rules necessary for the survival of representative democracy, which is proper to the constitutional state (de Vergottini, 2019).

On the contrary, there is no legal framework that regulates the phenomenon of biobanks in a uniform way, either at international or European level (Bombillar Sáenz, 2018). Similarly, there is no common definition of biobanks. The term biobank emerged around the mid-1990s to designate heterogeneous cases that have in common the collection of biological samples associated with clinical information (Mascalzoni, 2011). However, at an international level, the various documents developed define biobanks according to the different types of samples stored. Even at a national level, states often provide definitions that are not consistent, which contributes to the uncertainty inherent in the use of this term.

Two basic characteristics emerge from an analysis of the most common definitions. On the one hand, biobanks are defined as "service units", i.e. entities within the health system (public or private) that provide the pure service of storing human biological samples for multiple purposes: including treatment, diagnosis, and research. From this point of view, biobanks are nothing more than instruments whose function depends from time to time on the purposes for which the samples stored in them were collected. On the other hand, these service units are non-profit-making. Biobanks consist not only of biological material but also of personal data (clinical, genealogical, lifestyle, etc.) of the patients from whom the samples were taken. It is precisely the "informational" component that is crucial, not only because the collection of human biological samples is linked to the personal data and information regarding the donors but also because in many legal systems (including the Italian one) the regulation of biobanks is closely linked to the rules governing the processing of personal data (especially genetic data). Moreover, it is precisely the "informational" element that distinguishes biobanks from mere collections of biological samples. In terms of classification, it should be noted that biobanks established for the purpose of medical research do not constitute a homogeneous category (on the classification of biobanks, see inter alia Coppola et al., 2019; Hewitt and Watson, 2013). Indeed, there are:

- biobanks that collect biological samples only from individuals suffering from a specific disease (disease-oriented biobanks);
- biobanks that store tissues from entire populations, regardless of the disease suffered by the individual to whom the biological samples belong (population biobanks);
- biobanks that collect the genealogical information of the individuals who donate the tissues in order to carry out genetic studies (genetic biobanks), while others store only the clinical data of the individuals.

Of particular importance for the purposes of interest here are population biobanks, which combine genetic data, health data, lifestyle data and environmental data, and provide the basis for large-scale studies to identify the genetic and environmental components of diseases (Mascalzoni, 2011). For the characteristics of population biobanks, see Council of Europe, 2006). Such biobanks do not aim to study a specific disease, but rather to collect biological samples from a given population in order to study a generality of diseases. The usefulness and importance of such biobanks lies precisely in the fact that they make it possible, through the analysis of genealogical development, to highlight and isolate the genetic characteristics that determine the onset of a given disease. In addition to the significant benefits of such a biobank, it also raises a number of sensitive legal issues, such as the so-called secondary use of the data.

In accordance with the aforementioned definitional coordinates, the objectives of this paper are:

- the identification of the main features of the multilevel regulation of genetic data and biobanks,
- a critical evaluation of the existing legislation on the circulation and secondary use of biobanks,

- an exposition of the SharDna case, in order to critically assess the existing Italian legislation on the subject, which is deficient in several respects,
- and finally, the proposition of some proposals, also in the light of the European regulatory framework.

3 Multilevel regulation of genetic data and biobanks

3.1 International regulation

The legal regulation of genetic data and biobanks has been the subject of several acts adopted at international, European and national levels (Sarrión Esteve, 2018[7]), but the resulting framework is cumbersome. At an international level, soft law documents largely prevail over binding sources (Christ, 2018 who provides an overview of the international legal framework on genetic data). Let us first recall the Universal Declaration on the Human Genome and Human Rights, adopted by UNESCO in 1997[8], which states that *"Everyone has a right to respect for their dignity and for their rights regardless of their genetic characteristics"* (Article 2a) and that *"That dignity makes it imperative not to reduce individuals to their genetic characteristics and to respect their uniqueness and diversity"* (Article 2b). The declaration also states that *"In all cases, the prior, free and informed consent of the person concerned shall be obtained. If the latter is not in a position to consent, consent or authorization shall be obtained in the manner prescribed by law, guided by the person's best interest"* (Article 5b) and that *"the human genome, in its natural state, shall not give rise to financial gains"* (Article 4).

The Oviedo Convention on Human Rights and Biomedicine of 1997[9] establishes similar principles, in particular the primacy of the human being *("The interests and well-being of the human being shall prevail over the sole interest of society or science"*, Article 2), the need for the free and informed consent of the person concerned (Article 5) and the right to privacy (Article 10; Article 2), the need for the free and informed consent of the person concerned to an intervention in the field of health (Article 5) and the right to privacy and information with regard to information on the health of the person concerned (Article 10). At a European level, the Council of Europe Recommendation on Research on Biological Materials of Human Origin, adopted on 15 March 2006, and the OECD Best Practice Guidelines for Biological Research Centres (BRCs), adopted in 2007, should also be mentioned. More recently (October 2009), the OECD Council adopted the Recommendation on Human Biobanks and Genetic Research Databases (HBGRD). The Recommendation provides guidelines for the establishment, management, governance, operation, access, use and closure of HBGRDs. It recognises scientific research as one of the fundamental objectives of a HBGRD. The recommendation "seeks to facilitate broad access to data and materials for biomedical progress, while ensuring that research is conducted in a manner that respects participants and upholds human dignity, fundamental freedoms and human rights". Over the past fifteen years, the OECD Council has adopted several acts and recommendations, including a Recommendation on Health Data

[7] For an overview of the multilevel legal framework on genetic data see Garante Privacy (Italian Data Protection Authority), 2016.

[8] Universal Declaration on the Human Genome and Human Rights, adopted on 11 November 1997, followed by the International Declaration on Human Genetic Data on 16 October 2003 and the Universal Declaration on Bioethics and Human Rights on 19 October 2005.

[9] Convention for the protection of human rights and dignity of the human being with regard to the application of biology and medicine: Convention on Human Rights and Biomedicine (ETS No. 164) was opened for signature in Oviedo, Spain, on 4 April 1997.

Governance in 2017 and the report Health Data Governance for the Digital Age - Implementing the OECD Recommendation on Health Data Governance, published in May 2022. This latest study provides an overview of the implementation of the Health Data Governance Recommendation (2017) for the first five years up to 2021. It also indicates that efforts to support the implementation and dissemination of the 2017 recommendation will continue for the next reporting cycle (2022-27), with a focus on cybersecurity, harmonising health data governance to enable multi-country projects, increasing public engagement, and improving the interoperability of global health data.

3.2 Regional (EU) legislation and regulation

At a regional (European Union) level, the regulatory framework is composed of several (but not numerous) sources (see Sarrión Esteve, 2018). Firstly, several directives on the traceability of donated tissues and cells and on the legal protection of biotechnological inventions should be mentioned.[10] Secondly, Article 2 of the Charter of Fundamental Rights of the European Union of 7 December 2000 (also known as the "Nice Charter"), after reaffirming the principle that *"Everyone has the right to his or her physical and mental integrity"*, states that, with particular regard to medicine and biology, there must be respect for (a) the free and informed consent of the person concerned, as defined by law, (b) the prohibition of eugenic practices, in particular those aiming at the selection of persons, (c) the prohibition of making the human body and its parts as such a source of financial gain, (d) the prohibition of the reproductive cloning of human beings. The same charter also provides for the right to the protection of personal data, which must be *"processed fairly, for specified purposes and on the basis of the consent of the person concerned or some other legitimate basis laid down by law"* (Article 8(1) and (2)). The genetic characteristics of individuals are instead referred to in Article 21(1) of the charter, in the context of the prohibition of discrimination. As mentioned above, genetic data is regulated by EU Regulation 2016/679 (see Article 9, on which see Sarrión Esteve, 2018) it will be focus on this provision in more detail below. The treatment of genetic data is permitted only if it respects *"the essence of the right to data protection and provide(s) for appropriate and specific measures to safeguard the fundamental rights and interests of the data subject"* (Article 9 of Regulation (EU) 2016/679).

The GDPR has been seen as a "property-based conception" regulation (Victor, 2013; see also Sarrión Esteve, 2018). The need for informed consent is therefore, also under EU law, a necessary condition for the processing of data relating to people's health (health data), but also to conduct experiments on humans. This principle is also affirmed in the proposal of EU AI Act (Article 3bk)[11], where "informed consent" means *"a subject's freely given, specific, unambiguous and voluntary expression of his or her willingness to participate in a particular testing in real world conditions, after having been informed of all aspects of the testing that are relevant to the subject's decision to participate"*.

[10] Directive 2004/23/EC of the European Parliament and of the Council of 31 March 2004 on setting standards of quality and safety for the donation, procurement, testing, processing, preservation, storage and distribution of human tissues and cells; Commission Directive 2006/17/EC of 8 February 2006 implementing Directive 2004/23/EC of the European Parliament and of the Council as regards certain technical requirements for the donation, procurement and testing of human tissues and cells; and Directive 98/44/EC of the European Parliament and of the Council of 6 July 1998 on the legal protection of biotechnological inventions. This directive was transposed in Italy by Decree-Law No. 3 of 10 January 2006, converted into Law No. 78 of 2 February 2006).

[11] The version of the proposal we are referring to is that updated on February 6th 2024 based on the version endorsed by the Coreper I on February 2nd.

3.3 Italian legislation and regulation

With regard to national legislation and regulation, we note the almost total inertia of the Italian legislator, in contrast to what is happening in other systems, where there is a detailed and advanced regulation on biobanks and genetic data (for example, in the Spanish legal order, on which see Bombillar Sáenz, 2018). Article 2 *septies* of the Italian Data Protection Code (Legislative Decree 30 June 2003, No. 196, as updated by Legislative Decree 10 August 2018, No. 101) contains an explicit reference to the regulation set out in Article 9 of the GDPR, and confers on the national data protection authority the competence to regulate the matter from a technical point of view.

More specifically, the regulation on the processing of genetic data was provided for in Article 90 of the Italian Data Protection Code, before its repeal by Legislative Decree No. 101 of 4 September 2018 (in order to align the Code with the GDPR, which came into force on 25 May 2018). The provision stated that the processing of genetic data by any person was only permitted in the cases provided for by a special authorisation granted by the Italian Data Protection Authority (Garante Privacy) after hearing the Minister of Health, who had to obtain the opinion of the Higher Health Council for this purpose. Attempts were made to remedy this considerable inertia on the part of the legislator by means of technical regulatory acts, including General Authorisation No. 8/2016 issued by the Italian Data Protection Authority (Garante Privacy, 2016) and the more recent act issued by the same authority (Act No. 146 of 5 June 2019) on provisions concerning the processing of certain categories of data, pursuant to Article 21 of the Italian Privacy Code. The regulation of genetic data processing at an Italian community level is therefore based on the discipline of informed consent, which, together with the free nature of the data in question, affects both the legal nature and the circulation of the goods in question. In the discipline prior to the 2016 GDPR and the Privacy Code adapted to it in 2018, and in accordance with the Garante's authorisation (which complemented the discipline established in Article 90 of the 2003 Code), the processing of genetic data required the written, free and informed consent of the data subject. Moreover, in the light of Article 23 of the code (also repealed by Legislative Decree No. 101/2018), blanket consent was considered insufficient, since, according to paragraph 3 of the same provision, *"consent is validly given only if it is freely and specifically expressed with reference to a clearly identified processing"*.

With the entry into force of the GDPR, these rules have not disappeared, since, according to Article 9(2)(a) of this regulation, with regard to the processing of genetic data, it is necessary for the data subject to give his or her *"explicit consent to the processing of such personal data for one or more specific purposes"*. With specific reference to biobanks, in Italy there is no organic law and/or regulation that regulates this phenomenon. Since they – the biobanks – provide for the processing of genetic data, it is essential to take into account, in addition to the applicable multi-level legislation, the provisions of the Italian Data Protection Authority (Garante Privacy, 2019, point 4.2, lett. (e), first part), according to which genetic data and biological samples contained in lists, registers or databases must be processed *"using encryption or pseudonymisation techniques or other solutions which, given the volume of data and samples processed, render them temporarily unintelligible even to those authorised to access them and allow the data subjects to be identified only when necessary, so as to minimise the risks of accidental knowledge and abusive or unauthorised access"*. The implementation of such measures would legitimise, at least on a technical level, the use of human material that would otherwise allow the identification of the person who provided it.

Complete anonymisation consists, in fact, in giving a state of "information neutrality" to the information that can be extracted from biological material taken from an individual and related to that individual. In this way, the wealth of information could be stored without being traceable back to the individual from whom it originated. Only anonymised data (and not pseudonymised data) fall outside the scope of Regulation (EU) 2016/679 as non-personal data (whereas pseudonymised data are personal data). In this regard, Article 26 of the GDPR states that *"the principles of data protection should apply to any information concerning an identified or identifiable natural person. Personal data which have undergone pseudonymisation, which could be attributed to a natural person by the use of additional information should be considered to be information on an identifiable natural person"*. The same provision adds that *"the principles of data protection should therefore not apply to anonymous information, namely information which does not relate to an identified or identifiable natural person, or to personal data rendered anonymous in such a manner that the data subject is not or is no longer identifiable"*. As a result, "*if data cannot be linked to a specific person, it is outside the protection of the legislation and can be processed without the consent of the data subject"* (see Cippitani, 2018b: 68). It is precisely the removal of the subjective traceability of the data that constitutes the technical filter that guarantees the confidentiality of the data. However, such an operation is technically very complex and rarely occurs, as important studies have shown (Gymrek et al., 2013; Tallacchini, 2003; Lowrance, 2002). From a technical point of view, the processes of anonymisation "are likely to be reversible, and in principle any anonymised genetic data can be linked to an individual". The same can happen in the case of pseudonymisation (Cippitani, 2018b). In this regard, the Article 29 Data Protection Working Party has pointed out that "traceable pseudonymised data may be considered as information on individuals who are indirectly identifiable. Indeed, the use of a pseudonym means that it is possible to trace back to the individual so that the individual's identity can be discovered, but then only in predefined circumstances" (Article 29 WP, 2007, 18).[12]

4 The problem of the legal nature of biobanks

Defining the legal nature of human tissues removed from the body is a complex issue that is fundamental to identifying the disciplines applicable to genetic data and biobanks (and, before that, to the biological material from which such data are derived) (on the nature of genetic information, see Christ, 2018; Arnold and Arnold, 2018). At a national and supranational level, two principles recur time and again: gratuitousness and consent. We have already discussed the principle of consent above. With regard to gratuitousness, on the other hand, it is expressed in various international, EU and national sources. Article 3, par. 2 of the Charter of Fundamental Rights of the European Union (proclaimed in Nice on 7 December 2000, also known as the Nice Charter) states that, in the fields of medicine and biology, *"the prohibition on making the human body and its parts as such a source of financial gain"* shall be respected. In the same sense, see also Article 21 of the 1997 Oviedo Convention on Human Rights and Biomedicine, which stipulates that "the human body and its parts, as such, shall not be used for financial gain". Among the national legal sources, the general rule of free disposition can be found in Article 5 of the Civil Code, to be read in conjunction with specific legislation (in particular that on transplantation). According to Italian civil law, the gratuitous transfer of human biological material, which provides for financial compensation as a synallagmatic service, is to be

[12] As of 25 May 2018, the Article 29 Working Party is no longer in existence and has been replaced by the European Data Protection Board (EDPB).

considered radically null and void due to the illegality of the cause pursuant to article 1418, paragraph 2, of the Italian Civil Code (Resta, 2011).

The rule of free access to genetic data has been widely studied by scholars, and here we can limit ourselves to summarising the two possible interpretations of this principle. According to a first approach, the principle of gratuitousness excludes any possibility of establishing property rights over the human body and its constituent tissues, even after their removal from the body of origin. In this view, gratuitousness (or the prohibition of commodification) also acts as a guarantee of the principle of equality, since it avoids discrimination between social classes and prevents the poor patient from being forced to choose between economic well-being and the right to health (Rodotà, 1994). According to another point of view, the free rule expresses the mere prohibition to dispose of a detached part of the human body for payment, and the rule of extra-patrimoniality should be understood as a rule of organisation of the system of circulation of rights over the body, aimed at protecting the subjects involved, guaranteeing the freedom and spontaneity of donations. Only by adhering to this second direction would it be possible to configure a right of ownership over a part of the human body.

With specific reference to biobanks, it was stressed that their essence consists of biological samples and the information related to them. The specificity of genetic biobanks is that they maintain a permanent link between the biological samples and the genealogical, biographical, and clinical data of the individuals from whom the deposited material originates. Indeed, one of the fundamental characteristics of biological samples is their dual value as material and as information. The dual dimension of biological samples (material and informational) conditions their legal qualification: the material dimension is indeed shaped by the right to property, while the informational dimension is an expression of the biological identity of the subject. Thus, there is a right to property in the tissues and a right to confidentiality and self-determination with regard to the information that can be obtained from the tissues.

5 The circulation of genetic data

5.1 Ways of circulating biological samples

The legal nature of biological samples has a direct impact on the secondary use of genetic data and the dissemination of biobanks. The problem that arises from a legal point of view is to verify how the two entities (material and informational) of the goods under consideration can relate to each other; entities that, although different, concern the same goods. In this respect, we can distinguish two different models or approaches: the proprietary model and the personalistic (or informational) model.

The first (proprietary) perspective is an expression of the traditional perspective, which reconstructs the relationship between the individual and the detached parts of his or her body in a dominant key. According to this theory, the human body cannot be configured as an object of property; however, the individual would acquire a property right over the parts and products of the human body after detachment, based on principles analogous to those of fructification. Such an approach has been widely adopted in the United States[13], where biological specimens have been brought back into the realm of the real, thus favouring the protection of property

[13] See the leading cases Moore v. The Regents of the University of California in 1990 and Washington University v. William J. Catalona et al. in 2006 (and the same conclusion were reached on Appeal, Eighth Court, 2007) (see Gamber, 2007).

interests. In Washington University v Catalona, the principle that there is no property in biological material was clearly reaffirmed by the Court of Appeals. According to the Court, patients who have donated biological samples with valid consent have no ownership rights and cannot direct, transfer, or control their use (Borghi, 2018).

The second model is the personalist one, according to which the individual's power of control over the parts and products of his or her own body is a direct expression of the fundamental principle of self-determination in personal choices. According to this principle, which is expressed in several legal texts[14] in the form of informed consent, the individual should be able to freely determine not only the modalities of the intervention in his or her personal sphere (consent to removal), but also the subsequent destination of the biological material samples removed following the intervention (consent to collection, preservation, patenting, etc.). The need to obtain the prior express consent of the data subject (and the consequent power of veto over the secondary use of genetic data) implies that the data subject can impose a specific direction on the content of his or her authorisation act (the principle of purpose limitation), allowing certain uses (e.g. scientific research) and excluding others (e.g. patenting of research results).

Contrary to the circulation of patrimonial rights, here the author does not lose control of his biological material even when it passes into the hands of other persons, given the power of *ad nutum* revocability of consent granted to the same person. A valid, free, and informed expression of will is therefore required for all secondary uses of a subject's genetic material. This applies both to therapeutic uses (transplants, transfusions, implants for reproductive purposes) and to scientific research and industrial applications. This second approach - shared by recent doctrine and jurisprudence[15] and followed in many European countries - is based on a balance in which the right to privacy and self-determination prevails over property interests. This prevalence is embodied in the "granularity" rule, which implies the need for consent to be given for limited purposes and for specific situations. Consequently, "when the purposes of processing or the situation of the data subject change, the person should be requested to express a new consent" (Cippitani, 2018b). Such a rule was essentially referred to by the Italian Court of Cassation, order of 7 October 2021, No. 27325, when it stated that the new transferee data owner is required to inform the interested parties and, barring exceptions, to collect new consent (*il nuovo titolare cessionario di dati è tenuto ad informare gli interessati e, salvo deroghe, a raccogliere un nuovo consenso*) (a similar approach is followed in the Spanish legal order, and in particular in Article 34, par. 2 of Real Decreto 1716/2011 of 18 November[16], see Bombillar Sáenz, 2018).

5.2 Secondary uses of biobanks and the principle of purpose limitation

However, the granularity rule may be an obstacle to research activities, given the difficulty of obtaining consent for specific research programmes and the costs of obtaining consent for each specific scientific activity. This is particularly true for the activities of biobanks. In order to overcome the above limitations, some doctrine, practice, specific national regulations and some

[14] See e.g. Article 5 of the 1997 Oviedo Convention on Human Rights and Biomedicine, Article 3, paras. 2 and 8, par. 2 of the Nice Charter and Article 4(11) of EU Regulation 2016/679.

[15] See Italian Supreme Court of Cassation, decision of 7 October 2021, No. 27325. On this decision, see Ciancimino, 2022.

[16] According to Article 34, par. 2, "*En el caso de los biobancos, si el documento de consentimiento no prevé el empleo de la muestra para la línea de investigación, relacionada con la inicialmente propuesta, que va a desarrollar el responsable de la investigación al que se ceden las muestras, será necesario que el sujeto fuente otorgue un nuevo consentimiento*."

case law tend towards more flexible approaches than the (strict) application of the granularity rule. Thus, in some cases, reference is made to "broad consent" for a broad range of uses; in others, to presumed consent (individuals who do not wish to be involved in a particular activity must opt out); in still others, to "blanket consent", i.e. consent to any future use. More recently, the use of "dynamic consent" has been proposed, which would allow, among other things, the monitoring of secondary uses in real time. In this perspective, some scholars (Cippitani, 2018a) believe that "bilateral" solutions are needed, as people involved in research activities should be constantly informed about the progress (follow-up) of the research, so that they can participate in other projects, events, and activities. A common approach is that of "broad consensus", as is the case in Finnish law. Such an approach (which is also used in other European countries), although it aims, among other things, to "liberalise" access to biological material and related data in order to allow the scientific community and research to progress for the benefit of society, is not acceptable for several reasons, many of which are related to data protection.

First, consent must be informed, which implies, among other things, that it is freely given. This condition is not met - as laid down in Recital 43 of the GDPR and as recently clarified by the European Data Protection Board and by the European Court of Justice - when data subjects who give their consent find themselves in a "situation of imbalance of power" in relation to the person obtaining that consent. According to the EDPB, this situation may arise *"when a participant is not in good health, when participants belong to an economically or socially disadvantaged group, or in any situation of institutional or hierarchical dependency"*. Consequently, in such (not marginal) cases, "consent will not be the appropriate legal basis [...] and other legal bases than consent must be relied upon"(EDPB, 2019. More recently, see ECJ, 2023: paras. 4, 144 and 149, with particular reference to the special categories of personal data indicated in Article 9, paras. 1 and 2 of the GDPR). These other legal bases are, according to the wording of the EDPB, the "alternative legal basis", such as Article 6, par. 1e and 1f of the GDPR (EDPB, 2019).

In second place, the secondary use of databases (and of the genetic data contained therein) is subject to the principle of purpose limitation, already provided for in Article 6(b) of Directive 95/46/EC on the protection of personal data, and now included in Article 5(1)(b) of Regulation (EU) 2016/679 (a provision that - as we will see below - is also not properly remembered by those who support the idea of broad or blanket consent). According to the principle of purpose limitation, consent only has an exculpatory effect in relation to those types of interference with the body of which the subject has been made aware at the time of the request for consent and for which he or she has been expressly authorised. This implies that any secondary use of biological material and databases must be supported by a specific, free, and conscious expression of will on the part of the person concerned. Such a conclusion is primarily based on Regulation (EU) 2016/679. Indeed, if it is true that, on the one hand, personal data is "collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes" (Article 5, par. 1b, first part) and, on the other hand, "further processing for archiving purposes in the public interest, scientific or historical research purposes or statistical purposes shall, in accordance with Article 89(1), not be considered to be incompatible with the initial purposes ("purpose limitation2)" (Article 5, par. 1b, second part), it is also true that with regard to genetic data (which are a special category of personal data) Article 9 of the same regulation establishes a differentiated and stricter regime than that prescribed for other personal data, subjecting genetic data to specific safeguards so that the processing can comply with Regulation (EU) 2016/679 (starting with Article 6 of the GDPR on the lawfulness of the processing of personal data). See Sarrión Esteve, 2018). In particular, Article 9 in question presents a "two-tiered/biphasic structure": it lays down as a general rule

the prohibition to process the specific categories of data listed therein (including genetic data) (para. 1), but it also prescribes a number of exceptions to the prohibition.

The legal system of the European Union thus establishes a principle that we could define as a principle of increased relative unavailability of genetic data. This principle therefore does not share the characteristics of absoluteness, inalienability and unavailability, typical characteristics of personality rights as they have been constructed in Europe over more than a century (Alpa, 2019). One of the exceptions provided for in the provision is where *"the data subject has given his or her explicit consent to the processing of such personal data for one or more specific purposes"*. The data subject's consent must therefore be explicitly given for specific purposes (and not general, presumed, or blank). A similar position is taken by the European Data Protection Board, according to which consent must be "explicit", and therefore the silence of the person concerned or omissive behaviour are not considered as expressions of consent, as they do not manifest an unequivocal choice (EDPB, 2019).

This interpretation is supported by other important legal provisions, including Article 22 of the 1997 Oviedo Convention on Human Rights and Biomedicine, which states that *"When in the course of an intervention any part of a human body is removed, it may be stored and used for a purpose other than that for which it was removed, only if this is done in conformity with appropriate information and consent procedures"*.

6 The SharDna case

The Italian legal system has adhered to the personalist approach (Macilotti, 2013; Piciocchi et al., 2018), as the case of SharDna illustrates. The SharDna consortium, based at the Polaris Centre in Pula, Sardinia, was founded in 2000 by the entrepreneur (and future president of the region) Renato Soru and Mario Pirastu, director of the CNR's Institute of Population Genetics. Its consortium members included the San Raffaele Centre Foundation and the National Research Council (CNR). The company's statutory purpose was to carry out *"research activities [...] applied to the identification of genetic and non-genetic causes of simple and complex phenotypes"*.

The purpose of SharDna was to strengthen a research activity that had begun in 1995 by the Institute of Population Genetics of the CNR in Sassari, with the aim of studying the DNA of the citizens of a particular area of Sardinia (Ogliastra), which had ideal demographic and geomorphological characteristics for carrying out a capillary genetic study. Samples were taken, and laboratories and clinics were set up to collect demographic and genealogical data and blood samples from which DNA could be extracted. Free general and specialist medical examinations were also carried out for citizens who agreed to participate in the research project as donors. This included genetic data and biological samples from approximately 11,700 people who volunteered after being duly informed of the aims and purposes of the research[17]. Subsequently, the company SharDna was declared bankrupt by the Court of Cagliari with decision No. 76 as of 27 May 2012. On 13 May 2016, the bankruptcy judge authorised the receiver to sell the company's assets to third parties. SharDna was succeeded by Tiziana Life Sciences (TLF) PLC (a for-profit company incorporated under UK law) as the assignee of the biobank and all health, clinical, demographic, and genealogical data, with the acquisition of the rights to use the biological samples and data and the consent forms signed by the donors. The

[17] See Court of Cagliari, First Division, judgment of 18 May 2017, No. 1569.

English company therefore became the new data controller. Several authorities have intervened in this matter over the years, including the Italian Data Protection Authority[18], which does not deny the possibility that databases may circulate, but requires a further manifestation of consent for commercial use. The Italian Data Protection Authority's decision was challenged before the Court of Cagliari, which issued a ruling[19] that effectively paved the way for the commercialisation of genetic data and biobanks. However, the Supreme Court[20] overturned this position. In particular, the Sardinian judge (in a monocratic composition) annulled the decision of the Garante Privacy by which the latter had adopted the temporary measure of blocking the processing of personal data contained in the biobank, with the consequent obligation on the subject to refrain from any further processing of the data of the persons concerned and the use of biological samples (with the exception of specific processing operations listed in the judgment). The decision of the Sardinian court does not seem convincing and, in fact, follows an approach that tends to favour the financial interests of the acquiring company over the confidentiality of the data and the right to personal self-determination of the donors, whose consent was given for a purpose quite different from the commercialisation of their genetic data.

A similar approach to that of the Court of Cagliari seems to have been taken in a very similar case concerning the bankruptcy of the Icelandic company that managed the biobanks referred to by the appellant company (TLS): the deCODE Genetics case. In this case, an approach based on the blanket consent of the donor was used to legitimise secondary uses of biobanks (dissemination and commercialisation of genetic data). It is clear that the arguments put forward by the London company are completely at odds with a constitutional interpretation of the specific good to be protected, which certainly cannot be treated in the same way as any other good placed on a specific market. In the light of the principle of purpose limitation, the owners of the genetic data should have been put in a position to give their informed consent once again to a use not envisaged prior to the collection (which took place on a non-profit basis).
In addition, point 8.1 of the General Authorisation of the Garante Privacy[21] expressly authorises the processing of genetic data and the use of biological samples, but only with the express consent of the person concerned and for the purposes established in advance, otherwise there would be a presumption of consent, which is prohibited by Italian law. The Court of Cassation[22] finally ruled on the SharDna case. In fact, the Garante Privacy had appealed against the decision of the Cagliari Court which, as we have seen, had obtained the annulment of the Garante's provision by the company registered in the United Kingdom (Tiziana Life Sciences PLC). The Court of Cassation upheld the Guarantor's appeal, pointing out that consent to the processing of personal data is inextricably linked to the *intuitu personae* and that a change in the data controller determines the start of a new processing operation, which as such is subject to the general provisions on information and consent. With this ruling, the Supreme Court clarified some relevant aspects. In particular, it clarified that the definition of "processing" does not include the transfer of data to another controller. It must therefore be considered that the acquisition of data not from the data subject, but in the context of the acquisition of a business complex, determines the start of a new processing operation with a subjective change in the

[18] Provvedimento 6 October 2016, No. 389, issued against Tiziana Life Sciences PLC. In this measure, the Authority ordered the temporary blocking of the processing of personal data contained in the biobank. See also Provvedimento of the same Garante Privacy issued on 21 December 2017, No. 561, whereby the Garante partially upheld the appeal filed by certain donors interested in exercising their right to revoke the consent given at that time in favour of SharDna S.p.a.
[19] Court of Cagliari, First Division, judgment 18 May 2017, No. 1569.
[20] Court of Cassation, decision of 7 October 2021, No. 27325.
[21] General Authorisation No. 8/2016, issued by the Italian Data Protection Authority (Garante Privacy, 2016), has been deemed compliant with Regulation (EU) 2016/679 and the Italian Data Protection Code (as amended in 2018) by Garante Privacy (Provvedimento No. 497/2018, Annex 1, point 4.11.3).
[22] Court of Cassation, decision of 7 October 2021, No. 27325.

figure of the controller and the consequent obligation for the latter to inform the data subjects and obtain their consent, which, it is reiterated, can only be considered valid if it is freely and specifically given.

7 Final remarks

Under current multi-level data protection law, the individual has a veto over the (secondary) use of genetic data and biobanks. A different approach, based on presumed consent (as in the experience of the Icelandic legal system) and implying the commercialisation of such data (as in the case of the deCODE bankruptcy or in the SharDna affair, according to the perspective of the Court of Cagliari), raises significant problems, not only from an ethical point of view, but also from a legal one. In fact, it is clear that allowing the operation of broad or (*a fortiori*) blanket consent inevitably leads to the qualification of genetic data (and biobanks) as commodities and the consequent creation of secondary markets for such goods. Secondary markets that are completely illegitimate, not only because the goods in question do not have a market, precisely due to their legal nature and the fact that they relate to human dignity (Arnold and Arnold, 2018; Cippitani, 2018b; Bombillar Sáenz, 2018), but also because they are in clear contradiction with the multi-level legislation in force and the principles that govern the matter. In this respect, it is sufficient to recall the 2019 Guidelines issued by the European Data Protection Board[23], which, after noting that *"data protection is a fundamental right guaranteed by Article 8 of the Charter of Fundamental Rights",* and considering that *"one of the main purposes of the GDPR is to provide data subjects with control over information relating to them"*, observes that *"personal data cannot be considered as a tradeable commodity"*. In addition to that, it points out that *"Even if the data subject can agree to the processing of personal data, they cannot trade away their fundamental rights through this agreement"*. This is, *a fortiori*, valid for genetic data regulated under Article 9 of the GDPR.

This conclusion is therefore reached on the basis of the current multilevel legal framework on genetic data, but a clearer and more punctual intervention of the (Italian) legislator, aiming to regulate the circulation of genetic data and biobanks, seems necessary, also with the purpose of avoiding that data controllers, instead of data subjects, transfer their data for money. In fact, the regulation of such data and biobanks is left to the EU Member States, since health is not a matter on which the European Union can have a direct and significant influence. The international regulatory framework also has the limitations outlined above. A possible model to follow could be the Spanish one, which has one of the most specific and advanced regulations on the subject, based on an articulated administrative system and allows a certain degree of flexibility in the possible use of the samples, but without implying that the given informed consent is considered as a "blank" consent (see Bombillar Sáenz, 2018). A timid and indirect attempt, which could provide the legal basis for a strong protection of genetic data and biobanks, has been made by the Italian legislature, which has configured health as a global public good (Article 28 of Decree-Law No. 73 of 25 May 2021). The reference here is literally to "public goods" and not to "common goods", since the category of common goods has not yet found a specific legal framework. However, genetic data and biobanks could be qualified as global commons or

[23] EDPB, *Guidelines 2/2019 on the processing of personal data under Article 6(1)(b) GDPR in the context of the provision of online services to data subjects*, version 2.0, 8 October 2019, point 54. The same conclusion is reached in the EDPS Opinion of 2016, according to which "personal data is often perceived as the "currency" we pay for so-called "free" services on the internet. This trend does not, however, mean that personal data of individuals can legally be considered as property which can be traded freely as any other property on the market" (EPDS, 2016). Similarly, see also EDPB-EDPS, 2021.

genetic commons - see the works of Rifkin (2002), Faye (2004) Scharper and Cunningham (2006), Sedjo (1992), or configured as intellectual commons (Rampa and Camerlengo, 2014). In Hess's map of new commons, genetic commons would be included under the category of "science", which in turn would fall under the macro-category of "knowledge commons" (Hess, 2008). In this respect, it is worth recalling the proposal presented in 2007 by the Italian "Commissione Rodotà[24]", which proposes the codification of the legal category of "commons". However, this proposal does not mention genetic data.

It would therefore be necessary to amend the regulation of assets contained in the Italian Civil Code by introducing a strict management regime for common assets (in this case, genetic data and biobanks), expressly prohibiting the commercialisation of such specific categories of data. Such a conclusion may not be legally possible if the proposal for a regulation on the European Health Data Space is adopted in its current form. Indeed, while, on the one hand the Data Governance Act only sets general conditions for the secondary use of public sector data without creating a real right to secondary use of such data, and on the other, the Data Act (European Parliament and Council Regulation 2023/2854) improves the portability of certain user-generated data, which may include health data, but does not provide rules for all health data, the European Health Data Space complements these legislative proposals and provides more specific rules for the health sector (EU Commission, 2022). More specifically, in its proposal for a regulation, the European Commission points out that "On secondary use of electronic health data, researchers, innovators, policy makers and regulators would be able to have access to quality data for their work in a secure way, with trusted governance and at lower costs than relying on consent" (EU Commission, 2022).

The proposal seems hence to overtake the consent paradigm (Scialoia, 2023), also in the light of Article 33, par. 1e of such proposal (which within the minimum categories of electronic data for secondary use include *"human genetic, genomic and proteomic data"*), as well as Article 33, par. 5 of the proposal at stake (according to which *"Where the consent of the natural person is required by national law, health data access bodies shall rely on the obligations laid down in this chapter to provide access to electronic health data"*). This conclusion seems to be in breach of Article 9 GDPR, according to which *"Processing of personal data revealing racial or ethnic origin, political opinions, religious or philosophical beliefs, or trade union membership, and the processing of genetic data, biometric data for the purpose of uniquely identifying a natural person, data concerning health or data concerning a natural person's sex life or sexual orientation shall be prohibited"*.

However, although the European Commission affirms that *"the proposal is designed in full compliance not only with the GDPR but also with Regulation (EU) 2018/1725 (EU Data Protection Regulation) (EU Commission, 2022: point 1 of the Explanatory Memorandum)"*, the proposal needs to be amended in the parliamentary debate, taking into account Article 9 of the GDPR (this is also the position taken by Scialoia, 2023), in order to exclude the possibility of a market (*recte*: secondary use) of genetic data. If this change is not made, the EU institutions would place themselves in the hands of constitutional judges within the "*European constitutionalism of fundamental rights"*, which shows "*a significant tendency towards convergence"* and *"a functional link in the interpretation of written norms, in the determination of unwritten rights and in the adaptation of the law to major social changes"* (Arnold and Arnold, 2018). Indeed, there is a strong link between genetics and constitutional guarantees for individuals, as the multi-level legal framework (national, regional, and international) provides

[24] The Commission was set up by decree of the Italian Ministry of Justice on 14 June 2007 and tasked with drafting a bill to reform the regulation of public goods, as provided for in the national Civil Code of 1942.

instruments that are essentially constitutional in nature. In this scenario, apart from human dignity (the highest value in the EU Charter of Fundamental Rights, a value that is absolute and cannot be outweighed or limited in favour of another constitutional value), data protection is important for another feature of modern constitutionalism (Arnold and Arnold, 2018). Constitutional judges perform the above-mentioned functional connection by understanding constitutional texts as *"living instruments"*. These texts *"must be interpreted in accordance with the fundamental principle of freedom in a substantively and functionally efficient manner and brought into line with international perspectives"* (Arnold and Arnold, 2018). Even following such an alternative – but always possible – path, the conclusion would be the same: a market for genetic data and biobanks is not legally conceivable.

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Is Primorje-Gorski Kotar County Efficient in Fiscal Terms?

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ABSTRACT

Fiscal decentralization, if properly implemented, leads to greater efficiency. However, the efficiency of subnational entities may vary due to their inherent differences as well as the fiscal policies applied. The purpose of this research is to assess the efficiency at county level in the Republic of Croatia on the example of Primorje-Gorski Kotar County. The first objective is to compare it with the Croatian average (for counties) and comparable coastal counties using relevant indicators of fiscal decentralization. The second objective is to compare Primorje-Gorski Kotar County with other relevant counties by applying Data Envelopment Analysis (DEA) using categorical variables. The analysis is conducted for the entire counties (including the cities and municipalities on its territory). The results confirm Primorje-Gorski Kotar County to be efficient for the selected combination of fiscal and tourism inputs and GDP, as output, in the period 2015-2019.

Key words: *fiscal decentralization, counties, Primorje-Gorski Kotar County, efficiency, data envelopment analysis (DEA)*

JEL classification: *H72, 023, R11, C02, C61*

1 Introduction

The efficiency of local/regional units is a frequently researched topic, to the extent that some review papers and meta-analyses have been conducted (Kalb et al., 2012; Narbón-Perpiñá and De Witte, 2018; Aiello and Bonanno, 2019; Rueda López et al., 2020; Johnsson et al., 2021; Mergoni and De Witte, 2022; Milán-García et al., 2022). Two groups of these studies can be distinguished – the general ones, which use general economic and/or fiscal variables, and the partial or specific ones, which take into account only one service or activity. One of the most commonly used methods in all these empirical studies is Data Envelopment Analysis (DEA). In Croatia, there are several papers concerning DEA in Croatian counties (Škuflić et al., 2010; Rabar and Blažević, 2011; Rabar, 2013; Škare and Rabar, 2014; Korent et al., 2015; Borozan and Borozan, 2018; Škrinjarić, 2018; Hodžić and Muharemović, 2019; Rabar and Grbin, 2019; Slijepčević, 2019; Rabar, 2020; Šegota et al., 2024), but only four of them have used fiscal inputs (Rabar and Grbin, 2019[4], Hodžić and Muharemović, 2019, Slijepčević, 2019 and Šegota et al., 2024). The present study is an extension of these previous ones, especially the last one,

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[4] *It also used window analysis.*

as it uses categorical variables[5] and introduces tourism as an input due to its relevance for Primorje-Gorski Kotar County and other coastal counties (Rabar and Blažević (2011) have assessed the efficiency of Croatian counties in tourism). It encompasses the period from 2015 to 2019 (further years were not included due to the Covid-19 crisis).

The City of Zagreb is excluded from the DEA analysis as it is not a county in the strict sense, but a metropolitan area with a GDP per capita that is almost 50% higher than that of other counties with the highest GDP (Istria County and Primorje-Gorski Kotar County). At the NUTS 2 level, the City of Zagreb is a special region. Due to its dual status, it was also excluded from the analysis in Hodžić and Jurlina Alibegović (2019), Hodžić and Muharemović (2019) and Slijepčević (2019). Moreoever, it was identified as an outlier in Borzan and Borzan (2018) according to the Tukey's test. The special position of the City of Zagreb was also taken into account in Rabar (2013) and Škare and Rabar (2014), where it had a separate (its own) category variable (3). The first objective of the paper is to compare Primorje-Gorski Kotar County with the Croatian average (for counties) and other comparable coastal counties using relevant indicators of fiscal decentralization, tourism and GDP. The second objective is to compare Primorje-Gorski Kotar County with other coastal counties by applying Data Envelopment Analysis (DEA) using categorical variables. Although Primorje-Gorski Kotar County seems to have a relatively good performance, it has been categorised as largely inefficient in some previous general economic and/or fiscal studies (Škuflić et al., 2010; Rabar, 2013a; Rabar, 2013b, Škare and Rabar, 2014; Rabar and Grbin, 2019; Hodžić and Muharemović, 2019; Slijepčević, 2019; Rabar, 2020 and Šegota et al., 2024). In this paper, we attempt to address this issue by combining the county fiscal variables applied in Šegota et al. (2024), including the cities and municipalities within their territory (current expenditures, employee expenditures, capital expenditures), and the tourism variable (overnight stays of tourists) as input variables and GDP as the output variable.

Our hypothesis is that Primorje-Gorski Kotar County will now prove to be efficient. The Introduction is followed by Literature review which focuses on the efficiency position of Primorje-Gorski Kotar County in previous papers which have used DEA to analyse the various aspects of the efficiency of Croatian counties. The third - methodological - part is mainly dedicated to DEA with categorical variables. This is followed by a comparison of Primorje-Gorski Kotar County and other coastal counties (and the Croatian average) in terms of various broader input and output variables with a focus on fiscal decentralisation. The Results and discussion section presents the results of the DEA analysis with and without categorical variables, emphasizing the position of Primorje-Gorski Kotar County, as well as relevant projections based on the categorical variables. The Conclusions not only identify the limitations and problems of the research but also provide guidelines for future research and suggestions for improving the fiscal policy of Primorje-Gorski Kotar County.

2 Literature review

The literature on the efficiency of subnational units is extensive. Since the early 1990s, the number of published papers included in the WoS and Scopus databases has been steadily increasing (Milán-García et al., 2022). It is no wonder that the last decade has been characterised by an increasing number of literature reviews and meta-analyses on the topic (Kalb et al., 2012; Narbón-Perpiñá and De Witte, 2018; Aiello and Bonanno, 2019; Rueda

[5] Rabar (2013) as well as Škare and Rabar (2014) have also used categorical variables, but not the fiscal inputs.

López et al., 2020; Johnsson et al., 2021; Mergoni and De Witte, 2022; Milán-García et al., 2022). The highest average efficiency scores for subnational units by country are found for Germany (0.9) and Japan, the USA, Finland and Slovenia (all above 0.8), while the lowest, for South Africa (0.4), Morocco (below 0.5) and Indonesia (around 0.5). Interestingly, Italy and the Czech Republic turn out to be the fourth and fifth most inefficient countries with values below 0.6 (Narbón-Perpiñá and De Witte, 2018: 437). The countries with the highest number of papers are USA, Italy, Spain and the United Kingdom (Milán-García et al., 2022).

When calculating the efficiency of subnational units, non-parametric methods are usually used because they are more flexible and do not have such restrictive assumptions as parametric methods. The most commonly used non-parametric method is DEA. Due to its numerous advantages over traditional units (e.g. Škuflić et al., 2010), it has become a central method in measuring the efficiency not only of government units at different levels but also of companies and various other units. Common inputs in these studies are various forms of financial expenditures such as total expenditures, current expenditures (used in most studies), personnel expenditures (expressed as expenses of employees or number of employees), capital expenditures and other financial expenditures; various forms of financial resources such as total revenues and current transfers; and different forms of nonfinancial inputs such as area or various public services (Narbón-Perpiñá and De Witte, 2018). Output variables at the local level could be global output indicators/indices where different services are weighted according to selected criteria, total population (as a proxy for public services used), land area or built-up area, administrative services, infrastructure, various communal and other local services (Narbón-Perpiñá and De Witte, 2018). The higher subnational/local level of counties as regional units, which are also categorised as local units of the highest level, enables the calculation of GDP, which was used as an output in e. g. Rao and Coelli (1998), Krüger et al. (2000), Škuflić et al. (2010), Cherchye et al. (2011), Rabar (2013a), Rabar (2013b), Škare and Rabar (2014), Pastor et al. (2018), Rabar and Grbin (2019), Rabar (2020), Marto et al. (2022) and Šegota et al. (2024). Several empirical studies in Croatia have measured the general (overall) efficiency of Croatian counties based on general economic or fiscal variables (Škuflić et al., 2010; Rabar 2013; Škare and Rabar, 2014; Hodžić and Muharemović, 2019; Rabar and Grbin, 2019; Slijepčević, 2019; Rabar, 2020; Šegota et al., 2024). In addition, some partial studies relate to specific activities or sectors of counties - Rabar and Blažević (2011) measured efficiency in tourism, Korent et al. (2015) in entrepreneurship, Borozan and Borozan (2018) in energy, Škrinjarić (2018) in environmental consciousness in tourism, Rabar (2020) in the environment. Čiković et al. (2022) have prepared the first overview of the application of DEA for the different types of efficiency of Croatian counties. Table 1 presents the efficiency data – Y or N if no specific scores are given, as well as other relevant information (e.g. number of other efficient/inefficient counties), scores (if existing) and rank (if the score is below one) of Primorje-Gorski Kotar County in these studies. Additional information is provided on the specific details and versions of DEA (e.g. if more analyses are performed – input/output, window analysis or categorical variables).

Table 1 Efficiency of the Primorje-Gorski Kotar County in studies using DEA for Croatian counties

Author(s), year, type	Inputs and outputs	Efficiency: Y/N and scores (rank*)
General studies		
Škuflić, Rabar and Šokčević (2010)	Inputs: number of graduated students, active legal entities, FDI, equipment investment and exports Outputs: GDP and gross wages	N (among 13 inefficient counties)
Rabar (2013a)	Inputs: unemployment rate and number of support allowance users	Window an. (1 window): Input or.: 0.8163 (9), output or: 0.9441 (9)

	Outputs: share of the secondary sector in gross value added, gross fixed capital formation in fixed assets, level of import coverage by export, number of graduated students and GDP	Combined: 1 window and 3 categories: Input or.: 0.8235, total frequency 1 (10), Output or.: 0.9718, total frequency 3 (8)
Rabar (2013b)	Inputs: unemployment rate and number of support allowance users Outputs: share of the secondary sector in gross value added, gross fixed capital formation in fixed assets, level of import coverage by export, number of graduated students and GDP	CCR: 0.9006 (3); BCC: 0.9860 (8) Window an.: CCR; 0.7408 (3); BCC: 0.9023 (8)
Škare and Rabar (2014)	Inputs: unemployment rate and number of support allowance users Outputs: share of secondary sector in gross value added, gross fixed capital formation in fixed assets, level of import coverage by export, number of graduated students and GDP	Window an. (1 window): Input or.: 0.949312 (2.), Output or.: 0.982636 (6) Combined: 1 window and 3 categories: Input or.: 1, Output or.: 1 – in both cases among 3 efficient counties
Hodžić and Muharemović (2019) – fiscal	Inputs: gross earnings of employed people in counties, material expenses, borrowing costs Outputs: number of business and schools, population Model 1 – without borrowing costs, Model 2 – with borrowing costs	Model 1: N (8 efficient counties) Model 2 – Y (14 efficient counties)
Rabar and Grbin (2019) - fiscal	Inputs: tax revenues, current expenditures, capital expenditures, number of employees in municipalities and counties, total number of workers per county (minus previous input). Output: BDP	Window an. (1 window): 0.768 (20) Window an. (14 windows): 0.945 (16)
Slijepčević (2019) - fiscal	Input: total expenses of local government units in the county per capita Outputs: Number of inhabitants and projections (proxy for general administrative services), number of children per kindergarten/school (proxy for education), percent of the population served with waste collection (proxy for environment), road network density (proxy for infrastructure), number of cinemas/libraries per inhabitant (proxy for culture), number of inhabitants in county + 65 years old (proxy for social services)	0.57 (15)
Rabar (2020)	Input: population size Outputs: GDP, number of graduated students by residence, level of import coverage by export, the total number of persons in employment and number of medical doctors	0.8264 (11) below average efficiency
Šegota, Matić and Blažić (2024), fiscal	Inputs: current expenditures, capital expenditures, employee expenses in municipalities and counties (p.c.) Output: GDP (p.c.)	0.8395 (11)
Specific studies		
Rabar and Blažević (2011), tourism	Inputs: numbers of beds, seats, and employees, Outputs: number of arrivals, overnight stays, amount of turnover	N, 0.997 (13- assessment) Window anal. (1 window): 0.981 (4) Window anal. (5 windows): 0.999 (11)
Korent, Detelj and Vuković (2015), entrepreneurship	Inputs: total expenses and investments in fixed assets Outputs: total revenues and patents	CCR-O: N (only 4 counties efficient) BCC-O: N (9 counties efficient)
Škrinjarić (2018), environmental	Inputs: number of beds and rooms, municipal waste, current expenditures on environment protection, total investments on environment protection, tourism pressure, percentage of	BCC-O: window an. (2 years): 0.9556, 0.9999, 0.9942, 0.9630 (7 – assessment)

consciousness in tourism	current expenditures in GDP, percentage of total investments in GDP Outputs: number of tourist arrivals, number of overnight stays, reciprocal value of municipal waste, Undesirable output municipal waste (undesirable output)	
Borozan and Borozan (2018), energy	Inputs: labour employment, real gross fixed capital formation and final electricity consumption Input: real GDP	Overall technical efficiency: 0.9065 (10)
Hodžić and Jurlina Alibegović (2019), tourism	Inputs: average expenditures for tourism and average expenditures for recreation, culture and religion Outputs: total tourist arrivals and total tourist overnight stays	CRS: 0.384 (7), VRS: 0.670 (8)
Rabar (2020) - environment	Input: environmental protection expenditure and investments as a percentage of GDP Outputs: recovery rate of municipal waste collected by local government units, CO2 emission, share of treated water in total municipal wastewater discharge, and ratio of production and installed capacity of renewable energy plants	1 (among 15 other municipalities)

* There are 21 counties including the City of Zagreb and 20 without it (in Hodžić and Muharemović, 2019; Borozan and Borozan, 2018; Hodžić and Jurlina Alibegović, 2019)
Source: Authors

Although it is very difficult to compare the position of Primorje-Gorski Kotar County in different empirical studies with different methods and variables, especially when they refer to some special activities, some rough conclusions could be drawn. Although Primorje-Gorski Kotar County is one of the most developed counties (after the City of Zagreb and Istria County), the efficiency results are not among the best. Some (but not all) better results are achieved in the specific studies related to environment and tourism. However, the general studies – economic and fiscal ones - do not show that Primorje-Gorski Kotar County is among the best counties. The exceptions are one of the models (the combined analysis) by Škare and Rabar (2014) and one of the models by Hodžić and Muharemović (2019), but the latter is the situation in which even 14 counties turned out to be efficient. The inefficient position, but still a high rank (3), which coincides with its development rank, is also found in half of the research results of Rabar (2013b) – those using the CCR model.

3 Methodology

Assessing the relative efficiency of Croatian counties is a complex task that requires the application of an appropriate analytical method such as Data Envelopment Analysis (DEA). Data Envelopment Analysis (DEA) is a non-parametric method often used to assess the relative efficiency of Decision Making Units (DMUs) such as companies, hospitals, countries, etc., where a series of optimizations are performed for each DMU, while regression analysis performs optimization for all DMUs. This difference suggests that regression analysis is used when there is an interest in the general characteristics of all DMUs, while DEA is recommended when an individual DMU is compared to similar units. It allows multiple inputs and outputs measured in different units and does not require knowledge of the functional form of converting inputs into outputs, making thus DEA one of the most popular methods of operational research. After defining the set of DMUs that is intended to be assessed, the next step is to identify the relevant inputs and outputs which is a decisive step in DEA. The inputs represent the resources used, while the outputs represent the results or impacts achieved. In this research inputs are as follows: current expenditures (CuE), employee expenses (EE), capital expenditures (CaE) and overnight stays of tourists (OST), while the output variable is GDP (all variables are per capita).

The next step in conducting DEA is the construction of a model, which can be formulated as either input or output-oriented, depending on the research objectives and available data. If the DMUs are not homogeneous, i. e. are in a less favourable or more favourable situation, categorical variables are used to isolate the influence of a better position on a higher efficiency score. After selecting the counties and relevant inputs and outputs, the BCC model is used due to the variable returns to scale effect. The input-oriented BCC model (Cooper at al., 2000) evaluates efficiency by solving a linear program (in the form of an envelope):

$$
\begin{aligned}
(BCC_0) \quad & \min && \theta_B && (3.01)\\
& \text{s.t.} && \theta_B x_o - X\lambda \geq 0 && (3.02)\\
& && Y\lambda \geq y_o && (3.03)\\
& && e\lambda = 1 && (3.04)\\
& && \lambda \geq 0 && (3.05)
\end{aligned}
$$

The corresponding dual program in the form of a multiplier is:

$$
\begin{aligned}
& \max && z = uy_o - u_o && (3.06)\\
& \text{s.t.} && vx_o = 1 && (3.07)\\
& && -vX + uY - u_o e \leq 0 && (3.08)\\
& && v \geq 0, \ u \geq 0 && (3.09)
\end{aligned}
$$

Where $X = (x_j) \in R^{m \times n}$ is a set of data about inputs, $Y = (y_j) \in R^{s \times n}$ is a set of data about outputs, $\lambda \in R^n$ and e is a row vector whose elements are all equal to 1 while the production possibility set is defined as $P_B = \{(x, y) | x \geq X\lambda, y \leq Y\lambda, e\lambda = 1, \lambda \geq 0 \}$.

The output-oriented BCC model (Cooper at al., 2000) evaluates efficiency by solving a linear program (in the form of an envelope):

$$
\begin{aligned}
& \max && \eta_B && (3.10)\\
& \text{s.t.} && X\lambda \leq x_o && (3.11)\\
& && \eta_B y_o - Y\lambda \leq 0 && (3.12)\\
& && e\lambda = 1 && (3.13)\\
& && \lambda \geq 0 && (3.14)
\end{aligned}
$$

The corresponding dual program in the form of a multiplier is:

$$
\begin{aligned}
& \min && z = vx_o - v_0 && \\
& \text{s.t.} && uy_o = 1 && (3.16)\\
& && vX - uY - v_o e \geq 0 && (3.17)\\
& && v \geq 0 &&
\end{aligned}
\qquad (3.15)
$$

All units classified as efficient have an efficiency score of 1 (100 %) and are on the efficiency frontier, while all units with an efficiency value of less than 1 are inefficient and lie below this frontier. DEA enables not only the determination of inefficiencies but also projections to the efficiency frontier for each of these units. It means that DEA enables us to find the sources and the amounts of inefficiency.

4 Empirical data and analysis - Comparison of Primorje-Gorski Kotar County and other coastal counties based on input and output variables

In this section, Primorje-Gorski Kotar County is compared to other coastal counties and the Croatian average in terms of the input and output DEA variables including some additional fiscal variables as the focus is on fiscal decentralization indicators. The Republic of Croatia has a decentralized administration consisting of a central, regional and local government. The cities and municipalities represent the first level of local government, the counties are the second or intermediate level. The central level of government consists of various ministries and autonomous institutions of the central state authorities. There are a total of 555 local self-government units in the Republic of Croatia, including 127 cities and 428 municipalities and 20 regional self-government units, i.e. counties. The city of Zagreb, as the capital of the Republic of Croatia, has the special status of a city and a county. In total, there are 576 local and regional (county) self-government units in the Republic of Croatia (Ministry of Justice and Administration, 2024). An overview of the territorial structure of the counties showing the difference between the observed counties is presented below. The data in Table 2 show that the observed coastal (Adriatic) counties in the Republic of Croatia differ in terms of the number of inhabitants, the area they occupy and the number of local units on their territory. The data for the 2019 are presented, as this is the last observed year in the DEA analysis.

Table 2 Structure of the observed Adriatic counties in the Republic of Croatia and the Croatian average in 2019

County	No. cities	No. municipalities	Total	Surface area km2	No. Residents
Primorje-Gorski Kotar	*14*	*22*	*36*	*3,588*	*282,730*
Lika-Senj	4	8	12	5,353	44,625
Zadar	6	28	34	3,646	168,213
Šibenik-Knin	5	15	20	2,984	99,210
Split-Dalmatia	16	39	55	4,540	447,747
Istria	10	31	41	2,813	209,573
Dubrovnik-Neretva	5	17	22	1,781	121,816
Average CRO	*6*	*21*	*26*	*2,694*	*193,583*

Source: Croatian Bureau of Statistics (2018); Croatian Bureau of Statistics (2024)

The data presented show large differences in the number of cities and municipalities as well as in the area and population of the individual counties. The average population of the counties in the Republic of Croatia is 193,583 inhabitants. Split-Dalmatia County has the largest population (447,747), while Lika-Senj County, which has the largest area, has the smallest population (44,625). Most counties have been undergoing a depopulation process in recent years, which

ultimately affects the population decline in the Republic of Croatia, which is due to negative natural trends and external migration, especially to the countries of the European Union, which was exacerbated by Croatia's accession to the European Union in 2013. It is clear that the number of towns and municipalities by county ranges from 12 in Lika-Senj County to 55 in Split-Dalmatia County. Primorje-Gorski Kotar County has a larger population than the average, while Split-Dalmatia County has a larger population than the observed counties. The same applies to the number of local units.

As mentioned earlier, budgetary spending by lower levels of government plays a very important role in supporting or achieving positive economic indicators. Effective allocation of budgetary resources, both for current and capital expenditures, can promote economic growth and provide the infrastructure for service delivery. Capital investment (spending on the acquisition of non-financial assets) earmarked for the maintenance and construction of infrastructure such as roads, health facilities, schools, sports facilities and energy systems creates the conditions for the realization of economic activities. Similarly, current consumption can increase human capital, promote innovation and stimulate economic activity by channelling funds into education, promoting small and medium-sized enterprises and providing quality social services. The provision of quality social services, such as health and social care, can improve the productivity of the workforce. Table 3 shows spending by local units in the broader county area. Overnight stays by tourists in commercial accommodation establishments, which are especially relevant to the coastal counties, and their GDP are also included. To make the comparison as reliable as possible and given the large differences between counties, which are partly due to the large differences in population, all variables are considered on a per capita basis.

Table 3 Relevant input and output variables for Adriatic counties and the Croatian average in 2019

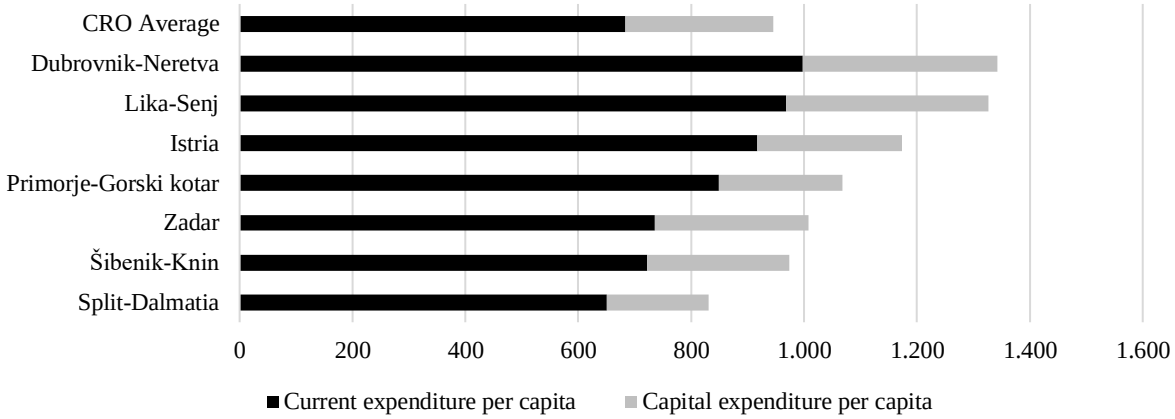
County	Tourist overnight stays per capita	GDP per capita	Employee expenses per capita	Current expenditure per capita	Capital expenditure per capita	Expenditure per capita
Primorje-Gorski Kotar	*54*	*14,937*	*98*	*849*	*220*	*1,069*
Lika-Senj	64	10,614	136	968	359	1,326
Zadar	59	11,381	86	736	272	1,008
Šibenik-Knin	56	11,205	88	722	252	974
Split-Dalmatia	40	10,594	84	650	181	831
Istria	126	15,702	105	917	257	1,174
Dubrovnik-Neretva	68	14,386	113	997	345	1,342
Average CRO	*22*	*13,458*	*82*	*683*	*262*	*945*

Source: Authors according to data from Ministry of Finance (Obrazac PR-RAS, za razdoblje 2014.-2020.); Croatian Bureau of Statistics (2024)

Table 3 shows that of the seven counties observed, six achieve per capita expenditure above the average for the Republic of Croatia, whereby these are mostly counties with an above-average GDP and an above-average number of overnight stays of tourist per capita. Looking at the expenditure per capita, Dubrovnik-Neretva County has the highest expenditure (EUR 1,342), followed surprisingly by Lika-Senj County. The fact that Lika-Senj County has above-average per capita expenditure is due to the fact that this county is largely financed by grants and transfers from the central government. Dubrovnik-Neretva and Lika-Senj counties have the highest investment and current expenditure per capita, as they have the highest total expenditure. The most developed county with the highest GDP per capita and the highest

number of overnight stays is Istria, followed by Primorje-Gorski Kotar and Dubrovnik-Neretva counties. Split-Dalmatia County has the worst economic indicators, with the lowest GDP per capita and the lowest number of overnight stays per capita. After Istria County, Primorje-Gorski Kotar County has the best economic indicators and values that are above the average for the Republic of Croatia. In terms of consumption, spending in Primorje-Gorski Kotar County is above the average for the Republic of Croatia, while in comparison to the Adriatic counties it is above the Dubrovnik-Neretva, Lika-Senj and Istria counties. The costs of wages and salaries, which indicate labour input and can provide information on whether certain units have too many or too few employees, are above the average for the Republic of Croatia in all Adriatic counties. Lika-Senj County has the highest costs per employee (EUR 136), while Split-Dalmatia has the lowest (EUR 84). The amount of budgetary resources available to local units in 2019 is roughly equal to the number of residents per county, and this ratio is largely a consequence of the fact that local units are highly dependent on personal income tax. Local units' expenditures are mainly used to finance economic affairs, general public services, culture and religion, education, and community and housing services. Effective budget management can increase the effectiveness of programmes and projects and ensure that optimal results are achieved. Figure 1 provides an overview of the realised expenditure of the local units in 2019, looking at current and capital expenditure. Current expenditure refers to expenditure that arises mainly from day-to-day activities, i.e. regular operations, while capital expenditure is often used as a means to promote economic growth and improve public services. Capital expenditures can vary significantly from year to year depending on projects and investments undertaken by lower levels of government.

Figure 1 Expenditures of local units in the area of observed counties in 2019

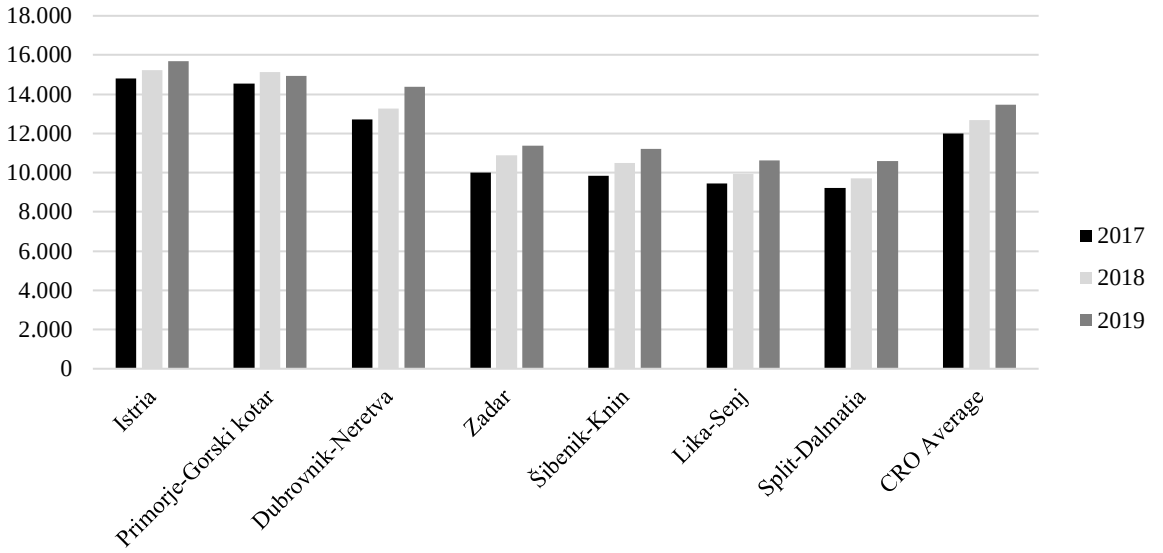


Source: Authors according to data from Ministry of Finance (Obrazac PR-RAS, za razdoblje 2014.-2020.)

The highest per capita expenditures were in Dubrovnik-Neretva County (EUR 1,342). Dubrovnik-Neretva County was followed by Lika-Senj County (EUR 1,326), Istria County (EUR 1,174) and Primorje-Gorski Kotar County (EUR 1,069). The lowest expenditures were incurred in Split-Dalmatia County (EUR 831), which is the only county below the average for the Republic of Croatia, and in Šibenik-Knin County (EUR 974). The largest amount is spent on capital expenditures, i. e. the acquisition of non-financial assets, in the following counties: Lika-Senj (EUR 359) and Dubrovnik-Neretva (EUR 345). Primorje-Gorski Kotar County allocated only EUR 220 per capita for capital expenditures in 2019, which is below the average for the Republic of Croatia. This type of expenditures usually has long-term consequences and benefits and can also have a positive impact on employment and the overall development of the community. In terms of current expenditures, Dubrovnik-Neretva County (EUR 997) and Lika-

Senj County (EUR 968) are again at the top of the list, while Split-Dalmatia County (EUR 650) has the lowest current expenditures. Current expenditures are an essential part of financial management, and monitoring and thus controlling these costs is key to maintaining financial stability. The inefficient use of funds in local units is often pointed out, i.e. funds are not used optimally or are not aligned with the priorities and needs of the community. The efficient use of public funds is an essential prerequisite for the long-term sustainability of public finances, the improvement of citizens' living standards and balanced and inclusive economic development. As GDP is a measure of economic activity in a county and represents the total value of all goods and services produced within certain limits in a given period and is used in this thesis as a key indicator of the economic performance and development of the counties, a comparative overview of the development of GDP over the three-year period for the counties observed is provided below in Figure 3.

Figure 2 GDP per capita of Croatian Adriatic counties and the Croatian average, 2017-2019



Source: Authors based on Croatian Bureau of Statistics (2024)

Figure 2 shows the development of GDP per capita in the Croatian Adriatic counties in the period from 2017 to 2019. The counties with the highest GDP per capita are Istria and Primorje-Gorski Kotar; in 2019, it was EUR 15,702 in Istria and EUR 14,937 in Primorje-Gorski Kotar. The most underdeveloped counties according to this indicator are Split-Dalmatia County, which had a GDP per capita of EUR 10,594 in 2019, and Lika-Senj County (EUR 10,614). All counties are below the Croatian average, except Istria, Primorje-Gorski Kotar and Dubrovnik-Neretva County. The average for the Republic of Croatia is raised significantly by the City of Zagreb, which is not included in this presentation. It is the driving force behind the development of the Croatian economy, as its GDP per capita is almost twice as high as the Croatian average.

If the City of Zagreb is excluded from the analysis, the Adriatic counties have a higher GDP than other counties. The GDP of the Adriatic counties in Croatia may be higher for several reasons. The Adriatic counties have a rich tourist offer due to their coastline, islands, and cultural attractions. Tourism can have a significant impact on the GDP of these counties as it attracts a large number of domestic and foreign tourists who spend money on accommodation, food, entertainment, and other services. The Adriatic counties have a favorable geographical position on the Adriatic Sea, which enables the development of maritime activities and trade. However, it is important to note that the higher GDP of the Adriatic counties is not always a sign of complete economic well-being or even development. There can also be challenges, such

as the seasonality of tourism, unemployment in some inland areas, and infrastructural deficiencies that limit potential growth. Therefore, it is important to understand the broader picture and properly interpret GDP data along with other economic indicators to get a more complete picture of the counties' economic situation.

5 Results and discussion – DEA without and with categorical variables

In this section, input- and output-oriented DEA results are presented and discussed. First, the counties without introducing categorical variables are evaluated, that is, by comparing each county with each other, without taking into account their differences, with the input-oriented and output-oriented direction of the BCC model. The results of efficiency averages for the 2015-2019 period are presented in Table 4, columns 2 and 4. It should be noted that there are no significant changes in the average efficiency results for input and output-oriented directions of the BCC model in the period 2015-2019, except for Zadar and Lika-Senj counties with the result significantly higher for the output-oriented BCC model than for the input-oriented model. This means that inefficiently used inputs in these two counties have a greater impact on the efficiency result than the lack of realized GDP per capita. Bjelovar-Bilogora, Požega-Slavonia, Virovitica-Podravina, and Vukovar-Srymia County show a better efficiency result in the input orientation than in the output orientation, which indicates that the deficit of realized GDP per capita influences the efficiency results more than the surplus of available inputs. The remaining inefficient counties such as Dubrovnik-Neretva, Istria, Karlovac, Sisak-Moslavina, Split-Dalmatia, Šibenik-Knin, Zadar and Zagreb achieved a better result with output orientation, indicating that the available inputs should be used more efficiently to achieve a higher GDP per capita. Brod-Posavina, Koprivnica-Križevci, Krapina-Zagorje, Međimurje, Primorje-Gorski Kotar and Varaždin counties were assessed as efficient over the entire period and with all models, while the Istria County achieved its efficiency with the output-oriented model. The next step was to extend the input and output-oriented BCC model by introducing categorical variables that reflect favourable and less favourable conditions.

The example of hierarchical categorization is used (Cooper et al., 2000) and categories 1 and 2 were assigned, where category 2 was assigned to Adriatic counties under more favourable conditions and lower category 1 to continental counties under less favourable conditions in terms of tourism capacity. The inclusion of categorical variables is an extension of the BCC model, in which the Adriatic counties were evaluated in comparison to all counties while continental counties were evaluated only within the same category. It is therefore assumed that the Adriatic counties (with the value of categorical variable 2) have an advantage over the continental counties (with the value of categorical variable 1), which is why they are compared with all counties, while the continental counties are only compared with each other. This ensures that the reference group consists only of units (counties) that have the same or worse values of the categorical variable, which means that for inefficient units (counties), the reference units (counties) are those within the same category. Such an approach allows for a fairer comparison and a more realistic projection of inputs and outputs than possible changes for inefficient counties to achieve efficiency. This increases the credibility of the findings on possible improvements.

The results of the average efficiency of counties in the period from 2015 to 2019 with the categorical approach, shown in Table 4, (columns 3 and 5), differ for most counties from the efficiency results without categorical variables, but not significantly. Only Lika-Senj County

has significantly different results of average efficiency under the output-oriented model with (85%) and without categorical variables (69%). The Brod-Posavina, Koprivnica-Križevci, Krapina-Zagorje, Međimurje, Primorje-Gorski Kotar, Varaždin, and Istria counties are still relatively efficient. Lika-Senj County with 51% has the lowest result of average efficiency under the assumption of input orientation, while the worst result under output orientation was achieved by Vukovar-Srymia County at 74%.

Table 4 Efficiency averages with and without categorical variables 2015-2019

County	Input-oriented without cat.	Input-oriented with cat.	Output-oriented without cat.	Output-oriented with cat.
Bjelovar-Bilogora	0.94	0.95	0.92	0.9
Brod-Posavina	1	1	1	1
Dubrovnik-Neretva	0.88	0.85	0.93	0.9
Istria	0.98	0.99	1	1
Karlovac	0.81	0.84	0.83	0.88
Koprivnica-Križevci	1	1	1	1
Krapina-Zagorje	1	1	1	1
Lika-Senj	0.54	0.51	0.69	0.85
Međimurje	1	1	1	1
Osijek-Baranja	0.97	0.96	0.97	0.96
Požega-Slavonia	0.94	0.96	0.9	0.92
Primorje-Gorski Kotar	*1*	*1*	*1*	*1*
Sisak-Moslavina	0.85	0.84	0.89	0.88
Split-Dalmatia	0.78	0.79	0.8	0.82
Šibenik-Knin	0.72	0.71	0.78	0.78
Varaždin	1	1	1	1
Virovitica-Podravina	0.8	0.82	0.76	0.77
Vukovar-Syrmia	0.81	0.82	0.75	0.74
Zadar	0.69	0.67	0.76	0.77
Zagreb	0.98	0.98	0.99	0.99

Source: Authors

Table 5 shows the results of efficiency for counties in 2019 according to the BCC model in both directions, with and without categorical variables. The efficiency results according to the BCC model in both directions without categorical variables are the same for all counties, with a relatively high average efficiency of 89%. The results obtained with the categorical variables differ: This justifies their inclusion in the analysis, as it is extremely important to compare counties within comparable groups. This allows the subnational government to make more meaningful performance comparisons. The average efficiency result is 88%, which is very close to the previous one. However, all efficiency results differ more or less for individual counties, most of which are Lika-Senj, Dubrovnik-Neretva, and Karlovac County. The average efficiency result with the output-oriented model with categorical variables is as high as 90% and is higher for six counties (Dubrovnik-Neretva, Lika-Senj, Osijek-Baranja, Sisak-Moslovina, Šibenik-Knin and Zadar) than with the input orientation, which leads to the conclusion that the ineffective use of inputs has a greater impact on the efficiency result than the lack of realized output, which is particularly true for Lika-Senj County. The result of the average efficiency for the continental counties with the input-oriented model and the categorical variable is 90 %, while for the Adriatic counties, it is slightly lower and amounts to 87 %. The result according

to the output-oriented model is still 90% for the continental counties and 91 % for the Adriatic counties.

Table 5 Efficiency scores with and without categorical variables for 2019

County	input-oriented		output-oriented	
	without cat.	with cat.	without cat.	with cat.
Bjelovar-Bilogorje	0.82	0.87	0.82	0.82
Brod-Posavina	1	1	1	1
Dubrovnik-Neretva	0.95	0.8	0.95	0.95
Istria	1	1	1	1
Karlovac	0.77	0.89	0.77	0.79
Koprivnica-Križevci	1	1	1	1
Krapina-Zagorje	1	1	1	1
Lika-Senj	0.71	0.55	0.71	0.89
Međimuje	1	1	1	1
Osijek-Baranja	0.91	0.89	0.91	0.91
Požega-Slavonia	0.78	0.88	0.78	0.78
Primorje-Gorski Kotar	*1*	*1*	*1*	*1*
Sisak-Moslavina	0.89	0.81	0.89	0.89
Split-Dalmatia	0.86	0.88	0.86	0.86
Šibenik-Knin	0.82	0.77	0.82	0.82
Varaždin	1	1	1	1
Virovitica-Podravina	0.76	0.84	0.76	0.76
Vukovar-Syrmia	0.75	0.79	0.75	0.75
Zadar	0.83	0.75	0.83	0.83
Zagreb	1	1	1	1
Average	0.89	0.88	0.89	0.9
Average cat 1		0.9		0.9
Average cat 2		0.87		0.91

Source: Authors

Below are the results of the potential improvements for all counties in 2019, using a categorical and output-oriented approach. Table 6 shows the category, the efficiency results for 2019, and the recommended changes in the percentages of each input and output for all 20 counties. The best efficiency results (100%) were achieved by the following counties: Brod-Posavina, Istria, Koprivnica-Križevci, Krapina-Zagorje, Međimurje, Primorje-Gorski Kotar, Virovitica and Zagreb. The lowest efficiency result is estimated for Vukovar-Syrmia County at approx. 75%, while the average value score is 90%. The highest average percentage of change required for all inefficient counties is almost 15% for input EE (employee expenses), which means that it has the greatest impact on the inefficiency score and should therefore be an important indicator for policymakers to consider when making decisions.

The next two inputs with the average percentage of change are OST with approximately 14% and CaE (capital expenditures) with close to 13% recommended change while GDP, as the only output, has the result of an average change of 12%. Primorje-Gorski Kotar County achieved 100% efficiency, which means that, compared to the other counties, it efficiently uses inputs.

Table 6 Projections of the output-oriented model with categorical variables in 2019

County	Category	Score	(I)CaE Change	(I)CuE Change	(I)EE Change	(I)OST Change	(O)GDP Change
Bjelovar-Bilogorje	1	0.82	-17.29%	-2.77%	-23.04%	0.00%	21.37%
Brod-Posavina	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Dubrovnik-Neretva	2	0.95	-34.04%	-13.57%	-12.04%	0.00%	4.89%
Istria	2	1	0.00%	0.00%	0.00%	0.00%	0.00%
Karlovac	1	0.79	-11.22%	-5.09%	-29.97%	-79.53%	26.70%
Koprivnica-Križevci	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Krapina-Zagorje	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Lika-Senj	1	0.89	-47.99%	-40.98%	-61.65%	-98.27%	12.35%
Međimuje	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Osijek-Baranja	1	0.91	-26.83%	-1.33%	-34.03%	0.00%	10.26%
Požega-Slavonia	1	0.78	-25.14%	0.00%	-16.79%	0.00%	28.93%
Primorje-Gorski Kotar	*2*	*1*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Sisak-Moslavina	1	0.89	-13.16%	-17.94%	-23.50%	0.00%	12.11%
Split-Dalmatia	2	0.86	0.00%	0.00%	-21.57%	-62.94%	15.90%
Šibenik-Knin	2	0.82	0.00%	0.00%	-5.58%	-29.83%	21.59%
Varaždin	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Virovitica-Podravina	1	0.76	-59.30%	0.00%	-21.00%	0.00%	31.88%
Vukovar-Syrmia	1	0.75	-25.36%	-12.88%	-48.51%	0.00%	33.04%
Zadar	2	0.83	-3.27%	0.00%	-1.93%	0.00%	21.07%
Zagreb	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Average		0.90	-13.18%	-4.73%	-14.98%	-13.53%	12.00%

Notes: CeE - current expenditures, EE - employee expenses), CaE - capital expenditures, OST - overnight stays of tourists
Source: Authors

Table 7 shows the category, the efficiency results for 2019, and the recommended changes in the percentages of each input and output under the categorical and input-oriented approach. The best efficiency results were achieved by the same counties as under the previous output orientation: Brod-Posavina, Istria, Koprivnica-Križevci, Krapina-Zagorje, Međimurje, Primorje-Gorski Kotar, Virovitica and Zagreb. Lika-Senj County has the lowest efficiency result of approximately 55%, while the average value score is 89%.

The highest average percentage of change required for all inefficient counties is close to 29% for input OST (overnight stays of tourists), which means that it has the greatest impact on the inefficiency score. The second input that should be carefully considered is EE with an average of almost 18% recommended change.

Table 7 Projections of the input-oriented model with categorical variables in 2019

County	Category	Score	(I)CaE Change	(I)CuE Change	(I)EE Change	(I)OST Change	(O)GDP Change
Bjelovar-Bilogorje	1	0.87	-12.63%	-12.63%	-17.33%	-12.63%	3.72%
Brod-Posavina	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Dubrovnik-Neretva	2	0.8	-33.70%	-20.17%	-20.17%	-20.17%	0.00%
Istria	2	1	0.00%	0.00%	0.00%	0.00%	0.00%
Karlovac	1	0.89	-11.09%	-11.09%	-26.01%	-68.52%	4.50%
Koprivnica-Križevci	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Krapina-Zagorje	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Lika-Senj	1	0.55	-44.53%	-44.53%	-61.24%	-97.36%	0.00%
Međimurje	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Osijek-Baranja	1	0.89	-14.49%	-10.73%	-30.51%	-10.73%	0.00%
Požega-Slavonia	1	0.88	-12.15%	-12.15%	-12.15%	-12.15%	13.45%
Primorje-Gorski Kotar	*2*	*1*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Sisak-Moslavina	1	0.81	-19.09%	-19.09%	-19.90%	-19.09%	4.10%
Split-Dalmatia	2	0.88	-11.71%	-11.71%	-32.56%	-97.42%	0.00%
Šibenik-Knin	2	0.77	-23.46%	-23.46%	-40.21%	-97.46%	0.00%
Varaždin	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Virovitica-Podravina	1	0.84	-49.95%	-15.66%	-15.66%	-15.66%	12.26%
Vukovar-Syrmia	1	0.79	-20.78%	-20.78%	-42.69%	-20.78%	10.81%
Zadar	2	0.75	-25.48%	-25.48%	-39.55%	-97.49%	0.00%
Zagreb	1	1	0.00%	0.00%	0.00%	0.00%	0.00%
Average		0.89	-13.95%	-11.37%	-17.90%	-28.47%	2.44%

Notes: CeE - current expenditures, EE - employee expenses), CaE - capital expenditures, OST - overnight stays of tourists
Source: Authors

It is interesting that a comparison could be made for the neighboring coastal Istria County not only because of the similarity in terms of economic development, the number of cities/municipalities, inhabitants and all fiscal variables included, but also because of the efficiency results (Istria is the only coastal county besides Primorje-Gorski Kotar that is efficient). These results are quite robust as they almost do not differ after applying categorical variables.

6 Conclusions

DEA efficiency results for Croatian counties with (and without) categorical variables have confirmed our hypothesis about Primorje-Gorski Kotar County being efficient for the selected combination of fiscal and tourism inputs and GDP, as output, during the 2015-2019 period. This is a new contribution to the DEA analysis of Croatian counties and especially the position of Primorje-Gorski Kotar County. The research results are relevant for the other counties as well. Out of the 20 counties included in the analysis, only 8 counties are rated as efficient: Brod-Posavina, Istria, Koprivnica-Križevci, Krapina-Zagorje, Međimurje, Primorje-Gorski Kotar, Virovitica and Zagreb. Out of these efficient counties, only 2 out of 6 belong to the Adriatic

county group and 6 out of 14 to the continental county group. The average efficiency values of around 90% for 2019 show that improvements are possible at regional level. The inclusion of categorical variables in the DEA models allowed the inclusion of qualitative factors that may influence efficiency but are not directly measurable as inputs or outputs. The DEA projections and efficiency differences between counties divided into two groups, defined by categorical variables, provided targeted policy interventions or strategies for resource allocation. The efficient use of resources in local entities such as counties, cities or municipalities is essential in ensuring sustainable development and the provision of quality services to citizens. Regardless the results ehich indicated that Primorje-Gorski Kotar County is efficient in comparison to other counties, it is necessary to regularly monitor and evaluate the activities and results in order to identify the areas where efficiency improvement is needed. Investments in infrastructure, equipment and other long-term material goods have a long-term impact on the economy and the community, and thus, Primorje-Gorski Kotar County should invest an even greater share of its funds into such projects. In terms of the current consumption, it is necessary to automate processes, optimise workflows, reduce unnecessary costs and find cheaper alternatives. The data obtained suggests that tourism in Primorje-Gorski Kotar County is managed in a sustainable way compared to other Adriatic counties in order to maximise the positive impact of tourism on GDP.

In addition, fiscal policymakers should utilize the identification of specific groups of counties that may need interventions to improve efficiency, as well as potential drivers of efficiency. The analysis is limited to the 2015-2019 period, which excludes the impact of the COVID-19 pandemic - a major event that could have significantly affected fiscal dynamics. This is one of the guidelines for future research that will compare "normal" and Covid-19 efficiency results. Furthermore, the findings are highly specific to one county and a particular set of conditions. This specificity could limit the generalizability of the results to other regions or contexts without similar fiscal structures and economic conditions. Therefore, the broader group of regions with similar economic structure (especially tourism-driven economies), e. g. those in the Mediterranean region could also be included in the efficiency analysis to further differentiate the efficiency of inefficient counties and identify possible necessary changes. In addition, super-efficiency could be examined in future studies, which would enable an additional classification of efficient countries/countries.

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The Role of E-Government in Economic Growth

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ABSTRACT

In recent decades, a trend that has changed the way governments and companies operate is the development and implementation of information and communication technologies. The term e-government refers to the digitalisation of the public sector and administration, which includes the use of information and communication technologies in the daily work of public administration. E-government also includes interaction between different government bodies and implementation of administrative processes through online platforms and digital channels, etc. Digitalisation of the public sector can affect economic growth through several channels. By eliminating unnecessary paperwork and manual processes, e-government can save time and resources, both for itself and for the rest of the economy. Due to greater transparency and easier access to information, citizens and companies can monitor government actions, and get information about policies or public expenditures more efficiently. As a result, there may be a reduction in corruption and an increase in private sector investments, which ultimately supports economic growth. The aim of this paper is to investigate the relationship between the application of information and communication technologies in the public sector (e-government) and economic growth. A panel data comprising 11 countries of Central and Eastern Europe is used for the period from 2012 to 2022. For this purpose, data are taken from Eurostat and UN databases. Given the structure of the available macroeconomic data, we apply panel data modelling. Research results suggest that components of e-government index, especially online services and telecommunication infrastructure, positively affect GDP growth and productivity in the analysed countries.

Keywords: *CEECs, economic growth, e-government*

JEL classification: H1, O1

1 Introduction

In recent decades, the development and use of modern information and communication technologies (ICT), in particular the internet, has changed the way we live and do business. The acceleration of transactions on the global market, the reorganisation of investment, goods and service flows, changes in social and professional life, the increase in available information in both the private and public sectors are the consequences of the accelerated spread and use of ICT. The new ICTs are now seen as the basis for the development of the knowledge society, and the ability to access and utilise ICTs is seen as crucial for personal and social progress.

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Instead of capital, information and expertise are becoming the basic unit of individual, social and economic growth.

E-government, which implies the use of information technology in public administration, has a special role to play in social development in this sense. E-government refers to the use of information and communication technologies to transform and improve the delivery of government services, to improve governance and public administration, to engage with citizens and to promote greater transparency and efficiency in the work of government agencies. E-government encompasses a wide range of digital initiatives, including online portals, mobile applications, electronic forms, digital identity systems, data analytics and more, all aimed at making government services and information accessible to citizens and businesses in a convenient and efficient way. E-government can be defined as a way for the government to utilise the most innovative information and communication technologies, especially web-based Internet applications, to provide citizens and businesses with a more convenient approach to government information and services, to improve the quality of services, and to provide more opportunities to participate in democratic institutions and processes (Guo, 2010). E-government aims to increase the efficiency, speed, openness and quality of public administration through the implementation of ICT solutions and digital transformation in public administration. These goals are usually aimed at improving the efficiency, effectiveness, transparency and accountability of the administration while promoting citizen engagement and participation. These e-government goals can vary from country to country or region to region, depending on the specific needs, priorities, and level of development. Governments often develop comprehensive e-government strategies to outline their goals and the steps required to achieve them. The successful implementation of e-government initiatives can lead to a more responsive, efficient, and citizen-centred public administration. The importance of the effectiveness of e-government became clear during the Covid-19 pandemic. The pandemic had an impact on all aspects of personal life and the economy as a whole, including the functioning of public administration. As social distancing was necessary, governments in all EU countries endeavoured to make e-government services accessible to all.

There are different types or models of e-government, each with their own characteristics and objectives. Common types of e-government are Government to Citizens (G2C), Government to Business (G2B), Government to Government (G2G) and Government to Employees (G2E). The G2C model focuses on the direct provision of government services and information to citizens via digital channels. Examples of this include online tax registration, driving licence renewal and online permit applications. Governments expect these systems to improve the relationship between citizens and the government, to promote transparency and accountability and to enable effective services for citizens (Alshehri and Drew, 2010). The G2B e-government model encompasses the interaction between government agencies and businesses. It aims to simplify processes for businesses, such as online business registrations, procurement portals and digital authorisation systems. The G2G model encompasses the interaction between different government agencies at different levels (local, regional, national). It aims to improve cooperation, data exchange and coordination between government agencies and authorities. G2E focuses on the provision of services and information for government employees. This includes human resource management, payroll systems and employee self-service portals (Seifert, 2003). These are some of the common types of e-government models, and many countries choose a combination of these approaches to meet the specific needs of their citizens and businesses. The choice of model depends on factors such as the country’s administrative structure, technological infrastructure and level of digital maturity.

The digital transformation of the administration is also seen as a driving force leading to the success of the EU's Digital Single Market strategy, which aims to ensure efficient and effective access to online services across Europe. The main objective of the Digital Single Market "*is to remove existing digital barriers, reduce administrative hurdles and ultimately increase the efficiency of interactions between governments and citizens, including businesses*" (European Commission, 2020). As part of the Digital Single Market Strategy for Europe, an e-Government Action Plan was launched for the period 2016-2020 with the aim of removing existing digital barriers to the Digital Single Market and impeding further fragmentation in the context of the transformation of public administrations. Although member states are implementing their own strategies and activities, this action plan sets out several principles that should be followed in future initiatives in order to realise the key benefits of e-government for businesses, citizens and public institutions themselves. Although many improvements have been made in the area of e-government, the results of Ravšelj et al. (2020) indicate that more than a third of the EU-28 countries perform relatively poorly in terms of the e-government development index and the e-participation index. This is particularly true for the new EU member states (NMS), which had very low scores for these two indicators before 2020. Governments in Central and Eastern Europe are therefore under pressure to improve e-participation and e-digitalisation.

Since there is little literature dealing with the role of e-government in economic growth for Central and Eastern European countries, the aim of this paper is to analyse the relationship between the use of information and communication technologies in the public sector (e-government) and economic growth in Croatia and the CEE countries. The paper therefore contributes to the existing literature by identifying the impact of different components of e-government on economic growth and labour productivity in selected countries. The rest of the paper is organised as follows. The introduction is followed by a brief literature review and a theoretical framework in which an overview of previous research and theoretical explanations of the contribution of e-government to economic growth are provided. The third empirical part of the paper presents the descriptives and methodology used in this study. The results and discussion are presented in the next section. The paper ends with concluding remarks.

2 Literature review and theoretical framework

E-government programmes lead to numerous improvements that contribute to GDP growth. A literature review of the relationship between e-government and economic growth reveals a complex interaction between the two. While there is evidence that e-government can contribute to economic growth, the specific mechanisms and outcomes vary from context to context. For example, the level of availability of telecommunications and internet is lower in developing countries, which very often leads to an increase in the cost of implementing e-government and sometimes, as such, to a negative effect, i.e. a difference between the expected benefits and the expected costs of this transformation. The e-government adoption plan should be analysed in detail and in accordance with the national economic environment in order to avoid the above-mentioned gap in developing countries.

Based on the literature review and theoretical framework, we propose the first research hypothesis as follows:

H1: E-government development and the components of the E-Government Development Index influence economic growth.

One of the main arguments in favour of the positive impact of e-government on economic growth is its potential to increase administrative efficiency and reduce administrative costs. Research by Dunleavy et al (2006) shows that e-government can lead to cost savings through streamlined processes and improved service delivery. These efficiency gains can free up resources for other public investments and stimulate economic growth. The introduction of e-government can modernise government processes, reduce bureaucracy (Cordella and Tempini, 2015) and eliminate inefficiencies (Evans and Yen, 2015). This leads to cost savings for both the government and businesses and makes it cheaper to operate and invest in a country. Efficiency gains can also lead to a reduction in corruption (Rustiarini, 2019), which can further improve the business environment, e.g. by simplifying regulatory procedures, reducing paperwork and providing online access to permits and licences. This can attract more businesses and entrepreneurs, stimulate investment, and promote economic growth (European Commission, 2019e). Hodžić et al. (2021) assess the effect of e-government maturity on government effectiveness and efficiency in the EU-28 and conclude that the development of e-government is inevitable and that it should ensure the proper functioning of public administration during the Covid-19 pandemic. The OECD e-Government Study (2010) investigates the impact of e-government on the modernization and efficiency of the public sector in developed countries and provides useful tools to support the creation of e-government policies in all OECD countries.

Building the digital infrastructure required for e-government, including fast internet access and secure online platforms, can stimulate growth in the technology sector and create jobs in IT-related fields (Alharmoodi and Lakulu, 2020). As e-government provides citizens and businesses with easy access to information and data, entrepreneurs and investors can be equipped with the information they need to make informed decisions, identify market opportunities and plan investments more effectively. A well-developed e-government infrastructure can improve the business environment by reducing regulatory burdens and simplifying bureaucratic processes. Choi et al. (2016) found that the introduction of e-government has a positive impact on the ease of doing business, which can attract foreign direct investment and promote entrepreneurship, which in turn contributes to economic growth. In addition, e-government can promote e-commerce (El-Ebiary et al., 2021) by facilitating online transactions, payment systems and digital signatures. This can boost online commerce, increase sales and expand the digital economy. By supporting start-ups and small businesses with the help of digital platforms and resources, e-government can promote innovation and entrepreneurship (Singh and Kour, 2014). These efforts can create new businesses and industries this contributing to economic growth. Some studies suggest that e-government initiatives can promote innovation in the private sector. E-government initiatives often lead to greater transparency and accountability in government activities (Halachmi and Greiling, 2013). This can increase public trust, attract foreign investment and create a more stable and predictable business environment. Transparent and efficient e-government procurement processes attract private sector participation and stimulate economic activity. E-government generates large amounts of data that can be analysed to inform policy decisions and economic planning; data-driven decision-making can lead to more effective economic policies and investments (Agbozo, 2018). When governments invest in e-government infrastructure and services, they often provide training and capacity-building opportunities for citizens and businesses (Stofkova et al., 2022). This can improve the digital skills of the labour force and make them more competitive in the global economy. Subsequently, the second research hypothesis is formulated as follows:

H2: The development of e-government and the components of the E-Government Development Index influence labour productivity.

The development of an efficient e-government has significant impact on labour productivity as it simplifies administrative processes, reduces bureaucratic inefficiencies, and promotes the improvement of services. Efficient e-government enables faster and more transparent interaction between the public administration and businesses, reducing the time and cost of compliance. Improved access to information and services encourages workers and businesses to work more efficiently, while improved telecommunications infrastructure and digital skills further support productivity gains by empowering a more skilled workforce. Faid et al. (2020) conducted a disaggregated analysis of the impact of e-government on productivity in the case of different countries. Their findings suggest that the implementation of ICT infrastructure in the public sector in middle-income countries is a driver of global productivity growth.

The theoretical starting point of our empirical study is the simple model developed by Corsi et al. (2006), which is based on the assumption that e-government programmes improve labour productivity in the public sector and accordingly contribute to several indirect outcomes (cost savings, less bureaucracy, etc.) and to economic growth. This model comprises five main channels through which e-government influences public sector productivity:

- Smith's Effect or the Market enlargement effect – it states that the labour productivity growth rate is a positive function of the growth rate of the economy or of the industries considered (McCombi, 2002).
- Ricardo's Effect or the Substitution Effect – it indicates that an increase in the relative cost of labour leads the firms to replace workers with machines (Carnevali et al., 2020).
- Back-Office Reorganization Effect - it "includes the impacts on reorganisation processes induced by ICT implementation initiatives, taking into consideration the potentially greater rigidity of the public sector towards modernisation phenomena in comparison with the private sector" (Corsi and D'Ippoliti, 2010).
- Schumpeter's Effect or Investment-Led Effect - it explains how the real investment level affects labour productivity. The influence of investment on productivity is dual. In the short run, it can have a negative impact on productivity since time is needed for new machinery to be used effectively. However, in the medium to long-run, investment is expected to improve labour productivity.
- Other Take-Up Driven Effects – the Take-Up Effect explains how environmental conditions enable e-government implementation and how they determine its efficacy.

To summarise, the impact of e-government on economic growth may depend on factors such as the degree of technological adoption, the quality of administration and the level of citizens' and businesses' engagement. Successful e-government initiatives are usually part of a broader strategy that encompasses economic development goals, digital inclusion and governance reforms. When e-government is implemented effectively, it can make an important contribution to a country's economic growth and development.

3 Descriptives and research methodology

The dataset used in this paper is combined from two different sources – the UN E-Government Knowledgebase and Eurostat. The E-government Development Index (EGDI) and its components are taken from the UN E-Knowledge Database for the period 2012 - 2022 while

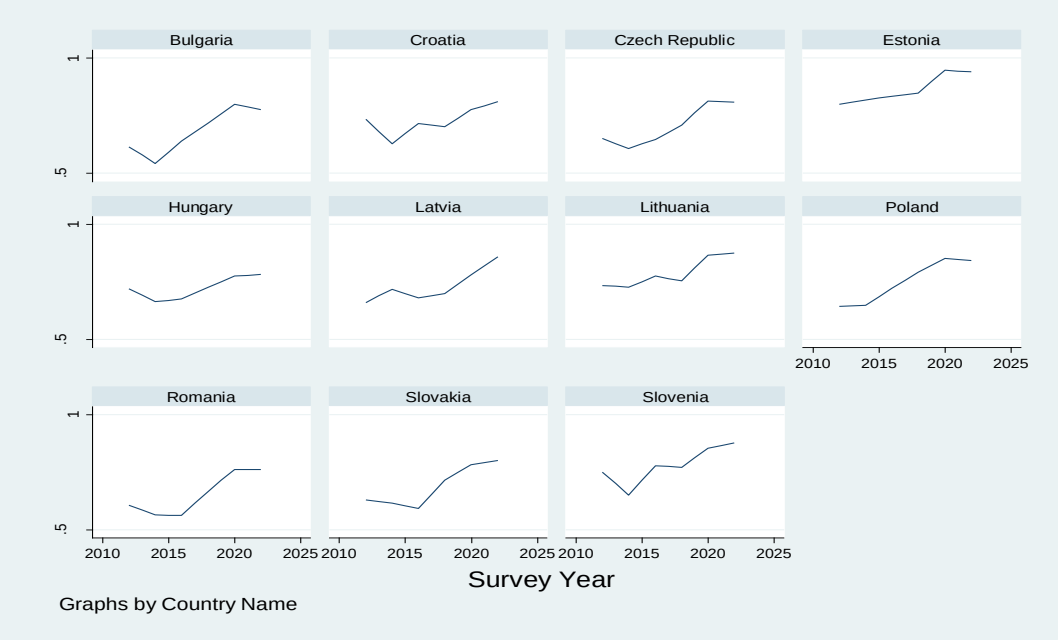
other relevant variables, such as general government output, compensation of employees in general government, gross fixed capital formation of general government are taken from official European statistics. Countries included in the analysis are Bulgaria, the Czech Republic, Estonia, Hungary, Litva, Lithuania, Poland, Romania, Slovakia, Slovenia, with special reference to Croatia.

The E-Government Development Index is an UN indicator that includes an assessment of the websites development in a country, as well as an assessment of the infrastructure and educational level, to evaluate usage of information technologies to promote access and inclusion of people. EGDI is an indicator calculated as the weighted average of three dimensions of e-government: provision of online services, telecommunications connectivity, and human capacity. The index takes a value between 0 and 1 and then countries are grouped into four levels:

- 0.75 to 1.00 - very high EGDI,
- 0.50 to 0.7499 – high EGDI,
- 0.25 to 0.4999 – middle EGDI,
- to 0.2499 - low EGDI countries.

Figure 1 shows EGDI for Central East European countries in the period 2012 – 2022.

Figure 1 E-Government Index (CEECs)



Source: UN e-Government Knowledgebase (2023)

As can be seen in Figure 1, all countries belong to the groups with a high or very high e-Government Index, which rises during the period analysed. The development of e-government in Central and Eastern European countries is progressing, driven by efforts to improve digital public services and the integration of technology into administrative activities. The Estonian government is the best performer in this respect. Estonia is a good example of how persistent, constant efforts pay off. The system was introduced gradually and with a high degree of system transparency, which promoted acceptance of the e-system among citizens. Romania and Bulgaria are at the lower end of the scale, with the EGDI index still not above 0.77. Compared to the other CEECs, Croatia is in the middle of the scale, even though the Croatian EGDI was

0.81 in 2022. The e–Croatia (Smart Government) programme has made significant progress over the last ten years and has followed the highest standards, enabling Croatian citizens and businesses to communicate with the public administration in a simplified way. Numerous systems have been developed in the last ten years, such as e-citizens, electronic court procedures, fiscalisation, electronic registration of employees, etc. Overall, the e-government framework in Croatia reflects efforts to digitalise public services and to make them more accessible and efficient for both citizens and businesses in the country.
Besides the E-Government Development Index, following Corsi et al. (2006), the model includes other government-related variables listed in the Table 1.

Table 1 Variables of the model

	Variable	Unit of measure
Growth	Average labour productivity	Change in productivity
	Change in GDP	Change in Millions of national currency
Market dimension	General Government Output	percentage of GDP
Cost of staff	Compensation of employees in general government	percentage of GDP
Investment	General government gross fixed capital formation	percentage of GDP
E-Government	Online Service	Index
	Human Capital	Index
	Telecom. infrastructure	Index

Source: Author

Economic growth is measured as a change in the value of a country's annual output and is commonly used to explain the economic activity of a country. Labour productivity is measured in two different ways: per person employed and per hour worked. In the first case, output is divided by total employment and in latter, it is divided by total hours worked by employees and the self-employed. General government gross fixed capital formation is an indicator of investments and includes all capital goods produced during the respective year, namely those that with additions to the value of non-produced assets are realised by the productive activity and those that replaced the old, expended capital goods. Compensation of employees in general government is an indicator of staff costs and includes payment to the employees for the work performed. However, average labour productivity could also be an indicator of growth in a country. Following Corsi et al. (2006), other variables cover general government because of data availability and the large share of the public sector in selected countries.

In order to test the two hypotheses, the general panel model in its mathematical form can be presented as follows:

$$Y_{it} = \alpha + X'_{it}\beta + \eta_i + \mu_{it} \quad (1)$$

where:

- Y_{it} - the dependent variable for entity i at time t. In this case growth indicators: growth in GDP, labour productivity per person and per hour
- α - intercept term, or average effect on Y_{it} even if all other variables are zero
- X_{it} - a vector of independent variables for entity i at time t. As the independent e-government variable, we used EGDI and also all three of its components individually (online service, telecommunications connectivity, and human capacity)
- β - a vector of coefficients
- η_i - the entity-specific effect
- μ_{it} - unobserved factors specific to entity i at time t that are not accounted for by the other components.

We ended up calculating six different equations which are presented in the following section. The first three equations examined generally the impact of e-government on three different growth variables while the second set of equations examined the influence of individual EGDI elements on growth measured by different indicators. H1 is tested with equations one and four, while H2 is tested with equations two, three, five and six. The dummy variables for the year 2020 (because of COVID- 19) and for Croatia are included in the previous model. From the previous model we can analyse the impact of e-government index elements on GDP growth for CEECs with special reference to Croatia. The Hausman test suggested that the random effects model is appropriate.

4 Results and discussion

Considering that the public sector makes up for a large GDP share in European countries, the efficiency of public administration can be considered as one of the drivers of competitiveness and economic growth. The implementation of e-government promotes GDP growth through four main channels: increase in labour productivity in the public sector, growth in total public sector production, efficiency of public administration and increase in aggregate demand. Some of them are analysed in our model and the results are given in Table 2.

Table 2 Results of the analysis

	(1) lnGDP	(2) lnALP	(3) lnALPh	(4) lnGDP	(5) lnALP	(6) lnALPh
EGovernmen~x	2.489***	0.472***	0.466***			
	(14.63)	(5.80)	(6.26)			
Output_Gen~v	-0.00180	-0.00783	-0.00995	-0.0394*	-0.0148	-0.0180
	(-0.08)	(-0.72)	(-1.00)	(-2.10)	(-1.39)	(-1.87)
Gen_Gov_Gr~r	0.0147	0.000799	-0.00252	0.00553	-0.00543	-0.00806
	(1.19)	(0.14)	(-0.47)	(0.53)	(-0.92)	(-1.52)
Compensati~v	0.0230	0.0244	0.0281*	0.00882	0.0197	0.0244*
	(0.87)	(1.89)	(2.39)	(0.40)	(1.60)	(2.19)
Y_2020	-0.155***	-0.0174	-0.0329*	-0.114***	-0.0119	-0.0266
	(-4.16)	(-0.98)	(-2.03)	(-3.75)	(-0.70)	(-1.72)
Croatia	-0.121	0.0445	0.00793	-0.0379	0.0694	0.0344
	(-0.48)	(0.24)	(0.05)	(-0.13)	(0.35)	(0.17)
OnlineServ~x				0.487***	0.000838	0.00968
				(5.46)	(0.02)	(0.21)
HumanCapit~x				-1.151***	0.0495	-0.00226
				(-3.46)	(0.26)	(-0.01)
TelComInfr~r				1.604***	0.380***	0.371***
				(12.91)	(5.45)	(5.90)
_cons	7.466***	3.827***	3.755***	9.811***	4.090***	4.067***
	(28.09)	(27.65)	(29.81)	(24.15)	(17.62)	(19.17)
N	121	121	121	121	121	121

t statistics in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Source: Authors' calculations

The first hypothesis assumed the relationship between e-government and GDP which is confirmed by the results presented in the table above. The e-government index is statistically significant in all three equations and has a positive effect on GDP. The second hypothesis assumed the influence of e-government index elements and labour productivity. Results suggest that EGDI is statistically significant and positively influences labour productivity both per

person and per hour. Furthermore, when analysed in more depth, two elements of the UN indicator EGDI are statistically significant: the index of online services has a positive effect on GDP, but not on average productivity, while the telecommunications infrastructure variables have positive coefficients, i.e. they have a positive effect on all dependent variables. Telecommunications infrastructures such as high-speed internet and mobile phone networks enable fast and efficient communication. This is essential for both internal and external communication of companies. Reliable networks enable remote working, allowing employees to work from anywhere, working in teams seamlessly, regardless of geographical location.

The use of information technologies in the public sector promotes the expansion of services provided by this sector, which leads to a simplification of administrative processes and greater efficiency, with greater transparency and accountability of public administration. E-government creates new forms of interaction between the public and private sectors, sharing information and creating new business opportunities, which affects the growth of aggregate demand and consequently economic growth. Other government variables in this model are not statistically significant, which means that the private sector is crucial for economic growth. As expected, for well-known reasons (COVID-19 and related lockdown), the coefficient next to the dummy variable for 2020 shows that GDP experienced a decline in CEECs. When we refer to Croatia, we can see that the coefficient is negative, meaning that, on average, GDP growth is lower than that in the rest of CEECs.

5 Concluding remarks

By introducing ICT solutions and digital transformation, the administration can increase its efficiency, openness, and quality of public services. The development of e-government differs from country to country, depending on specific needs, priorities, and level of development. Governments often develop e-government strategies to define the objectives and the steps required to realise them. The successful implementation of e-government initiatives can lead to a more responsive, efficient, and citizen-centred public administration. The aim of this paper was to analyse the role of e-government elements for economic growth in Central and Eastern European countries, with a special focus on Croatia. Over the past ten years, all countries have made great efforts to develop public sector e-services. The EGDI score has increased in all CEE countries analysed, with Estonia leading the way in the introduction of ICT in its public sector. Croatia also performs quite well with an EGDI of 0.81 in 2022. The largest part of e-government in Croatia is accounted for by the e-citizen system (G2C system), which was introduced in 2014 and was significantly improved and remodelled in 2021. In addition, the Croatian government has introduced numerous G2B systems, such as fiscalisation, e-court procedures, e-employee registration, etc. These systems facilitate communication between businesses and public administration, which contributes to their productivity. The research results indicate that EGDI has a positive impact on growth and productivity, while when analysing the components individually, the telecommunication infrastructure is crucial. It has a positive effect on both growth and productivity. However, the coefficient next to Croatia shows that Croatia is slightly below the CEEC average.

A major limitation of this study is the use of secondary data, which limits the analysis to the data provided in the databases. In addition, other relevant institutional aspects such as taxation, public services and government spending were not included in the analysis, which opens up a wide field for future research. Moreover, the focus of this paper was on Croatia, but further research should concentrate on analysing the situation in each individual CEE country. The

results of this work can contribute to analysing the current situation, which can be used for preparing strategies for further development of the administration and planning development activities and priorities. Based on the results of this research, several recommendations for policy makers could be proposed. Although much has been done for the development of e-government in Central and Eastern European countries in recent years, it is still necessary to work on its improvement. In order to realise the potential, the existing barriers should be removed. These barriers are primarily the individual ability to use e-government services, the issue of personal motivation, trust in the government and the information it provides, and awareness of the real benefits of using e-services and information. Measures to raise the level of education and digital skills of the population and the increasing number of services and information provided through e-government are some of the factors that will strengthen the potential of e-government. Policy makers should ensure that the objectives of e-government are clear and transparent. This will enable the introduction of mandatory performance measurement to monitor progress towards the goals set. In this way, the efficiency and effectiveness of e-government can be improved. Last but not least, policy makers should take action to promote accessible and useful e-government services on a larger scale.

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Digital Transformation of the Public Administration: Between Efficiency and Innovation

Martina Corbino[1]

ABSTRACT

The topic of automation, computerization or digitalization of public administration has been at the center of legislative interventions over the last few decades. It is becoming even more relevant following the commitments made by all EU member states and, in particular, by the Italian Government within the so-called Next Generation EU (N.R.R.P.) to complete digital transition. A fundamentally important aspect is constituted by the implications that the digital transition process has, and will have, on the activities of public administration, also considering the constitutional principles, as well as those of EU derivation. In particular, the phenomenon to be analyzed in all its implications, both positive and negative, is the use of algorithms in administrative processes, aimed at producing an administrative act. The algorithmic rule will be analyzed not only for its aspects relating to the protection of the constitutional principles of the proper functioning of the administration, but also in relation to the activity performed by civil servants. On one hand, they will be relieved of sometimes alienating tasks and duties, but on the other hand, they will require adequate training in the use of these tools and the necessary coordination with their work duties, in order to ensure proper productivity. The aim of the research is to analyses the degree of efficiency that digitization can bring to public administration' activities, through an analysis of concrete cases, in relation to both the external user, i.e. the citizen who benefits from the services and performances, and to the internal user, i.e. the civil servant who provides these services and performances.

Key words: *digitization, algorithm, productivity, civil servant, external user*

JEL classification: *K0, K10, K23*

1 Introduction

The digital era, developing from the 21st century onwards , introduces a new dimension of law and a new phase of constitutionalism which has to both regulate and define a new "sovereign power" linked to the so-called technological paradigm, conceived as a factor of personal liberation and social innovation and, therefore, as an inalienable right (Simoncini, 2020). The revolution developing is not only related to the use of digital tools for the creation and storage of data and documents. It is also, and especially, connected to the employment of tools able to create and determine the content of an administrative document. This revolution, more appropriately defined as the revolution 4.0 (Galetta and Corvalán, 2019) in reference to public administration and its activities, outlines the possibility that the administrative decision-making process is entrusted to software. Here, a series of data are fed to achieve a final decision by automating the process. Therefore, in public administration the reliance on the algorithm is understood as a *"finite sequence of elementary steps leading to the resolution of a problem"*

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(Ferragina and Luccio, 2017). This approach determines the arising of a new power and the consequent necessity to define its limits and scopes of application. In particular, the inherent characteristic of these algorithmic models is that not only do they determine measurements but also make evaluations or predictions, and thus decisions, based on the data from which they learn (the so-called "machine learning"). The algorithm serves as the basis for the development of the program or "software" and, therefore, programming represents the translation or encoding of an algorithm for solving a given class of problems into a string of commands, processed in a given computer language, in order to be effectively executed by a computer (Gallone, 2021).

As a result, the subject of the research is the use of the algorithm in the administrative procedure, intended not only as a preliminary tool for the administrative decision adopted by an official but also, and above all, as the true *dominus* of the administrative act, capable of reaching a decision tied to the discretionary and binding activity of the public administration. This disruptive innovation has generated some questions regarding the legitimacy of using algorithms in administrative decisions, especially concerning the responsibility of the administrative act and the protection of the fundamental principles enshrined in constitutional systems. In this perspective, the purpose of the research is to define this new power of the algorithm, to identify its areas of application and limits, as well as to understand to what extent it will be possible to use "machines" to replace human reasoning and the liability of public officers. Safeguarding fundamental principles is indispensable in modern legal systems, and assessing all "dangers" capable of undermining their integrity is paramount. For this reason, this research intends to contribute to the identification of all the tools used by legal systems, with particular reference to the Italian one, in order to bring the use of digital technology and algorithms in administrative decision-making within well-defined and legally identifiable boundaries. The use of the algorithm by a public administration must not and cannot be confined within a "black box", inaccessible both to the citizen, the final recipient of administrative choices, as well as the public officer, the internal user of computer programs; rather, the public administration, intended as a "glass house"[2] must make every decision and procedure intelligible and transparent.

The present contribution, therefore, is structured as follows. Section 2 will discuss the current state of the art, both through a look at the global scenarios of the algorithmic society and with a specific examination of the Italian legal literature, while section 3 will cover the research method employed. Section 4 will analyze the Italian *case study*, starting from the most significant case-law rulings on the use of algorithms for the production of administrative decisions, and will proceed to enunciate the fundamental principles identified by the administrative court. Section 5, based on the analyzed jurisprudential contributions, will identify the two main aspects on which the use of algorithms in public administration must be based: on one hand, the preservation of humanity, and on the other hand, the protection of the principles of transparency and non-discrimination. Finally, in the Conclusions, the pros and cons of using algorithms in public administration will be identified, along with possible future scenarios and the limitations encountered during the research.

[2] This statement is attributed to the parliamentarian Filippo Turati, during a speech given at the Chamber of Deputies in 1908: "Dove un superiore pubblico interesse non imponga un momentaneo segreto, la casa dell'amministrazione dovrebbe essere di vetro" (Where a higher public interest does not impose temporary secrecy, the house of administration should be made of glass). TURATI F., Proceedings of the Italian Parliament, Chamber of Deputies, session 1904-1908, 17 June 1908.

2 Literature review

The debate on the use of algorithms in administrative decision-making has affected all the legal systems of our modern society, involving both the public and private spheres and covering all the main areas of daily life: from healthcare to security, from education to justice. Numerous contributions have raised critical reflections on the use of algorithms, focusing primarily on the impact of automating public action on the principles of equal treatment, equality, and non-discrimination. This research begins with some introductory references on international experiences from a comparative perspective; it then focuses on the Italian *case study*, to understand the key role of administrative case-law in defining limits and spheres of intervention in the use of algorithms, and in identifying the fundamental principles to be protected.

2.1 Global algorithm society

The increasingly widespread and almost indispensable use of algorithms in our society has led several scholars to coin the term "algorithmic society" (Balkin, 2017) to identify a new structure based on the use of such tools in the daily lives of individuals. The phenomenon has been analyzed not only by the legal literature but also, and above all, by the literature of behavioral economics and cognitive psychology (Kahneman and Tversky, 2005), which has drawn fundamental utility from the use of algorithms, understood as tools capable of arriving at certain, impartial and irrefutable decisions, as opposed to the use of human reasoning, which is often conditioned by limited rationality and by conflicting passions and emotions. The decisions made by the algorithm thus assume an aura of neutrality, the result of sterile rational calculations based solely on data (Schwartz, 1992). On the other hand, another line of reasoning has developed, according to which algorithms operate a series of choices that are anything but objective and, precisely because of their alleged impartiality, become the protagonists of the so-called "math-washing", a passage through the numbers in which certain choices with a precise social impact are shrouded in neutrality because machines make them (O'Neil, 2017). From this arises the reflection on the impact of algorithms on the principle of equality and the risk of discrimination, which intersect with the crucial issue of their lack of transparency. Based on these considerations, the transition from the "algorithm society" to the "black box society" is fast, and for this precise reason, it becomes essential to identify the areas and limits of the use of these tools in order to also ensure their regulation.

In the context of public administration, the critical reflection on the use of algorithms has primarily focused on the impact of automating public action on equal treatment, equality, and discrimination. The use of algorithms has been the subject of harsh criticism in various parts of the world, such as in Australia, regarding the management of welfare systems, with the "robo-debt scandal" (Terzis, 2018), or in England and the United States, for its use by the police to determine the likelihood of a convicted person reoffending and to decide their continued imprisonment, with significant discriminatory outcomes. In particular, in England, due to the use of a software named *Hart*, decisions were made giving significant weight to the convicts' postal code**,** resulting in discrimination against those living in deprived and higher-risk areas of the city (Oswald et al., 2018). A similar situation can be observed in the United States, where similar software was used, resulting in a systematic overestimation of the probability of recidivism in the Afro-American population and an underestimation of the probability of recidivism in the Caucasian population. Thus, the automation of services in the USA, from health care to the homeless census to child protection through systems that predict the risk of

abuse, has generated a series of inequalities tied to the use of the algorithm and created a system of "digital poverty management", i.e., digital and automated poverty management that exposes people to total control by governments, as well as markets (Eubanks, 2018). From these examples, therefore, it can be deduced that the unregulated use of the algorithm in decision-making processes aimed at producing administrative rulings can generate a series of problems. Firstly, in terms of the transparency of the algorithm, with difficulty in accessing the information and sources that generate the algorithmic decision; secondly, in terms of the violation of non-discrimination principle, as data related to race, religion and political belief can be used to classify a group of people and define them according to certain categories. All of this poses a real threat to democracy and the protection of the fundamental principles guaranteed by legal systems, and precisely for this reason, it is necessary to use tools that allow for oversight of the algorithm and its effects (Epstein and Robertson, 2015).

2.2 Legal literature in Italy

The legal literature developed over the last few years in Italy has focused heavily on the admissibility of the use of automated decision-making processes by public administration, to define the areas where the latter can be applied and what are the imputation criteria and the consequent forms of liability to which they refer. Regarding the first issue, according to the most common opinion also adopted in the scope of case-law, a distinction has been made between the public administration's binding and discretionary activities. The binding activity of an administration, in fact, implies the rule-fact-effect (Capaccioli, 1983) sequence, since the unambiguous and incontrovertible identification of the conditions established by law ensures the certainty of the consequent administrative decision. For this reason, it was considered possible to entrust an algorithm with the construction of the necessary steps, by carrying out the entry of a series of inputs, i.e., assumptions predetermined by law, followed by the performance of a finite series of basic procedures, i.e., the verification of the existence of those assumptions in the specific case, to arrive at the final solution, corresponding to the final decision, or output (Cavallaro and Smorto, 2019). On the contrary, such an operation could not be applied in the context of discretionary activity, which, instead, implies the rule-power-effect sequence but also assumes an appreciation and comparative assessment of multiple public and private interests, which cannot be entrusted exclusively to an algorithm.

However, this argument is divisive: even if we admit that the binding activity is more suitable for the automation of a decision, it is nevertheless true that in some cases, even such an activity implies a process of evaluation, or at least interpretation concerning the presupposition, justifying the adoption of the act. Another crucial aspect relates to the imputation of the automated act and the related liability (Saitta, 2003). The adoption of an automated procedure undoubtedly responds to the logic of efficiency and effectiveness of administrative action, based on the assumption that when an activity traditionally performed by the official is entrusted to an algorithm, implementation times are reduced, and specific and exact solutions are obtained. Yet, this cannot exclude, in addition to the hypothesis of software failure, the total substitution of human beings in administrative choices and the imputation of the consequent activity to the administration in compliance with the principle of responsibility.

3 Methodology of analysis

The initial part of this study analyses the main case-law and doctrinal orientations that have developed in Italy in regards to the use and scope of application of algorithms by public administration in the implementation of the constitutional principles of effectiveness, efficiency, and good performance of administrative action, as well as transparency and accessibility by citizens. The first aspect to be analyzed, therefore, is the role and function that human intervention, in the person of the civil officer (internal user), may continue to assume in algorithmic decisions and how its formation and concrete actions may evolve in the immediate future, to enhance the production of efficient services for the entire community. The second aspect to be addressed, on the other hand, is to verify the impact of the algorithmic decision on the service provided to the citizen (external user), in terms of transparency and legality in the administrative ruling, as well as the accessibility and knowability of the algorithmic rule.

The study will lead to an in-depth analysis and the implications of the new principles identified by the case-law, in particular, the principle of knowability of the existence of automated decision-making processes and the logic used, the principle of non-exclusivity of the algorithmic decision and, finally, the principle of non-discrimination. This research methodology is functional to the analysis of the main issues and major limitations related to the unregulated use of algorithms in the realm of administrative decision-making, aiming to identify the necessary tools to align the use of algorithms with a general legal rule, thus making it subject to human control and accessible to legitimate users.

4 Empirical data and analysis

In Italy, the area generating most case-law was the implementation of Law No. 107 of 13 July 2015 on Educational Reform. It involved the use of a software tool developed by a privately-owned company to draw up the ranking list for teachers who had to be assigned to the relevant places of employment or rankings for their mobility applications. However, the decisions generated by the algorithm rose numerous complaints, as they were often found to be incorrect or incomprehensible, and led to numerous appeals before the Administrative Court. The Administrative case-law has thus led to a series of rulings which originated different currents of jurisprudence and established certain fundamental principles in a subject still in development. There was no shortage of setbacks, but each ruling added a new piece to the complex framework of algorithm-based decision-making.

4.1 The relationship between the administrative proceedings and algorithm-based rulings

In a first ruling of the T.A.R. Lazio, sec. III-bis, of 22 March 2017, no. 3769, the administrative judge determined that the algorithm sets the content of the teacher’s assignment or transfer document. This embodies the procedure that generates the administrative measure, resulting in the interested party’s right to inspect and produce a copy of it, as established by the Administrative Procedure Act. In this way, the software ultimately identifies the proceeding itself, as the final will of the acting administration is realized through the algorithm.

Through this decision, the administrative judge establishes two fundamental principles. The first one is related to the nature of the algorithm itself; although it is not written in Italian but in a computer language compiled according to a specific programming code, it still constitutes and determines the administrative proceeding, as the expression of the public administration's will to manage one of its proceedings by using an innovative tool, such as computer programming. The second principle relates to the right of the addressee of the document to have full knowledge of the computer program and, therefore, to acquire the source code of the algorithm, since a mere description of the algorithm, specifying the computer procedure used, does not suffice: the T.A.R., in fact, stated that "*la mera descrizione dell'algoritmo e del suo funzionamento in lingua italiana non assolve alla medesima funzione conoscitiva data dall'acquisizione diretta del linguaggio informatico sorgente"* (the mere description of the algorithm and its operation in Italian does not fulfill the same cognitive function provided by the direct acquisition of the source computer language). This also negates the idea that software, being an intellectual work, would be subject to intellectual property laws and thus destined to remain confidential: the T.A.R., while not denying that the software produced for administrative ruling is an intellectual work, states that this qualification is not decisive, since the rule on the access to Public Administration documents establishes that the nature of the intellectual work of the documents for which access is requested is not, per se, a sufficient reason for access denial (Article 24 of Law 241/1990).

Finally, with regard to the scope of the specific type of administrative document that can be determined through the algorithm, the T.A.R. establishes that it is legally admissible and legitimate in the context of the administration's binding activity because it is compatible with the logic inherent in software that translates factual elements and legal data into a mathematical language, creating a formalized logical reasoning leading to a conclusion that, based on the actual data, could not be different. Adversely, in the discretionary activity of a public administration, where it is possible to choose the events to be used to achieve the purposes determined by law (Sorace, 2014), algorithmic decision-making would not be permissible. In conclusion, therefore, in this decision, the T.A.R. considered using a decision-making algorithm permissible only in cases of binding administrative activity and not in exercising discretionary administrative power.

4.2 The humanity reservation and the principles of participation, transparency and access

Thereafter, the same section III-bis of the T.A.R. Lazio, with sentences of 10 September 2018, nos. 9224-9230 further reinforced the arguments expressed earlier, stating that the principles of participation, transparency and access cannot be legitimately disregarded by replacing human activity with that of the algorithm since this would produce a breach of the obligation to motivate administrative rulings and, therefore, a violation of the right of action and defense in court under Article 24 of the Italian Constitution, which is undermined whenever the absence of motivation does not allow the interested party to understand the logical legal process followed by an administration to establish a given ruling. The T.A.R., in fact, affirms a sort of "humanity reservation" claiming that computerized procedures can never wholly replace the cognitive, acquisitive, and judgmental activity that only a preliminary investigation conducted by an official, as a natural person, is capable of performing. The T.A.R. also said that, in order to ensure the implementation of the institutes of participation, procedural interlocution, acquisition of the collaborative contributions of the private individual and the interests involved in the procedure, the natural person must continue to be the *dominus* of the procedure itself, the

one managing the computerized procedures set up as a public administration service. Computer-generated tools, therefore, must be reserved to an instrumental and merely auxiliary role in the administrative procedure, and never be predominant over human activity. In this way, case-law sets the principles of the law on administrative proceedings as a fundamental safeguard for the actions of public administration and the constitutional values enshrined in Articles 3 (principle of equality), 24 (principle of the inviolability of defense), and 97 (principle of good performance and impartiality of administrative action) of the Italian Constitution, as well as Article 6 of the European Convention on Human Rights (right to a fair trial).

4.3 The algorithmic rule as a general administrative regulation

The case law orientations examined so far have been partly revised by the Council of State (Consiglio di Stato), Sixth Section, in its 8 April 2019 No. 2770, 13 December 2019 by rulings: 8472, 8473, 8474, and 4 February 2020 No. 881. The Council of State ruled that using computerized procedures in administrative documents constitutes a fundamental tool for complying with the general principles of efficiency and cost-effectiveness, as well as the constitutional provisions contained in Article 97 of the Italian Constitution. The reason is that algorithmic decision-making allows the acceleration of binding administrative proceedings where high quantities of instances are processed and where objectively verifiable data is acquired. Furthermore, the use of the algorithm also guarantees greater impartiality, especially in those cases where negligence, or even malice might be arisen from public officials.

However, jurisprudence also moves towards overcoming the dichotomy between binding and discretionary administrative acts, stating that binding and discretionary choices are both expressions of authoritative activities, performed in pursuit of the public interest, and can never be totally deterministic. Thus, the algorithm is naturally an instructive procedural tool integrated within an administrative proceeding and also applies to discretionary choices. In the latter case, the Court ruled that a public administration must ensure cooperation with the official responsible for the proceeding, establishing precise accountability and responsibility on the part of the governing body (Muciaccia, 2020). Administrative case law thus reconstructs a notion of algorithmic rule as a general administrative regulation, i.e., a legal rule expressed in the form of an algorithm (Papa, 2020), realizing an accurate principle of legality of algorithmic digital administration and reconstructing some fundamental references of a general nature, such as the principle of knowability of the existence of automated decision-making processes and the logics employed, the principle of non-exclusivity of the algorithmic decision and the principle of non-discrimination (Cardarelli, 2015). These principles are also based on the European General Data Protection Regulation (GDPR) (EU 2016/679): in particular, full knowability, combined with Articles 13, 14, and 15 of the GDPR and Article 41 of the European Charter of Fundamental Rights, which establishes the right of everyone to know of the existence of automated decision-making processes concerning them and to receive meaningful information on the logic used; the non-exclusivity of the algorithmic decision, in compliance with Article 22 of the GDPR, provides that, if an automated ruling results in legal effects on a person, that person has the right to have that decision based not solely on the automated process, but on the human intervention that can enable the officer to assess, validate or deny the automated decision; finally, algorithmic non-discrimination, as per Article No. 71 of the GDPR, implies that if the data controller employs mathematical or statistical rules for user profiling, he/she is obliged to take appropriate measures to prevent errors and inaccuracies in the data.

5 Results and discussion

The analysis conducted so far lead to two essential elements on which the following examination will focus: on the one hand, the role of human intervention and, hence, the responsibility of the public officer and, on the other hand, the application of the principles of non-discrimination, transparency, knowability and accessibility by the citizen, the final user of the service and holder of legitimate rights and interests. The use of algorithms in administrative decision-making is encouraged and even considered as a valuable deterrent against negligence and corruption. Furthermore, the reservation of humanity implies the exclusion of the encompassing use of automated decisions and that the administrative act's responsibility always remains with the public official, as a safeguard of the constitutionally guaranteed principles of a reasonable administrative action. Therefore, it is deemed helpful to understand whether algorithmic administrative procedures generating administrative acts for which a human person is responsible can coexist and, thus, to assess whether a theory of the "humanization of the algorithm" is sustainable, also given the considerable impact in terms of training human resources and producing efficient services.

5.1 The humanity reservation

The historical period we are currently experiencing is undoubtedly characterized by an unstoppable transition phase from human to digital, and this is even more evident in the work of public administration, where officers are still the most important resource for the proper working of the administration and the delivery of efficient and effective services. Public administration, as defined in the Italian Constitution, is identified not only with "public offices" in their objective dimension but, first and foremost, with "public employees": Article 97, paragraph 3 of the Constitution provides that *"nell'ordinamento degli uffici sono determinate le sfere di competenza, le attribuzioni e le responsabilità proprie dei funzionari" (the spheres of competence, powers and responsibilities of officials shall be determined in the organization of offices)* (Cassatella, 2018), which represent the cornerstone for the organization of the administrative apparatus according to the standards of good performance and impartiality. Such employees are thus identified with the natural persons holding this position and operating in the complex of material and instrumental resources necessary for the performance of public functions.

The humanity reservation is one of the various corollaries of the personalist principle underlying the Italian legislation (Ruggieri, 2013) and embodied in Article 2 of the Constitution: the human being is, in his/her irreducible uniqueness (but also in his/her social dimension), the absolute protagonist of the Constitutional Charter, and it is precisely this centrality in the constitutional framework that prevents any equalization, in terms of value, with the "machine". The latter, on the other hand, is not granted with any constitutionally guaranteed status (Gallone, 2021). From such framework, it can be deduced that the use of new technologies, although absolutely meaningful and inevitable in the digital age, cannot result in the complete dispossession of the person from the decision-making process to the exclusive benefit of algorithmic decision-making and, hence, the existence of a humanity reservation in the performance of administrative functions results in the prohibition of providing for totally automated ways of exercising authoritative capacities (Orofino, 2008). Thus, the use of information technology and algorithms, in a word digitalization, must be instrumental to administrative activity and not dominant over it nor over human activity. The necessity is to prevent the automation of the procedure from generating a process of depersonalization of

rulings, on the one hand, compromising the participation of the private individual in the procedure, in the absence of an interlocutor to turn to, and, on the other hand, obstructing the attribution of liability resulting from the decision taken.

Therefore, in addition to the principles of transparency and participation, the principle of accountability is, first and foremost, called into account, both in the final phase of the production of an administrative document, and in the prodromal phase of the construction of the algorithm, namely in the stage of the input entry and output management, which must comply with the general principles that govern administrative action: in other words, it must be clear, knowable and participatory, in order to adequately respond to the protection needs of the recipients of the automated decision. In other terms, once applied to the process of automating public decision-making, the principle of accountability translates into the need to limit the role of technology in general, and of the algorithm in particular, to a servant tool of the administration, thus retaining the officer the competence and responsibility arising from the adoption of the decision (Cavallaro and Smorto, 2019). Precisely with this in mind, the necessity of the intervention of algorithm experts emerged, a sort of court-appointed technical consultant with IT expertise who would play the role of the auditor of the algorithm company, with the task of certifying the correctness of a particular algorithm (Mayer-Schoenberger and Cukier, 2016), with the primary need, however, to anchor the automated decision-making process to the general principles that conform to administrative action, including the conditions for the exercise of judicial review and its consequences, also in terms of the liability of the administration and its officers. The public officer, therefore, becomes responsible, not just for the administrative procedure, but for the act and, as such, needs to be instructed and trained, not only on how algorithmic procedures work but also on the results they produce in order to guarantee an efficient service to the citizen, both in qualitative and quantitative terms.

5.2 The transparency and non-discrimination principles

The existence of a minimum field subtracted from automation contributes to the definition of the relationship between the citizen and the administration in terms of personal protection. In fact, if the humanity reservation is a rule of limitation for the legislator and the administration in its negative dimension, it is also the foundation of a specific prerogative of the citizen against the public power in its positive dimension.

Transparency is intended as a synonym for knowledge of the path followed to achieve the automated decision, and the central issue in automated decision-making becomes its “explainability”, through the identification of tools enabling interpretation of the source code in order to reconstruct the logical steps involved and make the procedures determining the results usable (Zalnieriute et al., 2019). Transparency is directly tied to the necessary motivation of the measure, as the administration that assumes a decision through an algorithm must be able to explain the logical-legal path leading to the final ruling. The algorithm, in fact, is still largely considered a “black box” (Pasquale, 2015), and motivating the administrative measure generated by it could be difficult, but only if one had the pretension of explaining how the algorithm itself works and not, instead, if one pursues a few simple objectives: firstly, that of the knowability of the existence of the algorithmic process; secondly, the right of access to the inputs used by the algorithm to produce the final output, that is, the possibility of understanding how the final decision was developed; finally, the right of the interested party to intervene directly in the proceeding, through the integration of documents necessary for the investigation.

Moreover, the knowability and comprehensibility principle of the algorithm must necessarily be related to another fundamental principle, namely, the principle of algorithmic non-discrimination (Simoncini, 2019), because the data upon which the algorithm is developed must be selected in such a way as to avoid any discriminatory effect on the outcome of the decision. In fact, provided that the requirements of knowability and comprehensibility of the algorithm are met and that it is not the exclusive motivation for the decision, the algorithm could be discriminatory per se and, therefore, contrary to the principle of equality, when the inputs and data entered are discriminatory[3].

It is not easy to identify legal bases in the legal system regarding discriminatory and unconstitutional algorithms. However, it is possible to retrieve some essential indications in Article No. 71 of the GDPR, where, regarding profiling, it is emphasized that the data controller should act "in a manner that takes account of the potential risks involved for the interests and rights of the data subject and that prevents, *inter alia*, discriminatory effects on natural persons based on racial or ethnic origin, political opinion, religion or beliefs, trade union membership, genetic or health status or sexual orientation, or that result in measures having such an effect." The argument is, hence, extensible, even beyond profiling, to any hypothesis of algorithm, especially predictive, and can be considered a corollary of the general principle of non-discrimination established by the Charter of Fundamental Rights of the European Union (Art. 20 et seq.) and the European Convention on Human Rights (Art. 14), as well as by the Italian Constitution, which protects the principle of equality (Art. 3) (Molaschi, 2021). The application of these fundamental principles to the algorithmic procedure and decision, therefore, grants and guarantees the protection of the citizen concerning a decision that is still administrative, that is, attributable to the activity of an organization of means and persons that acts according to the constitutional provisions of efficiency, effectiveness and good performance of its action. At the same time, the citizens' right to an efficient public administration is inevitably and increasingly being realized through digitization and the use of computerized procedures, which are able to guarantee fast, impartial, and fair acts.

6 Conclusions

These observations led to a possible conclusion: it is necessary to assume a balanced position regarding the use of algorithms in administrative decisions, as both the "pros" and "cons" must be weighed. The use of algorithms by public administrations certainly operates in the direction of effectiveness and efficiency, time-saving and simplification, as well as higher standards of impartiality and anti-corruption (Falcone, 2018).

[3] This question was mainly raised for the so-called predictive algorithms, for which the *Compas* (Correctional Offender Management Profiling for Alternative Sanctions) case is an emblem. *Compas* is an algorithmic system for predicting the risk of recidivism, developed by a private company and used by the U.S. criminal justice system, originally conceived as a tool for the Department of Corrections and not for the definition of criminal judgments ("sentencing"), as was actually later the case. The risk of recidivism is estimated based on the subject's criminal record, questionnaires administered to them, various statistical data, and other unknown elements, as covered by the company's intellectual property, which does not even allow us to know how the multiple factors are evaluated and the dangerousness rates calculated. Despite this, the Wisconsin Supreme Court has established that using *Compas* in criminal trials, if conducted appropriately and subject to certain limits and cautions highlighted by the Court itself, does not violate the right to a fair trial. However, the critical issues concerning its use are of significant importance. In fact, the algorithm classified minority offenders, in particular the Afro-American ones, at a disproportionately higher percentage as high risk of reoffending than Caucasian offenders, who had a higher probability of being qualified as low risk. In other words, the algorithm correlated the risk factors for recidivism assessment with criteria such as race and membership of particular social minorities. This results in the overestimation of the social dangerousness of Afro-American subjects, especially with regard to violent recidivism, and the underestimation of the risk of recidivism by Caucasian individuals.

In fact, in fully automated procedures, a third and impartial algorithm determines administrative decisions, and corrupt practices against public officers become ever more residual as human intervention increasingly decreases. On the other hand, the automation of repetitive and basic processes can bring enormous advantages for the public officers; by being unburdened from the production of serial acts and alienating activities that require constant production, they can concentrate and develop their skills on the series of acts that require more intellectual processing and discretionary evaluation. This does not imply relegating algorithmic decision-making to bare acts exclusively linked to a constrained type of activity but is intended to ensure the use of algorithms for the most complex discretionary administrative acts, with the maximum involvement of the public officer, who must be allowed to develop increasingly digital skills and acquire algorithmic training that may enable him/her to use these tools in a truly servant function for the activity of the public administration and not vice versa. This could mitigate the currently dreaded risk that algorithms might replace administrative activity, sometimes even eliminating it, increasing the fear of public officers, especially those in apical positions, of incurring some form of liability.

After all, uncontrolled use of algorithmic activity, if not adequately understood and explained, could result in a reduction of the safeguards – typical of democratic constitutions – that citizens benefit from in their relations with institutions and public administrations, with the consequence that the "despotic domination" of algorithms could become the "despotic domination" of public powers (Molaschi, 2021). Therefore, as noted in the course of this paper, the algorithmic rule, possessing legal and administrative validity for all intents and purposes, must follow the general principles of administrative activity, such as publicity, transparency, and accessibility by citizens. In addition, such a rule cannot leave unregulated spaces but must reasonably provide a defined solution for all possible cases. It is also necessary that the administration is always deemed accountable for the algorithm's functioning, by exercising constant monitoring, through continuous testing, updating, and refinements, especially with respect to progressive or deep learning algorithms.

Moreover, in this context, the judge must also be able to assess and evaluate the correctness of the automated process in all its components, from its construction to data entry to its validity and management. In conclusion, it is fundamental for the algorithm to be conceived and used as a tool by public administration for achieving the best efficiency and effectiveness of its activity and, hence, digitalization must be subservient to human activity and never assume a dominant role to it. To achieve this objective, which is first and foremost related to the constitutional values informing administrative action, it is fundamental for public officials to have knowledge and training on how the algorithm works and the consequent rulings. Therefore, the principles of knowability and transparency of the algorithmic rule must not only be expressed in terms of the protection of the citizen, the user of the services, but also, and above all, in terms of the understanding and mastery by the operators. It is only through the knowledge of the tools used that it is possible to create accountability among civil officers and provide quality services, ensuring respect for the constitutional guarantees of all citizens.

The result of this research is to have identified the main risks of uncontrolled use of algorithms in administrative decisions through the analysis of the algorithmic society in general and, specifically, the Italian case study. Such risks can be summarized in the difficulty in understanding and knowing the functioning of the algorithms themselves as well as in the threat to constitutional principles of transparency and non-discrimination. Case-law has identified some general principles, aimed at setting a limit to this unconstitutional and antidemocratic drift, defining a true general algorithmic rule and identifying in the principles of humanity,

transparency, and non-discrimination the pillars upon which to base any administrative action and decision in the protection of citizens and public officers. However, this research has encountered limitations in the difficulty of identifying a homogeneous and uniform set of rules in this area, as it has had to draw from numerous sources of case-law, in the context of a fragmented national and supranational legislation. The issue is certainly evolving, but the unstoppable use of technologies compels the legislator to run faster than them, to continue to provide citizens with adequate standards of constitutional protection and avoid violations of fundamental principles, concealed by the use of a technology that is not always perfectly unbiased and impartial. Furthermore, the absolute relevance of the research topic and its rapid evolution inevitably leave some void areas, which do not necessarily represent a lack of analysis but rather constitute an opening towards possible future scenarios to be further explored.

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Acquisition of Knowledge from External Sources and Production Innovativeness of Companies: A Quantile Regression Analysis

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ABSTRACT

Access to external sources of knowledge is extremely important for companies in today's dynamic environment in which they operate. Acquisition of external knowledge contributes to the improvement of the company's innovative performance and the achievement of a competitive advantage on the market. The objective of this research is to test the contribution of acquiring knowledge from external sources to product innovativeness in the company, by estimating the regression model for different quantiles. Therefore, this study provides an answer to the question whether different sources of knowledge vary in their contribution to product innovation in low, medium and high performing companies. The purpose of researching this topic is reflected in the fact that knowledge, as a key resource of companies in the new economy, is often unavailable within the company itself. For this reason, it is necessary to adopt it outside the company in order to achieve a higher level of product innovativeness. The research was conducted on a sample of 203 companies operating on the territory of Bosnia and Herzegovina. The main findings of this study identified customers, universities, suppliers and consultants as external sources of knowledge that significantly contribute to a company's product innovativeness. The main conclusion of this study is that acquisition of external knowledge represents a way in which companies can improve their product innovativeness and thereby achieve a sustainable competitive advantage on the market.

Key words: *knowledge acquisition, external knowledge sources, production innovativeness, quantile regression analysis*

JEL classification: *C10, D83, M11, M21*

1 Introduction

In today's turbulent and globalized business environment, companies very often do not have the knowledge necessary to achieve a higher level of innovation. For this reason, it is necessary that they acquire required knowledge from available external sources. The historical transition from a manufacturing to a service economy is one of the greatest challenges of the twentieth century. In the so-called new economy, which is often called the knowledge economy (Drucker

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1992), knowledge takes the role of a key resource in a company. In contrast to production economy, where the focus is on achieving the greatest possible volume of production, in knowledge economy the focus is on the quality of the delivered value. At the same time, scarce material resources are replaced by an abundance of intangible resources (Bolisani and Bratianu, 2018), which are manifested in the form of knowledge and information, i.e. intellectual capital. Knowledge is not the source of competitive advantage in itself, the source of competitive advantage is the strategy in which this knowledge is managed. Accordingly, the question that emerges is how to effectively find knowledge, develop new knowledge, adopt it, share it and use it (Hevner and Chaterjee, 2010). In the post-industrial economy, knowledge management is a discipline that has gained immense popularity among academics, consultants and practitioners (Jashapara, 2010). The final outcome of knowledge management is innovation that leads to improved organizational performance and strengthening of the company's competitive advantage (Andreeva and Kianto, 2011).

Therefore, numerous studies have indicated the key role of knowledge and knowledge management in achieving a higher level of innovativeness and superior company performance (Andreeva and Kianto, 2012; Shannak et al., 2012; Obeidat and Abdallah, 2014; Tieng et al., 2016; Bashir and Farooq, 2019). According to Andreeva and Kianto (2011), various studies cite various knowledge management processes as key in achieving innovation. All these studies emphasize innovation as the primary goal of knowledge management. However, the same authors emphasize that there is a gap in the existing literature when it comes to guidelines for company management, which knowledge management activities and processes to prioritize and improve in order to achieve higher level of innovativeness. Previous research dealing with knowledge management processes mainly focused on the analysis of these processes within the company (Grandinetti, 2016). However, knowledge in the company can be increased in two ways, by creating knowledge or acquiring knowledge from sources outside the company, which include the competition, public research institutions and other sources from the industry such as suppliers, customers, business partners (Andreeva and Kianto, 2011). Access to external sources of knowledge is extremely important for companies, especially small and medium sized companies (Durst and Edvardsson, 2012).

In the dynamic environment in which they operate, companies relying only on internal knowledge lag behind in accessing new technologies (Wuyts and Dutta, 2014). By constantly acquiring external knowledge, integrating knowledge and creating knowledge within the company, it is possible to respond effectively to changes in the external environment and achieve a competitive advantage (Zhao et al., 2013). Empirical examination of the insufficiently researched relation between the acquisition of knowledge from external sources and product innovation represents the research problem of this study. The objective of this research is to test the contribution of acquiring knowledge from external sources, which include customers, suppliers, the competition, consultants, universities and public enterprises/ institutions to product innovativeness in the company, by estimating the regression model for different quantiles. Therefore, this study provides an answer to the question whether the acquisition of knowledge from different external sources contributes to a company's product innovativeness, as well as whether there is a difference in the contribution of different sources of external knowledge to product innovation in companies with different performances in terms of product innovation. The purpose of researching this topic is reflected in the fact that knowledge as a key resource of companies in the new economy is very often unavailable within the company itself. For this reason, it is necessary to obtain it outside the company in order to achieve a higher level of product innovativeness.

In accordance with the defined object and research problem, the following hypotheses are proposed in this study:

H1: Knowledge acquisition from external sources (customers, suppliers, the competition, consultants, universities and public enterprises/institutions) contributes to product innovation in companies with low product innovation values.

H2: Knowledge acquisition from external sources (customers, suppliers, the competition, consultants, universities and public enterprises/institutions) contributes to product innovation in companies with medium product innovation values.

H3: Knowledge acquisition from external sources (customers, suppliers, the competition, consultants, universities and public enterprises/institutions) contributes to product innovation in companies with high product innovation values.

The research question that this study strives to answer is: Is there a difference in the contribution of different sources of knowledge in low, medium and high performing companies in regards to product innovation? The article made its scientific contribution through the achieved research goal related to the empirical testing of the insufficiently researched relationship between the knowledge acquisition from external sources and product innovation. By applying the quantile regression method, the results confirmed not only the importance of acquiring knowledge from external sources, but also differentiated between the key sources of external knowledge for companies with different performances in terms of product innovation. The continuation of the article provides an overview of the relevant literature in the field of research addressing the subject of this study. Methodology of analysis is the third section in the paper, in which we present the sampling method, data collection, the questionnaires used and the analysis methods performed. The fourth section in the article refers to the empirical data and analysis and contains the results of the analysis. Results and discussion is the section which explains the research results connecting them to previous relevant studies. The last section is Conclusions, in which the authors' thoughts and evaluation of the obtained results are presented.

2 Literature review

Knowledge represents the most important economic asset owned by a company and is a key determinant of a company's innovation and profitability (Hislop, 2018). The adoption of knowledge outside the company refers to the collection of knowledge from different sources available outside the company: the competition, public research institutions and other sources from the industry such as suppliers, customers, business partners (Andreeva and Kianto, 2011). Organizations very often find themselves in a situation where they do not have enough time to acquire the necessary knowledge and respond to the pressure of competition. In such situations, according to Jashapara (2010), organizations can resort to borrowing the competitor's strategy, practice and technology, i.e. vicarious learning, which includes copying or imitating other companies. According to Clausen (2013), the theory of absorptive capacity is relevant for understanding a company's ability to access external knowledge. Cohen and Levinthal (1990) published their pioneering work on absorptive capacity, defining this concept as a firm's ability to recognize the value of new external information that can be exploited and used for commercial purposes. Later research found that there is a close relationship between absorptive capacity and the knowledge management process, i.e. knowledge acquisition, knowledge creation, knowledge application and knowledge sharing (Sun, 2010), as well as the relationship between absorptive capacity and the innovative capabilities of a company (Marabelli and

Newell, 2014; Pilav-Velić and Marjanović, 2016). Innovation is present and considered in all areas of human activity, but there is a special emphasis on innovation when analysing the changes brought by the new economy. Global competition, changing consumer demands, accelerated technical changes and uncertainty are the basic characteristics of the business environment of the new economy (Montoya and Workman, 2013). Rainey (2008) cites the spectacular innovations of the twentieth century such as airplanes, the microprocessor, the Internet, and so on, as well as innovative companies of that period such as Boeing, Intel, Microsoft, General Electrics, Toyota, Siemens, Nestle, and Proctor Gamble for their new product development capabilities. The mentioned companies benefited from sophisticated new product development processes in order to be able to satisfy the needs and demands of their customers, as well as other interested parties, at the highest possible level. Furthermore, the same author writes that even more sophisticated products, technologies and processes are emerging in the twenty-first century.

Consumers are looking for products that are of better quality and have a greater value. The life cycle of a product is reduced. Managing such changes through innovation is a way to create a better world, with products and technologies that customers trust and that have a positive impact on the business environment. The numerous literatures and the large number of researchers studying various aspects of innovation are evidence of the understanding of the importance of innovation for the academia. In accordance with the diversity of disciplines that have studied innovative performances, a large number of different definitions of product innovation can be found in the literature. In this study, we will stick to the definition offered by the OECD (2017), which defines product innovation as the introduction of a product or service that is new or significantly improved with respect to its previous characteristics or purpose, including changes in technical specifications, embedded software or components, user support or other functional features. According to Rainey (2008), product innovation is focused on improving the strategic position and the ability to deliver products through creativity and leadership. From the multitude of existing product innovations, Reguia (2014) distinguishes:

- Development of old products that are already produced in the company, with modifications and partial changes in the form or the components of the product
- Creation of new innovative products to meet market needs
- Use of new techniques in the production process.

According to Lau et al. (2010) the company's ability to introduce innovative products to the market is a key innovative capability. Furthermore, the same authors, based on a review of the literature, state that in many industries, 30% of sales on the market refer to new products and that such products are very profitable and often have more than 90% return on investment.
Biazzo (2021) emphasizes the existence of two sources of creation of product development projects: the idea for product development as a completely new response to customer needs and new technologies that enable new characteristics and new performances. The ability to develop creative ideas and new technologies is "fed" and maintained by the systematic absorption of information from the outside world. According to the resource-based theory, effective innovative product development depends on the use of organizational capabilities and resources, which are usually owned by the company or other organizations, such as suppliers, customers, universities and research institutions (Lau et al., 2010). Zheng et al. (2011) confirmed the ability to acquire knowledge and create knowledge as important prerequisites for the process of knowledge combination with a positive impact on innovation. According to Fabrizio (2009), companies that are successful in acquiring knowledge from external sources have a higher level of innovation. Likewise, Cheng and Chen (2013) highlight external knowledge as a way of stimulating innovation in many companies. According to Von Hippel

(2005), customers and suppliers are the main sources of innovative ideas for developing new products. Customers can indicate their needs to the company and thus participate in the creation of a new product that would meet their needs. Zhang et al. (2010) write that the integration of customers and suppliers can be a significant resource for the company in terms of improving innovative performance. Furthermore, the same authors argue that inter-business cooperation and competition coexist in strategic alliances and that their contributions increase the acquisition of knowledge, which leads to the improvement of innovative performance. Hamel et al. (1989) also write about the importance of cooperation with competitors. They cite numerous examples such as the cooperation of General Motors and Toyota in the assembly of cars, Siemens and Philips in the development of semiconductors and so on. As they state, an alliance with a competitor is not devious. It represents the partner's ability to acquire the other partner's skills. Striukova et al. (2015) argue that in recent years, in many countries, it is increasingly common for universities to include industry as partners in their research. Additionally, they say that in order to foster innovation, the stimulation of open innovation between the private sector and the academia is encouraged by numerous public policies. The understanding of how to develop cooperation with universities in an open context for innovation, would enable managers to gain insight into the development of specific strategies that should improve their joint action (Striukova et al., 2015). At the end, that joint action would contribute to the improvement of a company's performance in terms of product innovation.

3 Methodology of analysis

The primary data were collected using the systematic random sampling method. The framework for the selection of the sample was the list of companies available at the financial and statistical institutions of Bosnia and Herzegovina and at the APIF and AFIP agencies. The sample was designed to include small, medium and large companies that were actively doing business at the time of sample creation. Survey questionnaires were sent to 1,723 companies' postal or e-mail addresses. After removing questionnaires with more than 10% of data missing (Hair, 2011), the number of usable completed questionnaires was 203, i.e. the final response was 11.78%. Product innovativeness is measured using the questionnaire developed by Wang and Ahmed (2004). For this purpose, a Likert scale from 1 to 5 was used for this purpose, where 1 represents totally disagree, while 5 completely agree. The questionnaire measures product innovation with the next four statements:

- Our company is often the first on the market with the introduction of new products/services.
- Customers often perceive our new products/services as a novelty on the market.
- Compared to our competitors, our company has introduced more innovative products/services in the past five years.
- Compared to our competitors, our company has a lower success rate in introducing new products/services to the market.

The same questionnaire was used in earlier studies that analysed the production innovation of companies (Chang et al., 2015; Vanhala and Ritala, 2016; Engelman et al., 2017; Butt et al., 2019). The questionnaire incorporates a statement with a negative key and the results of this statement were reversed before conducting the analysis. The intensity of knowledge acquisition from different external sources (customers, suppliers, the competition, consultants, universities and public enterprises/institutions) was measured in the way that respondents indicated the intensity of acquiring knowledge from the listed partners (sources). A Likert scale from 1 to 5,

where 1 indicates that they never acquire knowledge from external partners, while 5 that they very often acquire knowledge from external sources, was used for this purpose. To test the contribution of the intensity of knowledge acquisition from different external sources, which include: customers (IPZKUP), suppliers (IPZDOB), the competition (IPZKONK), consultants (IPZKONS), universities (IPZUNIV) and public enterprises/institutions (IPZJP) to the product innovation of the company, quantile regression analysis was performed, by using IBM SPSS Statistics 26 software. The quantile regression analysis estimates a regression model for different quantiles (Zellner and Theil, 1992). The quantiles used in this study are Q = (0.25, 0.50, 0.75), where Q1 = 0.25 indicates companies with low values of the dependent variable, Q2 = 0.50 indicates companies with average values of the dependent variable (median), and Q3 = 0.75 indicates companies with high values of the dependent variable. Linear regression analysis is one of the most common techniques used in developmental research, but it allows only the estimation of average relationships between the predictor and the outcome, while quantile regression gives estimates of the relationship between the predictor and the outcome over several points of the result distribution (Petscher, 2014). In this regard, quantile regression analysis is used in order to obtain robust estimates of associations or group differences at different locations in the distribution of the result, that is when researchers are interested in examining effects in the lower and upper tails of the distribution of the result (Konstantopoulos et al., 2019). In addition, according to the same authors, quantile regression analysis is used as a good alternative to linear regression analysis when there is asymmetry in the data distribution since the median is a more robust index of the mean value, as well as when estimates of the mean value can be biased in the presence of extreme values, located mainly in one of the tails of result distribution.

4 Empirical data and analysis

Below is a description of the characteristics of the companies that participated in the sample. Table 1 shows that the minimum age of the company in the sample is 3 years, while the oldest company was founded 90 years ago. The average age of the companies in the sample is 21.22 years. The smallest number of employees in the company is 5, while the company with the largest number of employees, employs 3,361 of them. The average number of employees in the companies in the sample is 130.50.

Table 1 Characteristics of the company in the sample according to the company's age and the number of employees

	N	Minimum	Maximum	Average Age	Standard deviation
The age of the company	202	3	90	21,22	13,640
Number of employees	203	5	3361	130,50	341,589

Source: Empirical research based on authors' calculation

From Table 2, we conclude that the largest number of companies in the sample is engaged in industrial activity (78 companies, or 39.2%) while 58 (29.1%) companies are engaged in service activities and 63 (31.7%) companies in other activities. The companies in the sample were classified based on the Classification of Activities of B&H (2010). The industry includes companies engaged in production activities, service includes companies engaged in service activities and the third group (other) includes companies engaged in all other activities from the aforementioned classification.

Table 2 Characteristics of the company in the sample according to activity

		Frequency	%	Valid %	Cumulative %
Company Activity					
Valid	Industry	78	38,4	39,2	39,2
	Service	58	28,6	29,1	68,3
	Other	63	31,0	31,7	100,0
	Total	199	98,0	100,0	
Missing Values		4	2,0		
Total		203	100,0		

Source: Empirical research based on authors' calculation

An overview of the results of the quantile regression analysis for the dependent variable product innovation (IP) is given in Table 3 and Figure 1.

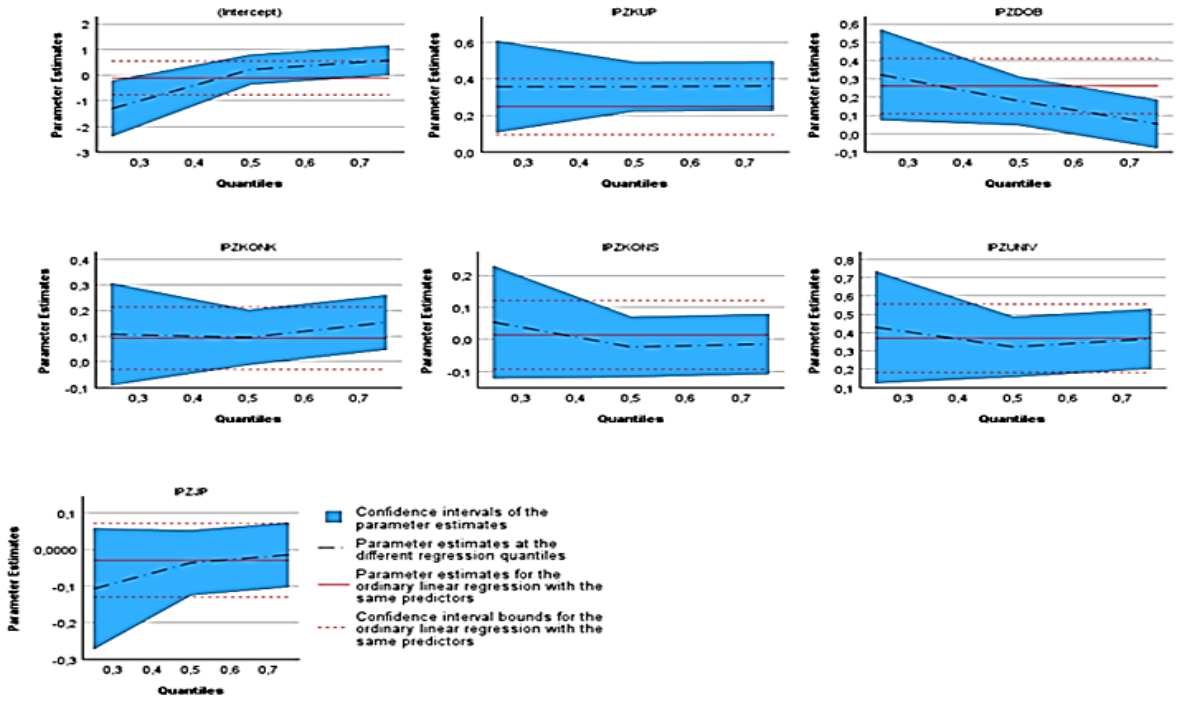
Table 3 Parameter estimation for IP according to different quantiles

Quantiles	q=0.25	q=0.5	q=0.75
Variables			
(Intercept)	-1.304 (.018)*	.214 (.468)	577 (.049)
IPZKUP	.357 (.005)*	.357 (<.001)*	.361 (<.001)*
IPZDOB	.321 (.011)*	.179 (.009)*	.053 (.428)
IPZKONK	.107 (.289)	.095 (.081)	.154 (.005)*
IPZKONS	.054 (.547)	-,024 (.619)	-.014 (.760)
IPZUNIV	.429 (.006)*	.321 (<.001)*	.365 (<.001)*
IPZJP	-.107 (.203)	-.036 (.430)	-.014 (.747)
Pseudo R^2	.273	.316	.333
a. Dependent variable: IP			
b. Model: (Intercept), IPZKUP, IPZDOB, IPZKONK, IPZKONS, IPZUNIV, IPZJP			

*P values are presented in parentheses

Source: Empirical research based on authors' calculation

Figure 1 Graphical representation of estimated parameters of quantile regression analysis for IP



Source: Empirical research based on authors' calculation

5 Results and discussion

The results for quantile 0.25 confirmed the significant positive contribution of knowledge acquisition from customers, suppliers and universities to product innovation. Quantile Q1 = 0.25, indicates companies with low values of the dependent variable. Therefore, acquiring knowledge from customers, suppliers and universities contributes to the innovation of products in companies that have low values of product innovativeness performances. For the 0.50 quantile, a significant positive contribution of knowledge acquisition from customers, suppliers and universities to product innovation is confirmed. Quantile Q2 = 0.50, indicates companies with average values of the dependent variable (median). Therefore, acquiring knowledge from customers, suppliers and universities contributes to the innovation of products in companies that have medium values of product innovativeness performances. For the 0.75 quantile, a significant positive contribution of knowledge acquisition from customers, competition and universities to product innovation is confirmed. Quantile Q3 = 0.75 indicates companies with high values of the dependent variable.

Therefore, acquiring knowledge from customers, the competition and universities contributes to the innovation of products in companies that have high values of product innovativeness performances Moreover, the results also showed that the largest contribution of knowledge acquisition from customers is for companies whose product innovation is at the 0.75 quantile, i.e. companies with high values of product innovation. The largest contribution of knowledge acquisition from suppliers and universities to product innovation is for companies whose product innovation is at the 0.25 quantile, i.e. companies with low values of product innovation. Knowledge acquisition from the competition has a significant contribution to product innovation only at the 0.75 quantile, i.e. among companies with high levels of product innovation. The results of this study can be linked to the studies conducted by Pilav-Velić and Jahić (2022), Pilav-Velić and Marjanović (2016), Chatterji et al. (2014), Pippel (2014) and Santoro et al. (2017). The results of the study conducted by Pilav-Velić and Jahić (2022) established that the input innovation practices of manufacturing companies at different stages of the innovation development process, starting from idea generation, experimentation, and commercialization, have a positive impact on their innovative performance. This study indicated a significant contribution of knowledge acquisition from universities to product innovation for companies with low, medium and high values of product innovativeness. Understanding how to develop cooperation with universities in an open context for innovation, would enable managers to gain insight into the development of specific strategies that should improve their joint action (Striukova et al., 2015). In this way assumptions for knowledge acquisition from universities would be created. This would ultimately contribute to the improvement of a company's performance in terms of product innovation. The study also identified customers as external sources of knowledge that contribute to the production innovation of companies with low, medium and high innovative performance. Such results are in accordance with previous research. Pilav-Velić and Marjanović (2016) confirmed the significant contribution of the acquisition of knowledge from customers to the company's production innovation. The results of this research pointed to the active or key role of customers as a source of external knowledge in product innovation, which is in line with research conducted by Bendapudi and Leone (2003), Burcharth et al. (2014), and Goyal et al. (2020). Acquiring knowledge from suppliers contributes to production innovation in companies with low and medium value of these performances.

Suppliers as a source of external knowledge do not contribute to production innovation in highly innovative companies. Highly innovative companies mostly develop innovations that

are radical, i.e. new for the market, and external sources of knowledge that contribute to such innovations are scientific sources. This could be a possible explanation for this result. In their study Santoro et al. (2017) distinguish between market and scientific sources of external knowledge. They analysed the importance of the mentioned sources of external knowledge for the development of radical and marginal product innovations. The results of their study showed that knowledge gathered from scientific external sources such as universities, research institutions, knowledge institutions and technology agencies have importance for the development of radical innovations unknown to the market. On the other hand, gathering knowledge from market sources such as buyers, suppliers, competitors and companies from other industries is important for the development of marginal product innovations. Competition as an external source of knowledge contributes to production innovation only in highly innovative companies. Therefore, the alliance with the competition, the exchange of knowledge and skills, would contribute to the production innovation of such a companies. A lot of money is needed to develop new products and penetrate new markets (Hamel et al., 1989), so companies can overcome resource constraints and achieve superior innovative performance by acquiring knowledge-based capabilities from alliance partners (Zhang, et al. 2010). Consultants and public enterprises/institutions in this study do not have a significant contribution to the production innovation of companies. The explanation for these results can be linked to the national context in which the research was conducted. Bosnia and Herzegovina is a country where partnership relations in the form of knowledge exchange between public institutions and the private sector have not yet been developed. Public institutions mainly limit their activities to administrative and technical tasks. Similarly, the provision of consulting services is an activity that is not yet sufficiently developed in this national context. The results of earlier research on the contribution of knowledge acquisition from external sources to innovation vary depending on the activity of the company in the sample, the intensity of the use of knowledge by the company in the sample, the national context in which the research is conducted, as well as the type of innovation that is the subject of analysis (Wang et al., 2016; Rodriguez, 2017; Aliasghar et al., 2023; Si et al., 2020).

6 Conclusions

This study researched the contribution of the knowledge acquisition from different external sources to product innovation in companies, i.e. the difference in the contribution of different sources of external knowledge to product innovation in companies with different performance in terms of product innovation. The importance of research on this topic is reflected in the fact that knowledge, as a key resource of companies in the new economy, is often unavailable within the company itself. It is necessary to adopt it outside the company in order to achieve a higher level of product innovation and thus a competitive advantage on the market. The study made distinction between companies with different performances in terms of product innovation and gave an answer to the question of whether there is a difference in the contribution of different sources of knowledge in companies with low, medium and high performance in terms of product innovation.

The first hypothesis is accepted in the part of the hypothesis that refers to the contribution of knowledge acquisition from customers, suppliers and universities to a company's product innovativeness. The part of the first hypothesis that researches the contribution of knowledge acquisition from the competition, consultants and public enterprises/institutions to a company's product innovativeness is rejected. Therefore, the first hypothesis is partially accepted.

The second hypothesis is accepted in the part of the hypothesis that refers to the contribution of knowledge acquisition from customers, suppliers and universities to product innovativeness in company. The part of the second hypothesis that researches the contribution of knowledge acquisition from the competition, consultants and public enterprises/institutions to product innovativeness in company is rejected. Therefore, the second hypothesis is partially accepted. The third hypothesis is accepted in the part of the hypothesis that refers to the contribution of knowledge acquisition from customers, competition and universities to product innovativeness in a company. The part of the third hypothesis that researches the contribution of knowledge acquisition from suppliers, consultants and public enterprises/institutions to product innovativeness in company is rejected. Therefore, the third hypothesis is partially accepted.

The study also provides an answer to the question whether there is a difference in the contribution of different sources of knowledge in low, medium and high performing companies in regards to product innovation. The study confirmed that there is a difference in the contribution of different sources of knowledge in companies with a low and medium value of product innovativeness on the one hand and companies with a high value in terms of product innovativeness on the other hand. Videlicet, research has established that knowledge acquisition from customers, suppliers and universities contributes to product innovation in companies with a low and medium value of product innovativeness. On the other hand, companies that have a high level of product innovativeness can improve their performance in terms of product innovation by knowledge acquisition from customers, the competition and universities.

The paper made its scientific contribution through the achieved research goal related to the empirical testing of the insufficiently researched relationship between the knowledge acquisition from external sources and product innovation. Furthermore, to the best of the authors' knowledge, quantile regression analysis was used for the first time for this type of analysis. Using this method, the results confirmed not only the importance of gathering knowledge from external sources, but also differentiated what are the key sources of external knowledge for companies with different performances in terms of product innovation. Acquisition of external knowledge contributes to the improvement of a company's innovative performance and the achievement of a competitive advantage on the market. Therefore, the management of the company must encourage the adoption of knowledge from external sources, i.e. from customers, universities, suppliers and consultants, in order to upgrade the internal knowledge base, create new knowledge within the organization and in this way stimulate innovation. Acquisition of external knowledge represents a way in which companies can improve their innovative performance and thereby achieve a sustainable competitive advantage on the market. This is a special opportunity for companies in transition economies, such as Bosnia and Herzegovina, where companies do not have enough resources available for research and development in order to develop innovative products and be competitive on the market where global companies are present. This study includes only companies that are actively operating on the territory of Bosnia and Herzegovina, which represents a limitation of this study. Therefore, a recommendation for future research would be to extend the study to other national contexts, in order to obtain comparative results, that would contribute to the generalization of the research results. The design of the study is transversal in nature, but the creation and implementation of a longitudinal design study would enable the analysis of the impact of changes in the intensity of knowledge acquisition from external sources on a company's product innovativeness. Additionally, a recommendation for future studies is to investigate the contribution of knowledge acquisition from external sources to other types of innovation by using quantile regression analysis.

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Students' Attitudes and Perceptions about Virtual Influencers

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ABSTRACT

Virtual influencers represent a relatively new and growing phenomenon in the sphere of digital marketing and digital business. They present a mixture of technology, marketing strategy and creativity and are used in order to communicate with the target public and to promote ideas, products and services. Using virtual influencing offers both opportunities and challenges for companies. In order to use virtual influencing successfully, it is crucial to understand customers' habits, attitudes and perceptions related to virtual influencers. Our main assumption is that younger generations are more exposed to and interested in virtual influencers. Therefore, we conducted a research on a sample of 102 Croatian students by using an online survey. We analyze the respondents' habits related to virtual influencing in terms of frequency of following and acquittance with certain virtual influencers, content type and preferred social network used for following. Students' attitudes and perceptions are analyzed through the rating of virtual influencers' content quality, authenticity and honesty, transparency, trust in the information they provide, as well as its impact on buying decisions. Students were also given the possibility to express their opinions related to the topics they consider relevant to be present in virtual influencing and what they expect from it in the future. The results indicate that students care about the topics such as ecology, ethics, product quality, gender equality and authenticity of virtual influencers and thus comapnies should take these elements into consideration when creating virtual influencing strategies for younger generation of customers.

Key words: *virtual influencers, students, perceptions, attitudes*

JEL classification: *M15, M30*

1 Introduction

Virtual influencers are a relatively new phenomenon in the sphere of digital marketing. Their occurrence and rise coincide with the growth of digital marketing strategies and IT development. Although highly present in our lives, the topic of virtual influencers is still in its infancy when discussing scientific aspects. There are many areas of scientific research that should tackle the topic of virtual influencing: IT, sociology and psychology, economics among others. Having in mind the broadness of the theme, in this paper we have decided to focus on an initial exploration of a mixture of psychological and business research aspects of virtual influencing. Since younger generations are more exposed to and familiar with virtual influencers, we designed a research that explores how they perceive virtual influencing and what their attitudes are towards virtual influencers. We believe it is crucial to understand these

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aspects both in terms of understanding younger generations' psychological functioning and as such, provide for an incentive for future research in this direction, and in terms of understanding how virtual influencers may be beneficial for companies and how companies should design their virtual influencing strategies in order to obtain higher impact and thus, better business results. The main aim of this research is to analyse students' attitudes and perceptions about virtual influencers. After providing a review of the literatures related to the science of influence and virtual influencing, we proceed with the section presenting the research methodology. The fourth part of the paper is related to the results analysis and discussion. The last sections of the paper include conclusion and references.

2 Literature review

Contemporary concepts of influencing have their origin in the science of social influence. Scientific research of social influence can be traced to the late 19th century (Pratkanis, 2007). The first author to systematically approach the question how a certain group impacts individual behaviour was Gustave LeBon, who published a book called *The Crowd*. According to LeBon (1895), when an individual is isolated, he/she has an incentive to be a cultivated person, while being a part of a group makes individuals subject to the influence of the group mind. LeBon believed that, when being members of a group, individuals use their anonymity and the possibility to hide within the group in order to perform their savage and barbarian behaviour, induced by their instincts (Pratkanis, 2007). LeBon's ideas were further on expanded by Freud in *Group Psychology and the Analysis of the Ego* (1922). Freud theorized that an individual feels safe by group numbers, i.e. by the fact that he/she is not isolated, thus having sense of power to practice behaviours he/she would not be willing to enter individually. Both LeBon and Freud believed that individual is in a state similar to hypnosis when being in a group. The time period following the First and Second World War was characterized by research related to war propaganda, as a special form of social influence. The mainstream research methods at the time being encompassed include: case and descriptive analysis of propaganda, experimental methods, survey research procedures and techniques, as well as field studies. The second half of the 20th century brought new lines of research directions within the science of social influence, including: mass communication, the theory of cognitive dissonance and theory of power (Pratkanis, 2007). Some of the current social influence science methods include case studies, descriptive field studies, experiments, computer simulations, content analysis, but also surveys and questionnaires (Pratkanis, 2007).

The beginnings of science of influence similar to current understanding of influencing can be dated back to 1984 when Robert Cialdini issued his book called *Influence: Science and Practice*. Cialdini (1984) explains seven principles of influence and how they can ethically be used in personal and business relations. These principles can be used as heuristics that help in decision-making or induce influence in others, and include: reciprocity, scarcity, authority, consistency, liking, social proof and unity. Reciprocity is related to the fact that individuals tend to be equal with others and are not keen on owing something, therefore, another person may be influenced by the first person to act on them expecting to get something in return. Scarcity refers to the fact that people find scarce resources more desirable. Authority is related to the fact that individuals prefer to be led by authoritative leaders, primarily those who are credible. Consistency means that people tend to behave as they had previously shown to behave, this is, they do not like to change their once displayed behaviours. Liking refers to individuals giving consent to what they find attractive. Social proof is often used in situations when individuals are not sure how to respond to a certain situation or how to behave. They are

then keen to adapt and behave as others, i.e. they are looking for actions of others they can identify with. Unity means that people tend to be more easily influenced by a group they belong to. Cialdini's (1984) main contribution was positioning science of influence within the business context. Since then, the science of influence plays a significant role within organizational psychology and marketing. One of topics that has been of special importance within the marketing field in the last decade and a half is the use of social media. Social media can be used for the purposes of generating higher profit through creating content, reaching target customers, strengthening relationships with clients, advertising, gathering data analytics, providing enhanced user experience and influencer marketing. Influencing is a wide known phenomenon that may be defined as social media users generating their own content, with the aim of accumulating cultural capital in order to shape the opinions or behaviours of larger audiences (Arsenyan and Mirowska, 2021; Audrezet et al., 2018; Djafarova and Rushworth, 2017). According to Jhavar et al. (2023), influencer marketing is a powerful branding and marketing tool used to increase brand salience and to attract users on social media, especially Generation Y and Generation Z users. According to Cao et al. (2018), who conducted a research on a sample of 285 companies from different industries based in China, the key antecedents to social media use by companies are external pressure, internal readiness, expected benefits, strategic goals and perceived level of risk. Audrezet and Koles (2023) state that social media influencers have been an integral part of contemporary marketing in the last 15 years, with occurrence and rise of virtual influencers in 2016, after the launch of the first virtual influencer LilMiquela.

A virtual influencers may be defined as "a *computer generated character designed for interaction with the public and its respondence on social media platforms. These digital avatars are totally fictional and created via technology using 3D modelling, animation and artificial intelligence"* (Forbes, 2022). Some of the currently most popular virtual influencers include Lu DO Magalu, Lil Miquela, Imma Gram, Leya Love, Bermuda, Seraphine, Barbie, Qai Qai and Apoki. Moustakas et al. (2020) state that although virtual influencing is a relatively new concept and phenomenon, its power measured in the number of followers has been in constant increase since 2018. The rise of virtual influencing has been encouraged by rapid development of IT, especially in the domain of artificial intelligence, and social media use in marketing purposes. Virtual influencing presents a very interdisciplinary field since it is connected to IT, artificial intelligence, psychology, sociology and economics. Although Shen (2024) finds that there is a high level of customer-brand engagement in non-branded virtual influencers and suggests partnering between brands and the existent virtual influencers, the financial estimates of virtual influencer market provide a strong rationale for companies to consider how creating and using virtual influencing may be used as a source of a competitive advantage and continuous improvement in key stakeholder relations. Namely, estimates by the Global Virtual Influencers Market (2024), the virtual influencer market is predicted to rise up to 856.5 mil USD in 2029 in comparison to 440 mil USD in 2022. Additionally, research results indicate that there is a high level of impact virtual influencing creates by using various emotional expressions, thus creating psychological reactions in social media users (Yu et al., 2024). Hedhli et al. (2023) find that the willingness to follow the recommendations made by virtual influencers is positively associated with the purchase intention. Research conducted by Belanche et al. (2024) implies that consumers perceive the advice of virtual influencers as more useful, especially if they are promoting utilitarian instead of hedonic products. Hudson et al. (2016) surveyed customers in France, the UK and USA and compared those who engage with brands via social media with those who do not. They found that social media use was positively related with brand relationship quality and conclude that companies that engage in social media interaction with customers achieve better results in their relationship with clients.

Although a hype seems to exist related to virtual influencer use by companies, due to the fact that it is a relatively new field, there are many questions both from business practice and the scientific research side that remain to be tackled and clarified. For instance, virtual influencing presents risk for companies. On the one hand, this risk may be considered negatively, if the company does not invest adequate funds in virtual influencing, uses wrong virtual influencing strategies or may encounter a reputational risk due to virtual influencing flaws. On the other hand, virtual influencing may be placed on a positive side of the risk spectrum in sense that it presents new opportunities for companies using it. Sands et al. (2022) analyze opportunities and challenges that virtual influencers present for companies. On one hand, they argue that virtual influencers can be a brand's ambassadors, by presenting its values and image. On the other, issues that arise from broader virtual influencers' use include consumer reservations, unrealistic notions of beauty, inauthenticity, regulatory and ethical considerations, and consumer subversion. Another important question related to virtual influencers is the related advantages it brings in comparison to human influencing. Hofeditz et al. (2022) hypothesizes that human influencers are more trustworthy than virtual influencers. They conducted a research on a sample of 112 respondents, exposing them to photographs of human and virtual influencers on Instagram. The results indicate that respondents do find human influencers as more authentic and trust them more. Some of the most interesting issues that we found in existing research are related especially to the aforementioned risks and opportunities that virtual influencers bring and comparing them to human influencers opportunities. We decided to design our research around questions that tackle the attitudes and perceptions related to virtual influencers, in order to deduce implications for future research and give initial guidelines for companies. We base our research on the fact that digital risk, risk of changing consumer preferences and sociocultural risks are some of the main categories of strategic risks contemporary companies are exposed to (Miloš Sprčić and Dvorski Lacković, 2023). Virtual influencing may be placed in all of these risk categories, especially if consumers' habits, attitudes and preferences are misunderstood and consequently wrongly implemented within a company's strategy. We, thus, focus our research on understanding users' attitudes and perceptions about virtual influencers.

3 Research methodology

As explained in the Literature review section, survey is one of the methods commonly used in research related to influencing. Since this research was conducted as a part of a bachelor thesis, the survey was found to be an appropriate research method. The primary reason for this is that a survey is a convenient manner to gather the data on attitudes and perceptions about a certain phenomenon. The second reason is that it does not require additional financial funds, making it convenient and appropriate for the purpose of our research. Our main assumption in the process of designing this research on virtual influencers has been that younger generations are more exposed to and are keener on following virtual influencers. Thus, we focused our research on the younger generation, i.e. Croatian students. The main aim of this research is to analyse students' attitudes and perceptions about virtual influencers. In order to ensure bias removal in terms of higher knowledge of students with an economics/marketing or ICT field background, we sent the survey invitation to students within different educational fields.

In order to reach the target population easier and enhance their respondence, we decided to conduct the research by a web-based questionnaire. The minimum required sample size was calculated based on a confidence interval of 95% and a margin of error of 5% amounts to 150

students. The survey was distributed to a total of 150 students and was conducted in two-time intervals, namely in July and August 2023. All participants were required to be students and social media users. Participants were recruited via social media and students' online forums, and they responded to the questionnaire via Google Forms. Google Forms was used to design the questionnaire since no registration is required and the service is accessible via different electronic devices (tablets, smartphones, laptops). All participants were informed about the objectives of the study. The survey was anonymous, all data was collected anonymously and respondents were informed that they could leave the study at any time. No compensation was provided for participation. Since the nature of this research is exploratory in relation to analyzing students' perceptions and attitudes, and intended to provide rationale for the identification of key topics in VI domain and setting ground for future research, the approach we used was to formulate by ourselves the questions that are related to students' habits, attitudes and perceptions and wider impact of virtual influencers. For validation purposes, a pilot version of the questionnaire was prepared in Croatian language, consisting of 18 questions divided into four sections. Estimated time of completion was around 7 minutes. The pilot survey was sent to 3 students and 2 professors in the economics field in order to test the understanding of wording. All five pilot respondents agreed that the wording is understandable. Minor grammar suggestions were offered by one professor and the recommendations were incorporated in the final version of the questionnaire. Sections of the questionnaire are presented in continuation.

a. Sociodemographic characteristics

Sociodemographic information was collected via three questions. One was dichotomous, asking whether the respondent was male or female. The second was polytomous, asking about respondent's age (18–20; 21-23; > 23). The third question was related to the field of study (Biomedicine and health, Social sciences, Humanistic sciences, Natural sciences, Technical sciences, Art field, Interdisciplinary).

b. Habits related to virtual influencers

There were four questions related to respondents' habits concerning virtual influencers. The researched variables were qualitative and related to the frequency of following virtual influencers, the level of familiarity with certain virtual influencers, and identifying the preferred content and social network used to follow virtual influencers.

How often do you follow virtual influencers?

Never
Few times per month
Few times per week
Daily

Mark the virtual influencers you are familiar with: Barbie, LilMiquela, Seraphine, Bermmuda, Imma.

If you follow any other virtual influencer, please write who it is.

What type of content do you prefer from virtual influencers? You can choose multiple answers.

Fashion
Beauty
Travel
Technology
Other (please name which)

Which social networks do you prefer for following virtual influencer content?

TikTok
Instagram
YouTube

c. Attitudes and perceptions about virtual influencers

This section consists of seven questions. The respondents were asked to rate the quality of the content that is shared by virtual influencers and the importance they contribute to influencers' authenticity and honesty. Both questions were intended to be answered on a scale from 1 to 5, with the explanation of ratings. Further on, they were asked qualitative questions related to influencers' transparency and trust in the shared information, decisions related to shopping and marketing relevance of virtual influencers.

Rate the quality of content shared by virtual influencers on a scale from 1 to 5 (1-very low quality, 5-very high quality)

Rate on a scale from 1 to 5 (1- completely non-important, 5- very important) how important it is for you that virtual influencers are authentic and honest while presenting certain content.

Do you believe that transparency is important when virtual influencers promote their products/services?

Yes
No
I do not know

Do virtual influencers impact your attitudes and decisions about shopping?

Yes
No
I do not know

Have you ever bought a product/service based on virtual influencers' recommendation?

Yes
No

Do you trust the information that is shared by virtual influencers about products/services?

Yes
No
Sometimes/It depends

Do you think virtual influencers are a relevant form of contemporary marketing?

Yes
No
I do not know

d. Wider virtual influencer related issues

In this section, there was one question in which respondents were asked to rate on a scale from 1 to 5, with ratings explained, how often they felt motivated by virtual influencers to improve a certain aspect of their lives. It was followed by three open type questions related to wider virtual influencer related issues. The intent was to provide the respondents the opportunity to

share some other perceptions and attitudes about virtual influencers, thus providing rationale for future qualitative research on the topics related to virtual influencing.

Rate on a scale from 1 to 5 (1-never, 5-always) how often you feel motivated by virtual influencers to improve a certain aspect of your life.

Which themes and topics do you consider relevant to be discussed by virtual influencers?
What type of change would you like to see in virtual influencers in the future?
How would you describe total impact virtual influencers have on your life attitudes?

4 Results analysis

a. Sociodemographic characteristics

A total of 102 Croatian students responded to the survey, which makes a high response rate of 68%. High response may be indicative in sense that students perceive the topic as relevant and interesting to spend some time sharing their opinions about it. Demographic characteristics of the sample are presented in Table 1. As can be seen, 68.63% of the sample is female, the dominant age category is 21-23 years, followed by 18-20 years. All fields of studies are represented, with most students belonging to technical sciences (38.24%) and social sciences (34.31%).

Table 1 Sample characteristics

Characteristic	Frequency	Percentage
Gender	**102**	**100.00%**
Female	70	68.63%
Male	32	31.37%
Age	**102**	**100.00%**
18 - 20 years	25	24.51%
21 - 23 years	71	69.61%
more than 23 years	6	5.88%
Field of study	**102**	**100.00%**
Biomedicine and health	6	5.88%
Social sciences	35	34.31%
Humanistic sciences	12	11.76%
Interdisciplinary	4	3.92%
Natural sciences	5	4.90%
Technical sciences	39	38.24%
Art field	1	0.98%

Source: Authors

b. Habits related to virtual influencers

Table 2 presents students' habits related to frequency of following virtual influencers' content. A relatively high share of 31.37% students answered that they follow virtual influencers daily, while 23.53% follow them a few times per week, and 25.49% of respondents answered they never follow virtual influencers' content.

Table 2 Frequency of following virtual influencers

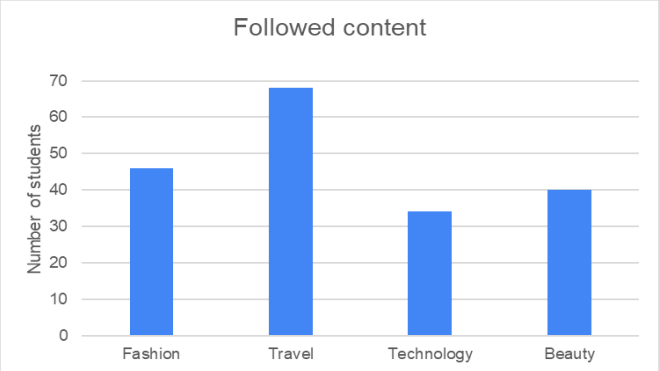
	Frequency	Relative frequency
A few times per month	20	19.61%
A few times per week	24	23.53%
Daily	32	31.37%
Never	26	25.49%
TOTAL	**102**	**100.00%**

Source: Authors

Most of the respondents (51%) are familiar with the virtual influencer Barbie, 13% with Lil Miquela, 6% with Seraphine, 5% with Bermuda and 4% with Imma. Some of the individual respondents answered they are familiar with virtual influencers Akuma Nihmune, MotherV3, Thewizardiiz and Integza.

As for content that students prefer from virtual influencers, the most preferred followed content is related to travel (68 respondents), followed by fashion (46 respondents) and beauty (40 respondents) while 34 respondents answered they follow technology-related content.

Figure 1 Virtual influencers followed content



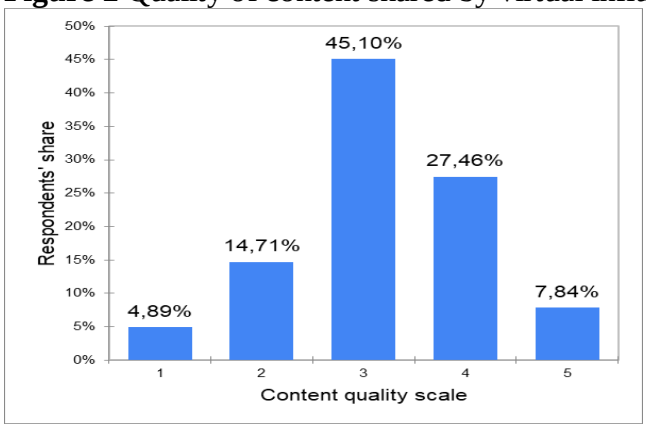
Source: Authors

The main social network on which respondents follow virtual influencers is Instagram (61.8%), while 20.6% follow via YouTube and 17.6% prefer TikTok virtual influencers. In order to test whether there is a link between respondents' gender and the preferred social network, we conducted the chi-square test and the results indicate that on the significance level of 5% there is a significant link between gender and social network used to follow virtual influencer content. Namely, female respondents are keener to follow virtual influencers on Instagram, while male respondents prefer YouTube. Further on, we tested the significance of field of study in regards to the preferred social network used to follow virtual influencers. Although overall there is no significant link between the field of study and the preferred social network, on the level of 5% of significance there is evidence that biomedicine and health, as well as art field students prefer TikTok, while technical science students prefer YouTube as a channel to follow virtual influencers. There is no significant evidence for other fields of study to be related to preferred social network.

c. Attitudes and perceptions about virtual influencers

When asked to rate the quality of the content shared by virtual influencers on a scale from 1 to 5, most respondents (45.10%) rated it as 3, indicating average quality, while a total of 35.30% of respondents perceive content quality as high or very high (scale 4 and 5).

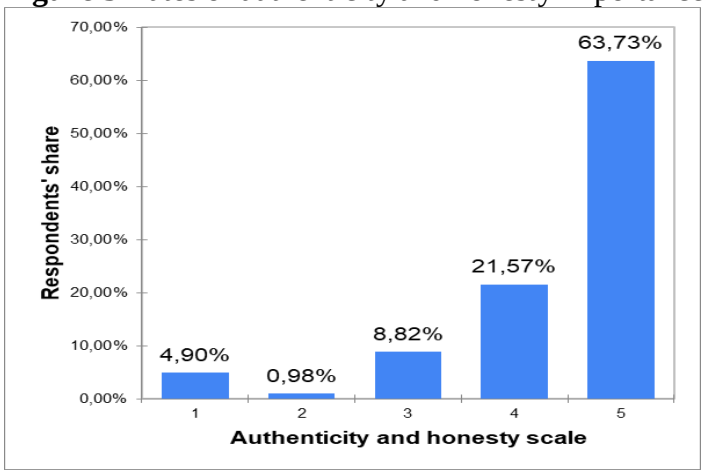
Figure 2 Quality of content shared by virtual influencers



Source: Authors

When asked to rate the importance they contribute to authenticity and honesty of virtual influencers, even 63.73% of respondents point out that they perceive virtual influencers' authenticity and honesty as very important (rate 5 on the scale), with additional 21.57% of respondents considering these features as important (rate 4 on the scale).

Figure 3 Rates of authenticity and honesty importance



Source: Authors

When asked about the importance of virtual influencers' transparency, 93.10% respondents claim that they consider transparency as a very important element in virtual influencers' promotion of products or services. A total of 53.90% of respondents state that virtual influencers impact their attitudes related to shopping, while 45.10% respondents confirm to have bought a product based on virtual influencers' recommendations. Having in mind a relatively high share of respondents who claim that virtual influencers have impact on their buying decisions, it seems very interesting that only 28.40% of respondents claim to trust the information shared by virtual influencers related to product or service features, while 25.50% of respondents are not sure or are keen to further check the information retrieved from virtual influencers. In the sample, 68.60% of respondents perceive virtual influencers as a relevant form of contemporary marketing.

d. Wider virtual influencer related issues

The majority of respondents (38.24%) do not have a clear opinion on whether they feel motivated by virtual influencers to change a certain aspect of their lives, as opposed to 35.30% of respondents who never or almost never feel this incentive and 26.47% of respondents who often or very often feel motivated to change a certain aspect of their life.

Respondents had the opportunity to provide answers to open-ended questions about which topics they consider relevant to be processed by virtual influencers. The reoccurring themes were related to "food", "health", "mental health", "environmental issues" and "gender equality". When asked about the feature they would prefer to be seen in influencers in the future, in an open-ended question type, the repeating answer was "more honesty". When describing qualitatively the total impact virtual influencers have on their lives, most respondents describe that "they do not feel to be under impact of virtual influencers" or they "sometimes take into consideration some recommendations from virtual influencers, but do not make it priority criteria when making decisions".

Based on the survey results, interesting discussion may be raised in several directions. Firstly, it is interesting to find that the student population is interested in society-important topics, such as health, environment or gender equality. On one hand this finding may be an impetus for researchers in social sciences to create different strategies that may benefit younger generations to further promote this awareness, but also to employ it for the benefits of the society they live in. This finding may also be beneficial for companies. Namely, all business entities should be very mindful of the socio-cultural risk. If a certain company does not pay attention to its customers' attitudes and habits, it loses its competitive advantage and possible market share. Therefore, it is very important to know what issues the young generations are keen to. These topics may then be used for new products or services launching, but also in developing advertising strategies. Students' interest in topics such as travel, fashion, beauty and technology may be used by these industries to further promote their products and use virtual influencing as a part of their digital marketing strategy. Additionally, it may benefit companies to be aware that female respondents are keener to use Instagram and male YouTube, when targeting audiences according to gender. Another very interesting finding of the research is related to the fact that the students have shown high interest in honesty, authenticity and transparency of virtual influencers. This means that companies should take these findings into consideration when communicating with the public, since there is evidently a quest for full transparency in younger generations. Companies should strive to communicate with the public more openly about different business aspects, especially related to their products or services. Students' requirements of content quality should present an impetus for companies for additional achievements in this field. This finding is especially important in the context of the relatively high share of respondents who are willing to consider virtual influencers' recommendations, but display a relatively low level of trust in the information provided by virtual influencers. Our results related to high importance that students relate to virtual influencers' authenticity and transparency may also be indicative in terms that it is very important that customers are fully aware whether an influencer related to a certain brand is human or virtual.

5 Conclusion

The intention of this paper has been to analyse the main results of an initial exploratory research based on student population in regard to their attitudes and perceptions about virtual influencers. We entered into research design with the assumption that younger generations are

more familiar with the term of virtual influencing and are thus more exposed to their content. Since the research has been exploratory, we designed a survey with both closed and open-ended questions. The response to the survey has been very satisfactory, indicating both responsiveness of the student population to surveys, but also their interest in the theme of virtual influencing. The main results indicate that students care about the topics of ecology, ethics, product quality, gender equality and authenticity of virtual influencers. The contribution to economic science, in terms of these findings, indicates that companies should pay attention to these cultural trends when designing their interaction strategies with the student population, especially on social media. A limitation of the research is a rather small sample and thus future research should be conducted on a larger sample that would include not only the student population, but the younger age population with various demographic characteristics. Additionally, the survey was conducted in Croatia and the obtained results may be culture-related, thus we propose that similar research is conducted in various cultural settings, i.e. other countries. Having in mind the broadness of the theme and interdisciplinarity of this research area, we also suggest future research to tackle various interactions between psychological and sociological aspects of using virtual influencing with business science, as well as artificial intelligence development and ethical considerations in the field. This research has not dealt with the issue of investment required to create and maintain a quality virtual influencing content and thus, future research may be conducted to find out the cost-benefit ratios for companies willing to invest in this type of content.

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Investigating Consumer Sentiment and Ratings of Sports Footwear Features

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ABSTRACT

The research objective of this paper is to determine the characteristics of sports shoe models made by two major competing brands, Adidas and Nike. The focus is on selected collections of men's and women's sneakers from both brands, based on a data set that includes model names, feature descriptions, average consumer ratings, and the corresponding number of consumer reviews. The textual feature descriptions are analyzed using Natural Language Processing (NLP) techniques such as topic modeling and TF-IDF frequency analysis. Additionally, sentiment analysis, based on the positive and negative consumer ratings and descriptions of sports shoe characteristics, will be conducted to gain insights into user satisfaction. The topic modeling technique is based on the unsupervised latent Dirichlet method (LDA), which enables the identification of latent topics in text content. In the context of sports footwear, this method can uncover key themes such as design aspects, material composition or performance characteristics, enabling a nuanced understanding of the features highlighted in the descriptions. A quantitative statistical analysis is conducted to test hypotheses about possible differences in the ratings of men's and women's sneakers both for individual brands and between them. This research contributes to a deeper understanding of the competitive landscape of the Adidas and Nike brands in the sports footwear industry and provides valuable insights that can be used to improve marketing strategies.

Key words: *characteristic of footwear, NLP analysis, marketing strategies, sport brands, consumer opinions*

JEL classification: *9C, 44P, M37, P36, P49*

1 Introduction

In the field of sports footwear, there is considerable dynamics in terms of competition between the major brands, which favours innovation and the establishment of new standards. In this paper, an overview of the characteristics of Adidas and Nike sports footwear models is analysed. The aim of the research is to uncover the key features that determine the status of these well-known brands, focussing on selected collections of men's and women's sneakers. The research part of this work is based on a robust dataset that includes the names of sports footwear models, detailed descriptions of their features, average ratings and the corresponding number of consumer reviews received. The textual descriptions of athletic footwear features are examined in this paper using state-of-the-art natural language processing (NLP) techniques (Piris, Gay, 2020) such as topic modelling and TF-IDF frequency analysis. The unsupervised

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Latent Dirichlet Allocation (LDA) method forms the basic part of the topic modelling technique and enables the discovery of latent topics within the text content itself. In the context of sports footwear, the LDA method uncovers key themes such as design nuances, material composition and product features, enabling a meaningful understanding of the highlighted characteristics contained in the descriptions. In contrast to the LDA method, the TF-IDF frequency analysis is a powerful tool that measures the importance of terms within the collected document corpus. This technique highlights terms that differentiate each brand or model from others, emphasising its unique selling points. By evaluating the importance of terms based on frequency and rarity, TF-IDF enables the accurate identification of attributes that contribute to the distinctiveness of sports footwear from both brands. The research goes beyond text analysis and extends to consumer sentiment. By analysing sentiment based on positive and negative customer reviews and descriptions of sports footwear attributes, deeper insights into user satisfaction will be gained. The quantitative statistical analysis is designed to test hypotheses and investigate possible differences in ratings between female and male consumers, both for individual brands and for competitive purposes. The anticipated results of this research promise to reveal nuanced similarities and differences between athletic footwear and provide valuable insights for consumers, manufacturers and researchers in the dynamic athletic footwear industry. It also aims to provide a quantitative understanding of potential gender differences in consumer evaluations, thereby contributing to a deeper understanding of the competitive dynamics between brands.

2 Literature review

The concept of brand-customer relationship was established as fundamental to marketing strategies by Aaker (1996) and Keller (2013). Aaker's model focuses on the brand as a set of assets and liabilities associated with the name and the brand elements that are used by companies to increase or decrease the value of a product or service. Keller's model, on the other hand, emphasises brand equity based on the customer. Keller's theory relies on both the rational and the emotional response that arises in the customer. Despite the slight differences between the two models, both emphasise the importance of the relationship between the brand and its customer for market success, highlighting the different aspects of this relationship that contribute to a strong marketing strategy. In their work, Alzate, Arce-Urriza and Cebollada (2022) highlight the importance of brand positioning in marketing and emphasise that brand perception is shaped by consumers. Valuable textual data for understanding consumer preferences and brand image is provided by online consumer reviews. The focus is on the importance of brand associations and brand image, which are characterised by various attributes, characteristics and usage situations. Previšić and Ozretić Došen (2007) state that "the concept of a brand in the narrowest sense includes a name, expression, slogan, sign, symbol, image and product design of one or a group of producers". Meler (2005) defines a brand as "a word, symbol, concept, special design, or a combination of the above if it serves the purpose of identifying a product or possibly a group of products", and Kotler et al. (2006) state that a brand is *"a name, term, sign, symbol or design, or their combination, intended to identify the goods or services of one producer and differentiate them from those of the competition. The essence of the brand is its value, which is recognized by the consumers themselves"* (Bolfek et al., 2014). The above is confirmed by Trbušić and Rimac (2020), who state that *"a brand is the overall appearance of elements such as name, sign, visual identity and other forms of design and communication"*. Brand perception is influenced by the degree and intensity of its presence in the media, propaganda messages and the wider market environment (Jalić et al., 2021 according to Šerić, 2009). Vukman and Drpić (2014) state that

a brand is built, that is, created by *"long-term, persistent, patient and dedicated work, during a process that includes careful planning and a large long-term investment"*. Brkljač et al. (2019) argue that a strong, successful brand can be recognized by the fact that consumers perceive the brand's offer positively and can easily differentiate the brand from competing brands on the market. The authors also point out that it is important to build a strong brand because it achieves consumer satisfaction, attracts and retains consumers, and creates a competitive advantage on the market. Alić et al. (2019) point out that today's consumers are extremely demanding and have great power when it comes to the success of products on the market. With regard to the amount of products on the market, the role of the brand is increasing because consumers distinguish products according to the brands they belong to. *"Perceived quality is a key determinant of brand success. That's why retailers try to increase the volume of commercial brands in a way that, on the one hand, they try to keep price-sensitive consumers, and on the other hand, they try to increase consumer awareness of the quality of commercial brands"* (Čirjak eta al., 2012 according to Sprott and Shimp, 2004).

The product brand provides consumers with functional and symbolic values, it is a guarantee of quality and security, and it reduces the purchase risk (Pandey, 2009; Vranešević, 2007). In their works Diamantopoulos, Smith and Grime, (2005) and Srivastava and Sharma (2013) associate brand strength with predicates such as authenticity, attractiveness, and expressed personality. Martinez Salinas and Pina Perez (2009) believe that the shorter the product life, the higher the costs of introducing a new brand and that the way out of this lies in the extension of the product brand. Considering virtual reality and the new technologies, Neuhofer, Buhalis, and Ladkin (2014) state that technology is used today to improve the "key customer experience of the brand". Martínez-Navarro et al. (2019) proved a positive effect on brand recall and purchase intention at purchases in an online environment. Maxian et al. (2013) suggest that brands consumers have encountered in the past tend to evoke stronger emotional reactions in consumers. Virtual interaction in an online environment enhances experiential brand learning, product and purchase intention as well as satisfaction (Algharabat and Dennis, 2010; Li et al., 2002; Papagiannidis et al., 2014). Jiang and Benbasat (2005), Algharabat et al. (2017), and Li et al. (2003) proved in their work that enjoyment is a key part of virtual marketing strategies, and that it affects greater cognitive involvement in shopping in an online environment. A positive brand image and positive attitudes have a positive effect on purchase intentions. The growing influence of consumers and the value of analysing online reviews to help shape the brand are important. Sports footwear brand Adidas focuses its marketing strategy on meeting customer needs directly through its products. Product design has a major influence on the customer's decision in favour of a brand. When it comes to pricing, in order to build a stronger bond with consumers, Adidas uses a strategy where the value of the products decreases with age. When advertising its products, Adidas uses motivational slogans and works with celebrities to raise brand awareness. Beyond customer loyalty, Adidas focuses on improving customer experience, credibility and sustainable growth through personalisation and innovation (Li, 2023). The marketing strategies of sports footwear brands are based on well-known theories, which are usually customer-centred. For example, the marketing strategy of the Nike brand emphasises the 4C theory (consumer, cost, convenience and communication). From the consumer's perspective, Nike distinguishes itself by recognising and satisfying their unique needs and preferences. Nike offers a wide range of product models characterised by different designs to appeal to different customer segments. In addition, Nike pays close attention to distribution channels and services to increase overall customer satisfaction and loyalty. Nike applies a high pricing policy in its marketing strategy to position itself in the premium market. This is justified by the continuous improvement of product quality, the customisation of services and the maintenance of an active brand image on social media. The

brand focuses on different price ranges to maintain a balance between quality and affordability. Finally, the communication concept in Nike's marketing strategy is based on marketing campaigns, such as launching products with cultural themes like the Air Jordan 1 during the Chinese New Year, building emotional connections with consumers and fostering stronger customer loyalty (Luo and Zheng, 2023).

3 Research design and methodology

In accordance with the research subject described in the introduction, the corresponding data set was collected. The data describing the characteristics of sports shoe models produced by two major competitors, Adidas and Nike, were collected on the Kaggle portal, which contains tens of thousands of data sets suitable for various analyses. The file, downloaded in CSV format, contains the names of the models and their characteristics for Adidas women's and men's sneakers and for Nike brand sneakers, without explicitly stating whether they are women's or men's models. The data relates to models up to 2020. The aforementioned CSV file has been split into three new CSV files. The first contains data for Adidas women's sneaker models, the second for Adidas men's sneaker models and the third for Nike sneaker models. Each file contains the name of the model, a textual description of the characteristics, the average consumer ratings and the number of consumers who have rated the models mentioned. Before further use of said files, it was necessary to clean up inaccurate data. In all files, it was found that there are ratings where the number of raters is 0, and thus, such records were deleted. The Adidas sneaker file for women contains 772 models, the Adidas sneaker file for men contains 1725 models and the Nike file contains 414 models. After this data preparation, it is possible to analyse the textual descriptions of the model properties using NLP methods and to carry out a corresponding quantitative statistical analysis.

3.1 Natural Language Processing

Textual analysis is about understanding cultural, economic, social or ideological elements contained in the essence of the text and their connections to specific contexts. In today's age of vast amounts of textual data, the integration of different knowledge and skills is necessary to transform complex structured data (Big Data) into useful information. Therefore, the use of computer systems and tools for process automation, pattern recognition and content categorisation has become essential. This approach facilitates the extraction of various content features such as names, countries and brand names. Text analysis is related to text mining and utilises machine learning, statistical methods and computational linguistics. A text consists of basic lexical units, the so-called "textual tokens", which are arranged in a specific order. The contextualisation of the text model determines its meaning.

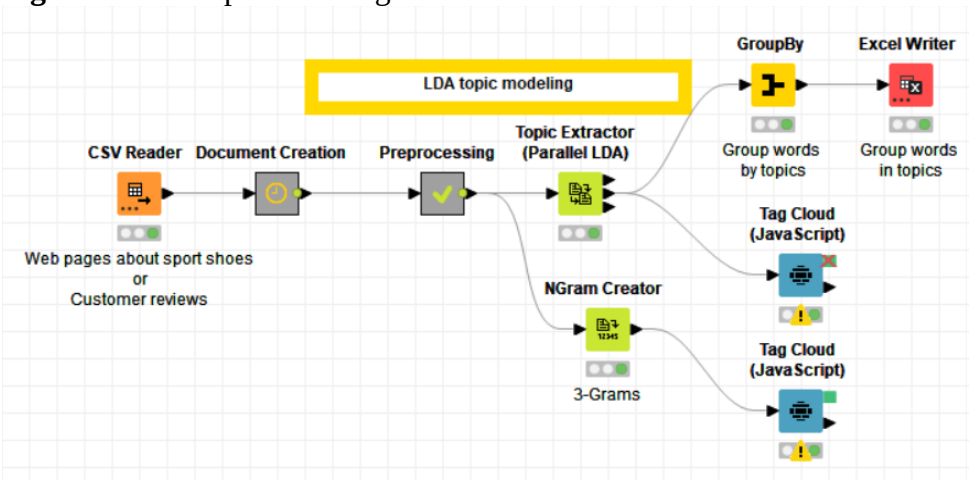
Natural language processing (NLP) methods have gained popularity in brand management due to their ability to analyse large amounts of data and derive meaningful insights into consumer behaviour and perceptions (Piris and Gay, 2020). NLP techniques such as sentiment analysis and topic modelling can be used to gain a deeper understanding of consumer attitudes towards a brand, its products or services and its marketing efforts. By analysing customer reviews, social media posts and other sources of customer feedback, NLP can provide insights into the effectiveness of a brand's marketing efforts, the quality of its products or services and the overall sentiment of the brand. NLP methods can be used to analyse consumer communication

on social media and derive metrics to measure key brand assets such as brand awareness, sentiment and engagement.

In today's world, where technology is constantly evolving, brands face the challenge of standing out and staying relevant in the digital environment. Digital transformation has changed the way brands communicate with consumers, providing them with new tools and platforms for promotion and interaction. The first step in establishing a brand in the digital environment is to create a strong digital identity. This starts with a professional website that not only serves as an online business card, but also as a central place for all information about the brand. The website must be functional, aesthetically appealing and optimized for users and search engines. Social networks play a key role in a brand's digital identity. An active presence on platforms such as Facebook, Instagram, Twitter and LinkedIn enables brands to reach a wide audience, engage in content creation and attract new users and build a community of loyal followers. Regular publishing of relevant content, interaction with followers and the use of visual elements such as images and videos, help strengthen brand recognition. Thanks to AR, VR, MR and XR technologies, there are many new possibilities for the favorable presentation of products and services to the user and the development and management of product brands. Following on how consumers today react to product brands, and on how they make purchase decisions, it can be concluded that there is an increasing belief in the reality of the attention indicator, which characterizes the effectiveness of interaction with the client in the process of strategic virtual and real communication.

The main challenge in applying natural language processing (NLP) and machine learning to text analysis is that computers are not able to process words directly, so conversion to numerical representations is required through techniques such as word embedding. In this process, words are assigned numerical representations based on their semantic meaning within a text sequence. NLP, a key component of artificial intelligence algorithms, underlies the process of natural language text processing and analysis. Before being analysed, the raw text content must be prepared in such a way that it is understandable for computer algorithms that need to extract certain features from the text (Nitin, 2015). The main steps of text pre-processing are to prepare the text data for analysis after tokenisation and word embedding using various machine learning algorithms. The most important steps in text pre-processing include filtering the content, removing punctuation and numeric data, converting all words (tokens) to lowercase, normalising by removing suffixes and prefixes from word roots (stemming) and mapping words to their root form (lemmatisation) and finally removing stop words that have no meaning in the text. The first step of the study aims to determine the dominant words in the text corpus using a frequency analysis called TF-IDF. After pre-processing the text corpus, the word frequency within the corpus is determined by applying a statistical algorithm called TF-IDF (Sarkar, 2016). TF-IDF consists of Term Frequency (TF) and Inverse Document Frequency (IDF). TF reflects the frequency of words within the document, while IDF assesses the rarity of words in the corpus. Frequently occurring words may not provide relevant information, especially when analysing sports shoe brands. Therefore, IDF identifies rarer words with greater meaning. The final TF-IDF score is the product of the TF and IDF scores. Topic modelling is described as an unsupervised learning method for identifying the most important topics and the words associated with these topics. The KNIME model shown in Figure 1 processes all documents in the text corpus after pre-processing and proceeds to the topic modelling module, which uses the unsupervised learning algorithm Latent Dirichlet Allocation (Blei et al., 2003).

Figure 1 LDA topic modeling KNIME workflow



Source: Authors

During topic modelling, the main topics within the text corpus are decomposed, which helps researchers to discover hidden semantic structures. For this purpose, the Latent Dirichlet Allocation (LDA) model is often used, which treats each document in the corpus as a mixture of topics consisting of words or word groups related to the topic. The determination of topics requires the specification of parameters such as the number of topics (K) and the number of words per topic (N). In addition, the initial parameters alpha and beta must be specified for a more precise determination of the topics and the dominant words.

3.2 Qualitative statistical analysis

After analysing the documents of the text corpus with the above-mentioned NLP methods, a statistical analysis of the model evaluations and their characteristics was carried out. Firstly, the parameters of the descriptive statistics were determined, on the basis of which the statistical tests to determine the similarity of the ratings between Adidas men's and women's models and to determine the similarity between all Adidas and Nike sneaker models can be carried out. Since the number of ratings is different for the three groups mentioned above, neither the t-test nor the Z-test are suitable for carrying out statistical tests. It was determined that the chi-square test is best suited to compare the statistical similarity of the ratings. In order to be able to carry out the chi-square test, the data was prepared accordingly in advance. A new categorical variable called sentiment was introduced, which has two categories: negative and positive consumer sentiment. With this variable, consumers rate the sports shoe models differently and express this through their mood, which can be positive or negative. Models with ratings greater than or equal to 0 and less than 2.5 have a negative sentiment, while ratings from 2.5 to 5.0 have a positive sentiment. The frequencies of positive and negative consumer sentiment were then determined for each group of models and chi-square tests were performed on this basis to confirm or reject the following hypotheses:

H1: There is no statistical difference between the ratings of Adidas sneaker models for men and women.

H2: There is no statistical difference in the ratings between all Adidas sneaker models and Nike sneaker models.

This gives us a better understanding of the attitudes of their consumers, which are expressed in the evaluations of the features of sneaker models and which play a decisive role in the development of marketing strategies for the Adidas and Nike brands.

4 Results and discussion

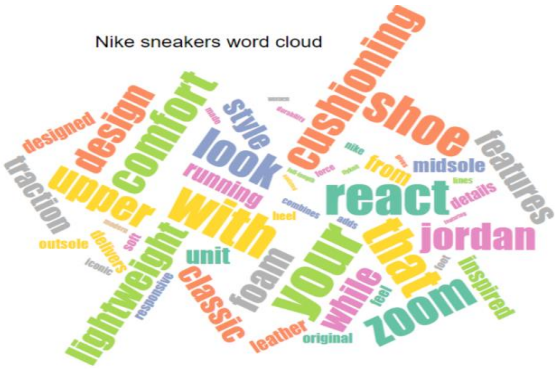
As described in section 2, both brands maintain the loyalty of their customers by emphasising design, quality and materials in their marketing strategies. The NLP document analysis describing the characteristics of the various models of sneakers was conducted using TF-IDF frequency analysis techniques and topic modelling. The TF-IDF analysis performed extracted dominant features that run through the entire text corpus of Adidas men's and women's sneakers as well as Nike sneakers. The results obtained are illustrated in Figures 2 and 3 with word clouds in which the dominant words with the highest TF-IDF values are shown in larger and bolder letters.

Figure 2 Adidas TF-IDF word clouds

Source: Authors

Dominant features emphasised for men's Adidas sneakers include durability, offers, rubber, while dominant words such as design, feel, leather, supple, soft, comfort are emphasised for women's Adidas trainers. The main common features for both types of Adidas sneaker models are running, cushioning, style, appearance, outsole, midsole, comfort, lightweight. From the common features, it can be concluded that Adidas pays equal attention to the models for men's and women's athletic footwear in its marketing strategy, emphasising durability for men's athletic footwear and comfort for women's athletic shoes.

Figure 3 Nike TF-IDF word cloud



Source: Authors

The most prominent features of Nike models relate to design, comfort, cushioning, lightweight, upper, design, Jordan, look, foam, classic and style. It is worth mentioning the word "Jordan", which refers to the Air Jordan model, that has gained a large fan base thanks to basketball player Michael Jordan in particular. In contrast to TF-IDF, the analysis carried out using the NLP technique LDA identifies dominant topics whose content is determined by keywords.

Table 1 Adidas women's sneakers topic modeling

TOPIC	ADIDAS WOMEN'S SNEAKERS KEY WORDS
TOPIC 1	upper, boost, midsole, cushioning, adidas, style, comfort, responsive, mesh, modern
TOPIC 2	upper, look, comfort, style, women, cushioning, lightweight, adidas, design, provides
TOPIC 3	feel, upper, mesh, design, sleek, adidas, midsole, snug, look, women
TOPIC 4	upper, outsole, women, mesh, midsole, comfort, cushioning, rubber, adidas, breathable
TOPIC 5	eather, style, upper, look, classic, rubber, outsole, adidas, platform, re
TOPIC 6	cushioning, upper, support, foot, fit, energy, knit, stretch, comfort, run

Source: Authors

As the LDA technique does not name the individual topics, the author named them as follows: In Table 1, Adidas women's sneakers in theme 1, called Design, highlight the following keywords: upper, midsole, cushioning, style. Theme 2, called Comfort, contains the following keywords: comfort, look, lightweight. Theme 3 refers to feel with the keywords: feel, look, sleek, snug. Theme 4 describe parts and materials of shoes: upper, outsole, mesh, midsole, rubber. Topic 5 highlights classic look: look, classic. Theme 6 stands to comfort: cushioning, energy, foot, run.

Table 2 Adidas men's sneakers topic modeling

TOPIC	ADIDAS MEN'S SNEAKERS KEY WORDS
TOPIC 1	comfort, outsole, adidas, synthetic, eva, rubber, upper, wet, straps, traction
TOPIC 2	outsole, upper, durability, rubber, midsole, mesh, provides, adidas, comfort, cushioning
TOPIC 3	upper, re, football, touch, boots, ready, ground, foot, control, firm
TOPIC 4	upper, cushioning, mesh, comfort, support, outsole, midsole, feature, provides, cloudfoam
TOPIC 5	upper, comfort, style, look, cushioning, midsole, feel, mesh, modern, adidas
TOPIC 6	upper, look, style, adidas, leather, design, suede, classic, midsole, modern

Source: Authors

In Table 2, which lists the themes for Adidas men's sneakers, Theme 1, Material, contains the dominant words: synthetic, rubber. Theme 2 is called Durability and the keywords are: durability, rubber, outsole, midsole, while Theme 3, Sport, is dominated by the following words: football, ground, control. Key words cushioning. comfort, support, cloud determine the topic 4 name as comfort. Theme 5 stand for comfort and modern style; comfort, style, modern. Theme 6 refers to the quality of the material: leather, design, suede.

Table 3 Nike sneakers topic modeling

TOPIC	NIKE SNEAKERS KEY WORDS
TOPIC 1	nike, lebron, look, responsive, lightweight, cushioning, inspired, plush, jordan, zoom
TOPIC 2	nike, traction, metcon, stability, training, designed, speed, lifting, forefoot, high-impact
TOPIC 3	nike, academy, fit, traction, plate, takes, boot, phantom, touch, create
TOPIC 4	air, nike, max, comfort, look, classic, design, style, cushioning, unit
TOPIC 5	nike, air, upper, zoom, lightweight, foam, cushioning, comfort, feel, flyknit
TOPIC 6	nike, air, jordan, design, react, comfort, look, leather, retro, tongue

Source: Authors

In Table 3, which shows the themes for Nike sneakers in Theme 1 responsiveness and light materials are emphasized: responsive, lightweight, cushioning, inspired, plush, Jordan.
Theme 2 relates to purpose with the keywords: stability, training, speed. Theme 3 it is related to academic users: academy, fit. Theme 4 relates to design, with the keywords: air, comfort, look, classic, design, style. Theme 5 emphasizes materials for the expectation of comfort: upper, lightweight, foam, cushioning, comfort, feel. Theme 6 has to do with models, where the following expressions dominate: air, Jordan, comfort, look, retro.

Both TF-IDF and topic modelling analysis highlight similar features of sneaker models, with topic modelling providing a better insight into the context by linking dominant topics and words. After gaining a broader understanding of the characteristics of athletic footwear that both brands describe through NLP analysis, a quantitative statistical analysis of consumer evaluations of athletic footwear models was conducted. Firstly, the parameters of the descriptive statistics were extracted and are presented in Table 4.

Table 4 Parameters of descriptive statistics

Sneaker models	Column	Min	Max	Mean	Std. deviation	Variance	Skewness	Kurtosis
ADIDAS MEN'S	Rating	0	5	3.36	1.17	1.36	-0.80	0.38
	Reviews	1	99	49.18	28.71	824.03	0.02	-1.19
ADIDAS WOMEN'S	Rating	0	5	3.38	1.15	1.33	-0.83	0.51
	Reviews	1	99	49.59	28.49	811.80	0.01	-1.23
NIKE	Rating	1	5	4.25	0.81	0.66	-1.55	2.90
	Reviews	1	223	11.15	18.76	351.95	5.05	42.51

Source: Authors

Based on these parameters, in particular the mean values and standard deviations, a significant similarity in the ratings between the Adidas men's and women's sneaker models can be determined. The mean values and the standard deviation of the Nike sneakers differ significantly from the ratings of the Adidas models. Even if it seems possible at first glance to confirm or reject the hypotheses put forward, this still needs to be proven by a suitable statistical test. In order to confirm or reject the hypotheses, the chi-square test was therefore used on the basis of the observed frequencies of the categorical variable sentiment, which comprises two categories, namely the positive and the negative sentiment.

Table 5 Observed frequencies of Adidas men and women sentiment

ADIDAS OBSERVED FREQUENCIES			
	MEN	WOMAN	TOTAL
POSITIVE	1398	638	2036
NEGATIVE	327	134	461
TOTAL	1725	772	2497

Source: Authors

Table 6 Expected frequencies of Adidas men and women sentiment

ADIDAS EXPECTED FREQUENCIES			
	MEN	WOMAN	TOTAL
POSITIVE	1406.5	629.5	2036
NEGATIVE	318.5	142.5	461
TOTAL	1725	772	2497

Source: Authors

Table 5 shows the observed and table 6 expected frequencies for the Adidas men's and women's sneaker models. Based on observed and expected values, the chi-square test was performed using the Excel function chi-square test, which yielded a p-value of 0.68, which is well above the significance level of 5%. The result obtained shows that there is no reason to reject hypothesis H1, thus confirming a significant similarity in consumer ratings of Adidas men and women's sneakers. To prove or reject hypothesis H2, the observed frequency values for all Adidas and Nike sneaker models were used.

Table 7 Observed frequencies of all Adidas and Nike sentiment

ADIDAS AND NIKE OBSERVED FREQUENCIES			
	ADIDAS	NIKE	TOTAL
POSITIVE	2035	400	2435
NEGATIVE	461	14	475
TOTAL	2496	414	2910

Source: Authors

Table 8 Expected frequencies of all Adidas and Nike sentiment

ADIDAS AND NIKE EXPECTED FREQUENCIES			
	ADIDAS	NIKE	TOTAL
POSITIVE	2140.9	355.1	2496
NEGATIVE	355.1	58.9	414
TOTAL	2496	414	2910

Source: Authors

The chi-square test based on the values from Tables 7 and 8 resulted in a p-value of 0.00095, which is significantly below the significance level of 5%. Hypothesis H2 is therefore rejected

and it can be concluded that there is a significant statistical difference between the ratings of Adidas and Nike athletic shoe models. The above NLP and statistical analysis results provide marketers with valuable insights when developing marketing strategies for potential product improvements.

By addressing the technical challenges and methodological steps involved in text analysis, this discussion highlights the importance of NLP and machine learning in harnessing the power of textual data to drive business insights and decisions. The research problem in this paper was addressed by two key analyses: the NLP analysis of textual descriptions of the characteristics of Adidas and Nike sports footwear models, and the statistical analysis of numerical data shown in consumer ratings. The results confirmed the objectives. The ability to convert pre-processed text into numerical formats opens the door to various analytical techniques such as sentiment analysis, topic modeling, and feature extraction. The key topics obtained from the LDA analysis related to Adidas women's sneakers are design, comfort, and materials. For men's footwear, the topics are durability, sports, and comfort. Nike sports footwear is characterized by themes such as responsiveness and light materials, academic users, and dominant models like Air Jordan and Air Max. The NLP analysis identified dominant attributes such as materials, style, robustness, and consumer feelings towards the brands. This was confirmed through statistical analysis and tests that ultimately provided convincing support for hypothesis H1 and the rejection of hypothesis H2. In conclusion, only such a combination of powerful comparison tools was able to effectively compare the ratings of sports footwear models for both male and female Adidas, as well as for Adidas's rival brand, Nike. For Adidas models, 81% of users expressed a positive sentiment, whereas for Nike models, a significantly higher positive sentiment of 96% was observed. Further analyses should aim to uncover the reasons driving consumer preferences for Nike footwear.

A comprehensive analysis of the sports footwear market, including product characteristics, consumer sentiment and gender differences, provides key insights for brands to optimize their products and marketing strategies. The conducted research has limitations that are manifested in a limited sample that does not represent a sufficiently wide spectrum of the population considering the global strategies implemented by manufacturers of sportswear and footwear. Technology and trends in sports footwear change rapidly, which makes it difficult to follow the current preferences and needs of consumers. The preferences of sports footwear consumers vary significantly between different geographical areas, which affects the generalizability of the research results. Future research should be conducted on a wider demographic coverage, which would provide for including different demographic groups of consumers in research results, and thus the obtained research results would represent the basis for obtaining comprehensive results. In addition, future research thanks to various longitudinal studies will enable the monitoring of changes in consumer preferences and mood over a longer period, which can provide a deeper insight into trends and changes.

5 Conclusions

The use of VR technology in marketing represents a significant opportunity for brands to improve their interaction with users, current and potential customers and to create an unforgettable experience with the selected product brand. However, success in this area depends on the brand's ability to overcome technological challenges and to create content that is both innovative and relevant to their target audience. Virtual reality enabled clothing and footwear brands from Sporty to have a global reach, an innovative brand image, a better

presentation of products in the online environment, and a high level of engagement. Virtual reality has enabled sportswear and footwear brands to experience an experience that holds attention longer than traditional media. In line with the topic and research objectives stated in the introduction, the results obtained justified the application of NLP methods and statistical analyses to a large amount of data from the Internet which would be difficult to collect using traditional questionnaires. The results obtained made it easy to gain insights into the characteristics of Adidas and Nike sneaker models. By statistically analysing consumers' evaluations of sneaker models, a more comprehensive perception of the brands they use could be obtained. The statistical chi-square test confirmed hypothesis H1 regarding the significant similarity of the ratings of Adidas men's and women's athletic footwear models, while hypothesis H2 regarding the similarity of all Adidas and Nike models was rejected.

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A Comprehensive Review of Artificial Intelligence Applications in the Financial Sector

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ABSTRACT

This review paper presents an examination of the evolving landscape of Artificial Intelligence (AI) applications within the financial sector, aiming to shed light on how advancements in machine learning, natural language processing, and predictive analytics are revolutionizing tasks such as risk management, fraud detection, customer service, and investment strategies. To achieve this, a systematic literature review was conducted, encompassing a wide array of scholarly articles, research papers and proceeding papers indexed in the WoS database. Initial searches yielded a substantial corpus of articles, which were subsequently refined. The selection of 17 key papers, guided by citation count and abstract analysis, forms the basis for a nuanced discussion of AI's impact on various financial domains. Findings reveal the multifaceted contributions of AI, from enhancing operational efficiency to mitigating risks and fostering innovation within financial institutions. This review underscores the transformative potential of AI applications in fostering a more resilient, adaptive, and efficient financial ecosystem.

Key words: *financial industry, machine learning, risk management, fraud detection, costumer services, robo-advisors*

JEL classification: *G21, G24, O33*

1 Introduction

The financial industry has undergone a profound transformation in recent years, driven by the rapid integration of artificial intelligence (AI) technologies. AI, encompassing machine learning, natural language processing and predictive analytics, has become a catalyst for innovation across various financial sectors. An important area of AI implementation is risk management. Financial institutions are using sophisticated machine learning models to analyze historical data, identify patterns and assess potential risks. This not only improves the accuracy of risk assessments, but also enables real-time monitoring and proactive decision-making. Fraud detection is an area in which AI has made considerable progress. Machine learning algorithms can quickly analyse huge data sets and detect anomalies and unusual patterns that indicate fraudulent activity. The dynamic nature of these models allows for continuous learning and adaptation to stay one step ahead of evolving fraudulent tactics. In customer service, AI-

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driven technologies such as chatbots and virtual assistants are now commonplace. These systems provide immediate responses to customer queries, streamline communication processes and improve the overall user experience. AI's ability to understand natural language contributes to personalized interactions and makes financial services more accessible and user-friendly. The use of AI has also brought about a paradigm shift in investment strategies. Machine learning algorithms analyse market trends, historical data, and complex patterns to optimize investment portfolios. This has led to improved decision-making, increased efficiency and, in some cases, better returns on investments. However, the growing role of AI in finance is not without its challenges. Ethical considerations, the interpretability of AI models and the need for a robust regulatory framework are pressing concerns. A balance between innovation and ethical use of AI is essential to build trust and ensure responsible financial practices. The research objective of this paper is to systematically review and analyse the existing literature on the applications of artificial intelligence in the financial sector in order to provide a comprehensive understanding of the development, current state and future trends in the adoption of AI. The review seeks to identify key themes, challenges, and opportunities across various domains within the financial industry, including risk management, fraud detection, customer service and investment strategies. In addition, the research aims to uncover gaps in the literature and contribute insights that can inform future research directions and practical implementations in the rapidly evolving landscape of AI in finance.

The paper is structured as follows: after the introductory part, a brief historical overview of the development and application of AI in finance is given in the second section. The third section contains the methodological framework in which the research approach is determined. The main findings of the bibliometric analysis are in the fourth section, while the fifth section contains the main conclusions based on the research of key papers in the field of AI application in risk management, fraud detection, service improvement and development of investment strategies. The paper ends with a conclusion.

2 Foundations of AI development

The financial industry has witnessed a remarkable journey with the adoption of artificial intelligence (AI), marking pivotal milestones that have redefined traditional practices and paved the way for a new era of innovation. In the early stages, AI applications in finance were primarily rule-based systems and expert systems. These laid the foundation for credit scoring and risk assessment. Notable books, such as Thomas, et al. (2002), delved into these early applications, setting the stage for the subsequent evolution of AI in the financial domain. A significant breakthrough came with the rise of machine learning in finance. Breiman's exploration of Random Forests (2001) introduced a powerful ensemble learning technique that revolutionized predictive modelling. Machine learning algorithms started outperforming traditional models, particularly in tasks such as credit scoring and portfolio optimization, ushering in a new era of data-driven decision-making. The advent of high-frequency trading and algorithmic trading systems marked another critical milestone. Researchers like Lopez de Prado (2018) explored the intersection of AI and high-frequency trading, showcasing how machine learning algorithms can analyze vast datasets and execute trades at unprecedented speeds. This era redefined the landscape of financial markets, introducing algorithms capable of adapting to rapidly changing market conditions. Natural Language Processing (NLP) emerged as a game-changer in understanding and leveraging textual data within finance. Studies such as Liu's (2012) investigation into sentiment analysis using NLP highlighted the potential for extracting valuable insights from news articles, social media, and other textual

sources. Sentiment analysis became integral for assessing market sentiments, news impact, and investor perceptions. As the financial industry grappled with the need for transparency and regulatory compliance, the adoption of Explainable AI (XAI) became a milestone. Chen et al. (2020) emphasized the importance of interpretable models in financial decision-making, addressing concerns related to bias and ethical considerations. This shift towards explainability paved the way for responsible AI applications in finance.

3 Methodological framework

A comprehensive review methodology involves a systematic and thorough approach to examining a topic, issue, or body of literature. This methodology is often used in many academic research, but can also be used in various fields such as healthcare, policy analysis and market research (Bocconcelli et al., 2018). In this paper, the research approach follows the recommendations of Webster and Watson (2002) and Rowley and Slack (2004). It includes several steps: (i) defining the research question and the research objective, (ii) determining the sources (relevant databases) and the criteria for inclusion or exclusion of studies and articles, (iii) conducting a comprehensive search by identifying the relevant literature, (iv) extracting relevant data from each selected study (study design, sample size, methodology, main findings and conclusions), (v) analysing and synthesizing the results from the included studies to draw some conclusions and recommendations for practitioners, policy makers or for further research.

The research question of this paper is how AI revolutionizes tasks such as risk management, fraud detection, customer service and investment strategies. In order to create an overall picture of the research question posed, this paper summarizes recent research findings in relevant academic papers. The search was conducted in the Web of Science (WoS) database in the period from 20/2/2024 to 20/3/2024. The WoS database was considered suitable for this study for several reasons. First, WoS is a three-index database that covers more than 18,500 journals and tracks the topics with the highest impact factors and citation analysis, and it is one of the world's leading relevant databases (Li et al., 2010; Norris and Oppenheim, 2007). Second, there are a large number of articles in the WoS database that deal with the topic under study. Third, only one database was selected to avoid the overlap that inevitably occurs when articles are cited in multiple databases. The database was searched using very broad keywords, after which additional keywords were introduced and the articles were filtered to select those relevant to the specific research area. Table 1 shows the initial keywords and characteristics of the starting point for this research.

Table 1 Overview of the initial database search

Range	2015-2024	
Search within	Article title, abstract, keywords	
Keywords	(AI OR “artificial intelligence” OR “machine learning” OR “deep learning” OR “neural network”) AND finance	
Total number of papers	17916	
Document type (number of papers)	Article	12645
	Proceeding paper	4565
	Review article	548
	Other	158
Categories	Computer Science Artificial intelligence or Information systems	7147
	Engineering Electrical electronic	2535
	Business Finance	2251

	Other	5983
Publication years	2024	539
	2023	3541
	2022	5702
	2021	3082
	2020	2254
	2019-2015	2798

Source: Prepared by the authors based on data from the WoS database

From this initial group of papers, papers within WoS categories "Business finance", "Economics", "Management" or "Business" dealing with the following topics were selected: "Risk management", "Fraud detection", "Customer service", and "Investment strategies". Table 2 contains research strings and number of papers per every research topic.

Table 2 Number of papers per research topic

Category	**Keywords**	**Fields**	**Number of papers**
Risk management	(AI OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network") AND finance *(all Fields)* AND "risk management" OR "credit risk" *(Topic)*	Business finance, Economics, Management, Business	256
Fraud detection	(AI OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network") AND finance *(all Fields)* AND "fraud detection" OR "financial fraud" *(Topic)*		51
Customer service	(AI OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network") AND finance *(all Fields)* AND "customer service" OR chatbot *(Topic)*		28
Investment strategies	(AI OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network") AND finance *(all Fields)* AND "investment strategies" OR robo-advisor *(Topic)*		47

Source: Prepared by the authors based on data from the WoS database

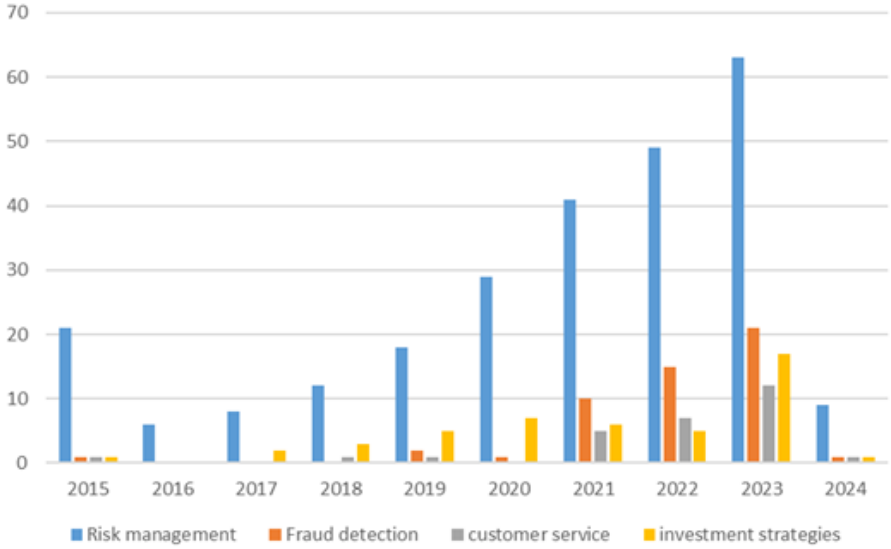
All papers from Table 2 are analyzed according to the co-occurrence of keywords, bibliographic matches and co-citations. After that, a content analysis of these papers was carried out, from which 17 papers were selected. The results and conclusions of these papers were used to identify the role of artificial intelligence in modern finance. A summary of the research design, sample, methodology and main findings of these papers is given in the table in the appendix

4 Bibliometric analysis – the main findings

The research query is: (AI OR "artificial intelligence" OR "machine learning" OR "deep learning" OR "neural network") AND finance (All Fields) AND "risk management" OR "credit risk" OR "fraud detection" OR "financial fraud" OR "customer service" OR chatbot* OR "investment strategies" OR robo-advisor (Topic) and 2024 OR 2023 OR 2022 OR 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 (Publication Years) AND Business Finance OR Economics OR Management OR Business (Web of Science Categories). There are 377 results for this query. When comparing the number of papers by category, we see that as many as 67% are from the field of risk management, and only 7.3% from the field customer service. The

largest number of papers was published in 2023 in the field of risk management (41 – see Figure 1). The most cited paper is titled: "Machine learning in energy economics and finance: A review" (authors: Ghoddusi, H., Creamer, G. G. and Rafizadeh, N) from 2019 (194 citations), and it is also in the field of "Risk management".

Figure 1 Number of papers by category



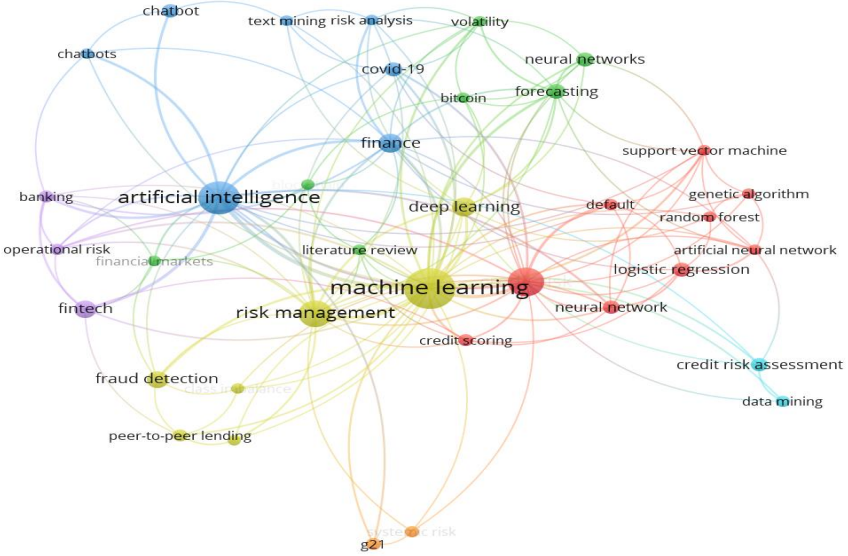
Source: Prepared by the authors based on data from the WoS database

The majority of papers are assigned to the "Business finance" (234 – 62%) and "Economics" (132 – 35%) WoS category. Most of the authors come from the Republic of China (99 – 26%) and from USA (69 – 18%). The WoS citation analysis classifies papers in 10 macro, 326 meso and 2444 micro categories. Most of the papers are classified under "Artificial intelligence & Machine learning" (142) and "Economics" (102) meso categories, and in "Credit scoring" (121), "Option pricing" (58) and "Economic growth" (19) micro categories.

The papers in table 2 were analysed using the VOSviewer program package, which enables bibliometric mapping of the co-occurrence of keywords, authors and co-citations. Bibliometric mapping of the co-occurrence of keywords involves visualizing the relationships between keywords based on their frequency of appearance in academic literature. This method provides insights into the intellectual structure of a research field by identifying clusters of keywords that are frequently mentioned together within scholarly articles (Van Eck and Waltman, 2010). Through bibliometric mapping, researchers can uncover patterns of co-occurrence among keywords, revealing underlying themes, concepts, and trends within a particular domain of study.

The keywords on the topic of applying AI in finance in scientific papers included in the WoS database are arranged in seven clusters (minimum number of occurrences of a keyword is five). The first cluster includes nine keywords, the second, third and fourth clusters include seven each, the fifth cluster contains three keywords, and the sixth and seventh clusters two keywords each. The most frequently occurring keywords are "Machine learning" with 88 occurrences, 31 links and a total link strength of 91, "Artificial intelligence" with 55 occurrences, 19 links, and total link strength of 65, and "Credit risk" with 41 occurrences, 19 links and a total link strength of 41 (see Figure 2).

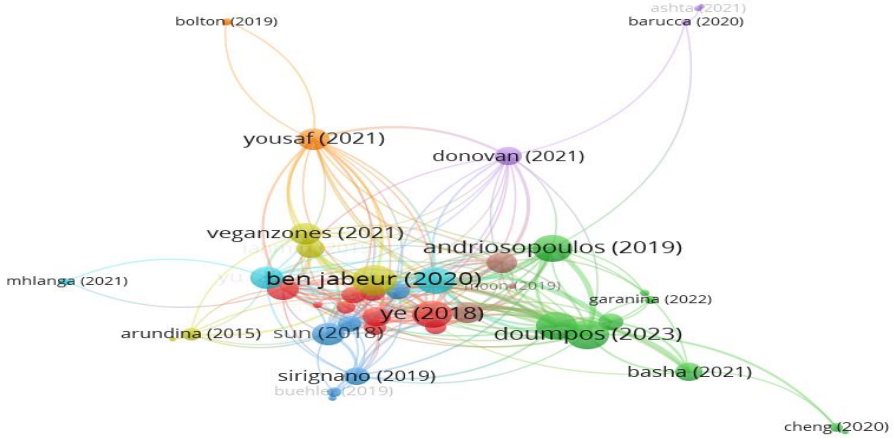
Figure 2 Network visualization of co-occurrence of keywords



Source: Prepared by the authors in VOSviewer based on data from the WoS database

Bibliographic coupling is a method used in bibliometrics to analyze the similarity between documents based on their citation patterns. It relies on the idea that documents sharing references are likely to be related in content or subject matter. When a document cites another document in its references section, it indicates some level of intellectual connection between the two works. Bibliographic coupling capitalizes on this by considering documents that share common citations as potentially related to each other. The degree of bibliographic coupling between two documents is determined by the number of references they share (White, 2003). Bibliographic coupling can be represented as a network, where nodes represent individual documents (such as academic papers) and links between nodes represent the degree of bibliographic coupling between them. Documents that share more references will have stronger connections in the network. Figure 3 shows the bibliographic coupling network. Bigger circles mean stronger total link strength. The minimum number of citations of papers in represented network is 20. The papers are classified into 8 clusters. The first two clusters include nine papers each, the third contains six papers, the fourth, fifth and sixth contain five papers each, and the other two clusters contain two papers each. Paper Jabeur et al. (2020) has 24 links with total link strength of 70, Doumpos et al. (2023) has 26 links with total link strength of 70, and Zhang et al. (2020) has 20 links with total ling strength of 59.

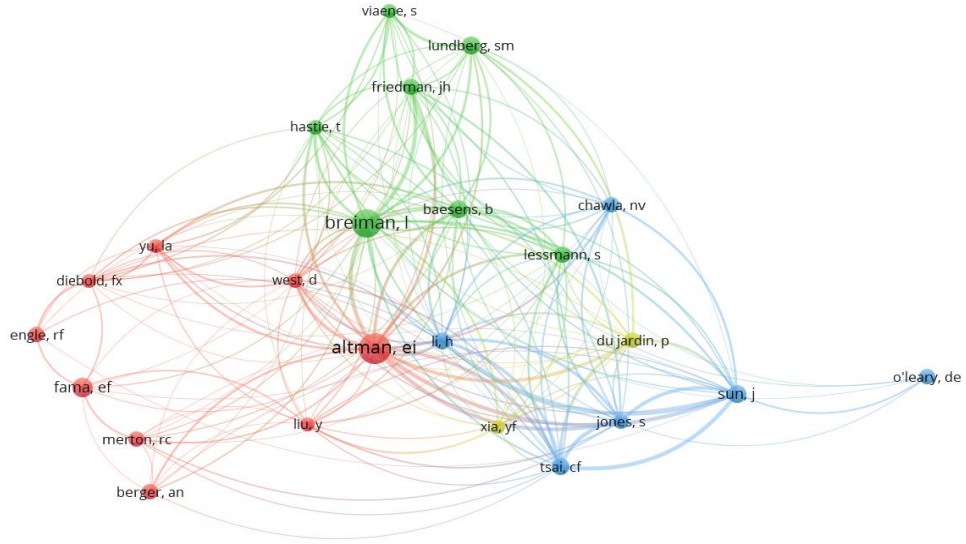
Figure 3 Network visualization of bibliographic coupling



Source: Prepared by the authors in VOSviewer based on data from the WoS database

Finally, the co-citation analysis of cited authors was conducted. Co-citation analysis, a method frequently employed in bibliographic research, examines the associations between authors or documents based on their co-citation patterns within academic literature. The unit of analysis in co-citation analysis is the cited authors, focusing on the connections between authors who are cited together. By compiling a dataset of citations from relevant academic literature, researchers can identify commonalities and connections between authors, revealing insights into the intellectual structure of a research field (White and McCain, 1998). Researchers begin co-citation analysis by collecting citations from scholarly articles, books, or other documents, which represent connections between the citing author and the cited author or document. Through the analysis of co-citation patterns within this dataset, clusters of authors frequently cited together can be identified, indicating shared research interests or intellectual influence (Small, 1973). This method unveils crucial information about the intellectual structure and evolution of a research field, including core concepts, influential authors, and emerging trends (White and McCain, 1998). One of the key advantages of co-citation analysis is its ability to reveal implicit relationships between authors or documents, uncovering hidden connections and associations that may not be apparent from individual citations alone. This facilitates the identification of potential collaborators, tracking the dissemination of ideas across disciplines, and discovering emerging research interests (White and McCain, 1998).

Figure 4 Network visualization of co-citation



Source: Prepared by the authors in VOSviewer based on data from the WoS database

The authors are arranged in four clusters, with the first cluster including 9 authors, the second cluster seven authors, the third six, and the fourth two. The authors with the most citations are: Edward I. Altman, with 93 citations and a total link strength of 366, followed by Leo Breiman with 77 citations and a total link strength of 259, and Jie Sun with 32 citations and a total link strength of 248.

5 Results and discussion

5.1 Risk management

AI has revolutionized risk management in the financial sector by providing advanced tools and techniques to assess and mitigate various types of risks. One of the ways in which AI is

implemented in finance to manage risk is through credit risk assessment. Cheng and Qu (2020) discuss the impact of bank FinTech on credit risk reduction, highlighting how AI-driven algorithms analyze vast amounts of data to evaluate borrowers' creditworthiness more accurately. By leveraging machine learning and predictive analytics, banks can assess the likelihood of default more effectively, enabling them to make more informed lending decisions and reduce credit risk exposure. AI plays a crucial role in risk management within the credit card industry as well. Butaru et al. (2016) emphasize the importance of risk assessment and mitigation strategies in credit card operations. AI-powered algorithms analyze transaction data in real-time to recognize problematic credit card transaction in order to minimize credit card risks. Another area where AI is implemented to manage risk is in the realm of social credit assessment. Yu et al. (2015) provide a comprehensive review of social credit systems and their implications for risk management in finance. AI algorithms analyze individuals' social behavior, online activities, and transaction history to assess their creditworthiness and likelihood of default. By incorporating non-traditional data sources, such as social media interactions and online reviews, AI-driven credit scoring models provide a more holistic and accurate assessment of borrowers' credit risk profiles, enabling lenders to make more informed lending decisions and reduce default rates.

AI-driven network valuation techniques have emerged as a powerful tool for risk management in financial systems. Barucca et al. (2020) discuss the application of network valuation methods to assess systemic risk and contagion effects in interconnected financial networks. AI algorithms analyze the complex network of relationships between financial institutions and assets to identify key vulnerabilities and systemic risks. By simulating various stress scenarios and shock events, AI-driven network valuation models enable policymakers and regulators to evaluate the resilience of financial systems and implement targeted risk mitigation measures to enhance stability and prevent systemic crises.

5.2 Fraud detection

Artificial intelligence (AI) has become an indispensable tool in fraud detection across various sectors, including banking, finance, and insurance. By harnessing advanced algorithms and machine learning techniques, AI systems can analyze vast amounts of data to identify patterns, anomalies, and potential instances of fraudulent activity. In the realm of banking and financial services, AI is revolutionizing fraud detection by enabling institutions to monitor transactions in real-time and flag suspicious activities promptly. Ashta and Herrmann (2021) highlight the role of AI in enhancing the efficiency and effectiveness of fraud detection systems. AI-powered algorithms can analyze transactional data, customer behavior, and historical patterns to identify deviations that may indicate fraudulent behavior. Moreover, AI systems can adapt and learn from new fraud patterns, continuously improving their detection capabilities over time.

Digital finance platforms, such as online banking and mobile payment apps, are particularly vulnerable to fraud due to the volume and speed of transactions processed. Sun et al. (2023) discuss how AI technologies are deployed in digital finance to combat corporate financial fraud. Machine learning algorithms can analyze transactional data, network connections, and user interactions to detect anomalies indicative of fraudulent activities, such as unauthorized fund transfers, account takeovers, and identity theft. By leveraging AI, financial institutions can strengthen their fraud prevention measures and safeguard the integrity of digital transactions.

In the insurance industry, AI-driven fraud detection systems play a crucial role in mitigating fraudulent claims and minimizing financial losses. Aslam et al. (2022) provide insights into how AI and machine learning techniques are utilized in insurance fraud detection. By analyzing claim data, customer profiles and historical patterns, AI algorithms can identify suspicious patterns and flag potentially fraudulent claims for further investigation. Furthermore, AI-powered predictive models can assess the likelihood of fraud based on various risk factors, enabling insurers to prioritize resources and focus on high-risk cases. One of the key advantages of AI in fraud detection is its ability to adapt and evolve in response to emerging threats and sophisticated fraud schemes. Kumar et al. (2019) examine the effectiveness of alert models for fraud detection, particularly in protecting elderly clients who are often targeted by financial scams. AI algorithms can analyze transactional data and customer interactions to generate alerts for potentially fraudulent activities, such as unauthorized withdrawals, deceptive sales practices, and identity theft. By leveraging AI-driven alert systems, financial institutions can proactively identify and prevent fraud, thereby safeguarding the financial well-being of vulnerable customers.

5.3 Customer service

Artificial intelligence (AI) is increasingly implemented in the finance sector to enhance customer service experiences, offering personalized and efficient interactions across various touchpoints. One of the key areas where AI is deployed is in the insurance industry. Riikkinen et al. (2018) discuss how AI is utilized to create value in insurance by improving customer service and satisfaction. AI-powered chatbots and virtual assistants can assist policyholders with inquiries, claims processing, and policy management, offering timely and accurate support. By leveraging natural language processing (NLP) and machine learning algorithms, insurance companies can automate routine tasks, reduce response times, and provide personalized recommendations, thereby enhancing overall customer experiences and loyalty.

Similarly, AI-driven chatbots are transforming customer service in the banking sector. Cimpeanu et al. (2023) explore how AI-powered chatbots help banks improve customer interactions and satisfaction. Chatbots can handle a wide range of customer inquiries, including account balances, transaction history, and account management, through natural language conversations. By analyzing customer queries and preferences, chatbots can provide tailored responses and recommendations, leading to more efficient and personalized customer service experiences. AI chatbots offer 24/7 availability, allowing customers to access support and information at their convenience, regardless of time zones or business hours. Bhattacharya and Sinha (2022) discuss the role of AI in banking for enhancing customer experience. AI-powered recommendation engines can analyze customer data and behavior to offer personalized product suggestions, such as credit cards, loans, or investment opportunities. By understanding customer preferences and financial needs, banks can deliver targeted and relevant offers, increasing the likelihood of customer engagement and satisfaction. AI chatbots can provide proactive support and assistance, such as notifying customers of suspicious transactions or upcoming bill payments, thereby enhancing security and trust. Pham et al. (2022) demonstrate the application of RASA technology to design an AI virtual assistant for learning finance and banking terms in Vietnamese. Virtual assistants can engage users in interactive conversations, answering questions, providing explanations, and offering quizzes or exercises to reinforce learning. By incorporating AI technologies, such as natural language understanding (NLU) and dialogue management, virtual assistants can adapt to users' learning styles and preferences, providing personalized learning experiences. Moreover, virtual assistants can track user

progress and provide feedback, helping users master complex financial concepts and terminology effectively.

5.4. Investment strategies

In the financial sector, the integration of artificial intelligence (AI) has significantly transformed investment strategies, particularly through the emergence of robo-advisors. These AI-driven platforms utilize advanced algorithms to analyze vast amounts of financial data, enabling them to provide personalized investment recommendations and manage portfolios with minimal human intervention. A longitudinal case study by Shanmuganathan and Manchuna (2020) sheds light on the evolving landscape of robo-advisors and their role in investment decisions. By leveraging AI capabilities, robo-advisors can effectively navigate the complexities of financial markets, offering investors a streamlined and efficient approach to portfolio management. One of the key advantages of AI in finance is its ability to mitigate behavioral biases that often plague human investors. Bhatia et al. (2020) highlight the potential of robo-advisors in addressing these biases, particularly in the Indian context. Through sophisticated algorithms, robo-advisors can objectively assess market conditions and make data-driven decisions, minimizing the influence of emotions and cognitive biases. By providing investors with rational, evidence-based recommendations, AI-powered platforms help enhance portfolio performance and mitigate the adverse effects of behavioral biases. The evolution of robo-advisors represents a paradigm shift in the financial industry, where AI is increasingly replacing human discretion in investment management. Tokic (2018) discusses the emergence of BlackRock Robo-Advisor 4.0, exemplifying the transition towards AI-driven investment solutions. By leveraging machine learning and predictive analytics, these advanced robo-advisors can continuously learn from market trends and adapt investment strategies accordingly. This iterative learning process enables them to optimize portfolio performance and capitalize on emerging opportunities in real-time, surpassing the capabilities of traditional human advisors.

Furthermore, the integration of AI in finance has implications for regulatory frameworks and access to financial services. Lee (2020) explores the regulatory challenges associated with AI adoption in the financial services industry, emphasizing the need for robust frameworks to govern AI-driven platforms effectively. As robo-advisors become increasingly prevalent, regulatory authorities must address concerns related to data privacy, algorithmic transparency, and consumer protection. By establishing clear guidelines and standards, regulators can foster innovation while safeguarding the interests of investors and maintaining market integrity. Despite the potential benefits of AI-driven investment strategies, there are lingering questions about who stands to benefit from robo-investing. D'Hondt, et al. (2020) delve into the socioeconomic implications of AI alter egos, highlighting disparities in access to robo-advisors across different demographic groups. While affluent investors may reap the rewards of AI-powered portfolio management, marginalized communities and underserved populations may face barriers to entry. Addressing these disparities requires a concerted effort to enhance financial literacy, promote inclusivity, and ensure equitable access to AI-driven investment solutions.

6 Conclusions

This exhaustive review has thoroughly explored the multifaceted realm of artificial intelligence (AI) applications within the financial sector. Through the utilization of bibliographic analysis, a substantial corpus of academic papers was scrutinized to evaluate the impact of AI on various fields of financial operations, including risk management, financial fraud detection, customer service enhancement, and investment strategy optimization. An initial exploration of the Web of Science (WoS) database yielded 17,916 articles pertaining to AI applications in finance. Subsequent refinement of the search parameters through the inclusion of additional keywords facilitated the identification of seminal articles within specific domains. These key articles, selected on the basis of citation count and abstract analysis, amounted to 17, thus providing a foundational framework for delineating the role of AI in financial contexts. The contribution of this paper to economic science is manifold. Firstly, it offers a comprehensive synthesis of the diverse applications of AI in the financial domain, thereby providing scholars, practitioners, and policymakers with a holistic understanding of AI's transformative potential. By elucidating AI's role in risk management, fraud detection, customer service enhancement, and investment strategy optimization, this review contributes to the burgeoning literature on the intersection of AI and finance. Secondly, by critically analyzing the key papers in each subfield, this review identifies emerging trends, challenges, and opportunities, thereby enriching scholarly discourse and guiding future research directions. Thirdly, this review underscores the imperative for financial institutions to embrace AI-driven technologies to enhance efficiency, mitigate risks, and foster innovation. However, this review is not without its limitations. The scope of this paper is delimited to a bibliographic analysis of existing literature, thereby precluding original empirical research. Besides that, the inherent biases and limitations of the selected papers may influence the generalizability of conclusions drawn from this review. Additionally, it's worth noting that ethical issues and the legal framework of the use of AI in finance were not addressed in this research, leaving a potential gap for future investigations.

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APPENDIX

Table A1 Relevant and most cited articles in WoS database which were used in considering the role of AI in finance

Authors	Title of the article	Journal	Study design	Methodology and sample size	Key findings and conclusions
Risk management					
Cheng, M. and Qu, Y. (2020)	Does bank FinTech reduce credit risk? Evidence from China	Pacific-Basin Finance Journal	Cross-sectional study -Econometric modelling	Regression model, 60 commercial banks from 2008 to 2017	The development of bank FinTech is faster in state-owned banks than in other banks. Among the five subareas of bank FinTech, the development of internet technology is ahead of artificial intelligence technology, blockchain technology, cloud computing technology, and big data technology.
Butaru, F., Chen, Q., Clark, B., Das, S., Lo, A. W. and Siddique, A. (2016)	Risk and risk management in the credit card industry	Journal of Banking & Finance	Panel analysis	Machine-learning techniques, credit card data from six major commercial banks from January 2009 to December 2013	substantial heterogeneity in risk factors, sensitivities, and predictability of delinquency across banks, implying that no single model applies to all six institutions. Efficacy also varies widely across institutions.
Yu, L., Li, X., Tang, L., Zhang, Z. and Kou, G. (2015)	Social credit: a comprehensive literature review	Financial Innovation	Literature review on the topic of social credit	Authors surveyed a wide range of academic articles, books, reports, and other scholarly sources	The most popular credit scoring methods include expert systems, econometric models, artificial intelligence. The most urgent task for regulatory mechanisms overseeing social credit to avoid credit fraud is the establishment of common credit databases with consistent data standards.
Barucca, P., Bardoscia, M., Caccioli, F., D'Errico, M., Visentin, G., Caldarelli, G. and Battiston, S. (2020)	Network valuation in financial systems	Mathematical Finance	Theoretical and computational study on network valuation in financial systems	Mathematical modeling. Authors used simulated networks to test their methodologies and algorithms.	Under mild assumptions about valuation functions, the valuation problem admits a greatest solution, that is a solution in which the equities of all banks are maximal. Authors provide a simple iterative algorithm to compute such solution. They show how an ex ante valuation model can be derived from a clearing model, that is from a model in which the valuation is performed at maturity.
Fraud detection					
Ashta, A., and Herrmann, H. (2021)	Artificial intelligence and fintech: An overview of opportunities and risks for banking, investments, and microfinance	Strategic Change	Case study	Reviews of media and annual reports of relevant financial organizations and business literature. Interviews with high-growth and high-value managers.	The overview shows that AI innovations analyze big data to help cut costs, reduce risk, and increase customization, leading to economic growth through an increase in aggregate demand and investments.
Sun, G., Li, T., Ai, Y. and Li, Q. (2023)	Digital finance and corporate financial fraud.	International Review of Financial Analysis	Panel analysis	Panel data of A-share listed corporations in China from 2011 to 2020	Digital finance significantly inhibits corporate financial fraud. The combination of coverage and depth is needed to improve the success of digital finance on corporate financial fraud. The heterogeneity analysis shows digital finance has a greater inhibitory effect for large-scale corporates, state-owned corporates, and corporates in areas with low degree of marketization.
Aslam, F., Hunjra, A. I., Ftiti, Z., Louhichi, W. and Shams, T. (2022)	Insurance fraud detection: Evidence from artificial intelligence and machine learning	Research in International Business and Finance	Predictive model	Boruta algorithm; Logistic regression; Support vector machine; Naïve Bayes; Publicly available car insurance dataset	Support vector machine outperforms in terms of accuracy, and the logistic regression achieves the highest f-measure score. The fault, base policy, and age of the policyholder are the most influential features

Kumar, G., Muckley, C. B., Pham, L. and Ryan, D. (2019)	Can alert models for fraud protect the elderly clients of a financial institution?	The European Journal of Finance	Logistic regression, random forest and support vector machine learning techniques	5 million accounts of clients aged 70 years and older, and over 250 million transactions extending from January 2015 to August 2016	Authors provide a new alert model for the protection of elderly clients at a financial institution, with out-of-sample predictive accuracy. Their findings show the relative influence of client traits and account activity in chosen external fraud alert models
Customer service					
Riikkinen, M., Saarijärvi, H., Sarlin, P. and Lähteenmäki, I. (2018)	Using artificial intelligence to create value in insurance	International Journal of Bank Marketing	Conceptual framework	Case examples	Chatbots represent a new type of interaction through which companies can influence customers' value creation by providing them with additional resources. Four metaphors are identified that characterize how insurance chatbots can support customers' value creation
Cîmpeanu, I. A., Dragomir, D. A. and Zota, R. D. (2023)	Banking Chatbots: How Artificial Intelligence Helps the Banks	Proceedings of the International Conference on Business Excellence	Case study, participant observation, focus group	Authors present and analyse five examples of use of chatbots	The paper identifies various benefits of AI-powered chatbots for banks, such as improving customer service responsiveness, reducing wait times, and lowering service costs. The authors discuss the challenges and limitations associated with the implementation of AI-powered chatbots
Bhattacharya, C. and Sinha, M. (2022)	The role of artificial intelligence in banking for leveraging customer experience	Australasian Accounting, Business and Finance Journal	Interviews of senior officials and head of IT team in major banks	10 interviews of senior officials	Paper reveals banking features integrated with AI. It is proved that there is a positive correlation between the two most popular use-cases. The paper proposes IT Architecture and best practices for the digital banking sector
Pham, T. M. N., Pham, T. N. T., Nguyen, H. P. T., Ly, B. T., Nguyen, T. L. and Le, H. S. (2022)	An Application of RASA Technology to Design an AI Virtual Assistant: A Case of Learning Finance and Banking Terms in Vietnamese	The Journal of Asian Finance, Economics and Business	Case study	Number of participants or users involved in the evaluation of the AI virtual assistant	The paper report the successful development and implementation of an AI virtual assistant using RASA technology to facilitate learning experiences related to finance and banking terms in Vietnamese.
Investment strategies					
Shanmuganathan, M. (2020)	Behavioural finance in an era of artificial intelligence: Longitudinal case study of robo-advisors in investment decisions.	Journal of Behavioral and Experimental Finance	Longitudinal case study	Collecting data over an extended period to observe the behavior of investors using robo-advisors	Emphasize the importance of robo-advisors in addressing behavioral biases and improving investment decision-making processes.
Bhatia, A., Chandani, A. and Chhateja, J. (2020)	Robo advisory and its potential in addressing the behavioral biases of investors—A qualitative study in Indian context	Journal of Behavioral and Experimental Finance	Qualitative study	Interviews and focus groups with investors and experts in the field	Identify specific biases commonly observed among investors and explore how robo-advisors help mitigate these biases through personalized recommendations and objective decision-making algorithms
Tokic, D. (2018)	BlackRock Robo-Advisor 4.0: When artificial intelligence replaces human discretion	Strategic Change	Case study	Analysis of industry reports	The study reveal insights into the features and capabilities of the BlackRock Robo-Advisor 4.0, highlighting how AI-driven algorithms replace human discretion in investment decision-making processes.
Lee, J. (2020)	Access to finance for artificial intelligence regulation in the financial services industry	European Business Organization Law Review	Qualitative study	Systematic review of existing literature, regulatory documents, and industry reports	The study identifies various regulatory challenges stemming from the rapid proliferation of AI in finance, including issues related to data privacy, algorithmic transparency, and consumer protection

D'Hondt, C., De Winne, R., Ghysels, E. and Raymond, S. (2020)	Artificial intelligence alter egos: Who might benefit from robo-investing?	Journal of Empirical Finance	Panel analysis	22,972 individual investors covering a sample from January 2003 to March 2012	Investors that display high risk averse and low income stand to gain significantly. Machine learning methods provide important portfolio return improvements. AI Alter Ego spreads are related to behavioral biases. During the financial crisis, robo-investors have a greater propensity to cash out of the market.

Source: Authors

Artificial Intelligence and Public Management: A Literature Review of the Prevailing Directions of Research

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ABSTRACT

Although Artificial Intelligence (AI) has been in use in management and business operations since 1980's, increased technological developments in the ICT industry, have led to an increase in the attention given to it in recent years. This also applies when it comes to its application in the public sector. The paper at hand focuses on the analysis of the main issues addressed by scholarly debates on the two-way relations between artificial intelligence and public management. A data-gathering procedure is utilized to collect the research data, which is based on the systematic literature review process. The sample publications from the Web of Science, Scopus and Google Scholar databases are used, and our search evolves around the occurrence of keywords Artificial Intelligence in Public Administration, Public Sector and/or Public Governance. A five-step review protocol is established, where we specifically focus on recently published scientific sources listed in the field Management/Public Administration, published in high-ranking journals discussing implications of AI in the public sector, general attitude towards AI in the management process, and the perception of change that AI can create in the sector. The results of the analysis are based on the finalized search process. The results of the scoping review indicate the existence of four main groups of research focus and reveal that research direction is mainly concentrated on the challenges related to AI integration and implementation in the sector, and attitudes towards AI and trust in it. There is however a lack of studies that analyse the role of AI in performing managerial functions in the sector. Thus, we argue that the relevance of AI for public management should be further analysed.

Key words: *artificial intelligence, public management, public sector, management functions, scoping literature review*

JEL classification: *D73, M15, H83*

1 Introduction

Although artificial intelligence (AI) has been used in management and business operations since the 1980s, there has been increasing attention given to it in recent years, as a result of increased technological developments in the ICT industry. The literature, originating already from the 1980s, has envisaged the role of artificial intelligence as a tool for promoting and supporting managerial planning functions, as well as enabling managers to devote more time to their core tasks, like strategizing etc. These issues have been mostly portrayed within the context of the private/for-profit sector. One of the earliest pieces of research in this domain has stressed that AI can help override the fact that strategic planning embedded itself in crisis since AI can overcome the negative attitudes by offering hardware and software systems to support strategic

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planning (Orsini, 1986). Namely, the use of machines and preprogramed logical constructs was envisaged to be used in problem solving and decision making at all organizational levels, thus enabling managers to devote more time, energy, and effort to more demanding and integrative tasks, such as strategizing. The idea set was that AI enables managers to rely on a higher degree of logic, rationality, and accuracy, and the strategic management process may be delegated top-down to the lower levels of management instead of being delegated to specialized staff or even of being outsourced (Geisler, 1986). More recently, Kolbjørnsrud et al. (2016) broadened the scope of applicability of using AI in performing managerial functions, and argue that AI should be used almost entirely for performing administrative coordination and control tasks. Managers should devote more time for (human) judgement and decision-making work, as many decisions require insight beyond what AI can squeeze from data alone, accompanied by the knowledge of organizational history and culture possessed by managers, as well as their ability of empathy and ethical reflection. This is the essence of human judgment - the application of experience and expertise to critical business decisions and practices, whereas AI assists in decision support, data-driven simulations and search and discovery activities. Moreover, managers should spend more of their effort to boost creativity and innovations in their organizations, thus working more like designers, which means also developing social skills and networks. This indicates the prevalence of the augmentation concept rather than automation concept. The augmentation concept suggests that humans collaborate closely with machines to perform tasks, leading to the superior performance, but still automation is not entirely neglected (Raisch and Krakowski, 2021).

To contextualize the framework, the recent pandemic has demanded from organizations to build agility to manage risks, improve capabilities, and amend strategies, among other. This has shifted the perspective to the increased use of technology also when conducting strategic foresight – AI thus serving as a pathway to modelling attributes, characteristics, practices, support structures, maturity levels and other aspects of future strategic change (Shafiabady et al., 2023). A question remains, how this role and relevance of artificial intelligence has been discussed in the context of management within the public sector. Following, this paper addresses the role of artificial intelligence in public management, and portrays more specifically the analysis of the main issues addressed by scholarly debates on the two-way relations between artificial intelligence and public management. A scoping literature review is conducted, in which we also search for knowledge on the governance of AI, the performance of public managers' tasks and changes in decision-making, thus contributing to the evidence on how the management science is currently involved in the research on the use of AI in organizations, specifically those in the public sector.

2 Literature review

There have been several attempts to systematically interlink artificial intelligence and its role in implementing management functions predominantly focusing on the for-profit context. For example, Keding (2021) found two main research scopes: condition-oriented research, which explores prerequisites for leveraging the use of AI in strategic management, and outcome-oriented research, which studies the consequences of AI in strategic management.

Borges et al. (2021) investigated the existing literature on the integration of AI to organizational strategy and argue that strategic use of AI has not been well explored by literature yet. Oppioli et al. (2023) provided a structured literature review on the utilisation of AI and management decisions. They argue that literature in this field is emerging, and that the focus is on using AI

as forecasting and classification for management decision-making among other, and that the evolution of publications has significantly increased only after 2018. They also argue that future research should focus on understanding the necessary skills that managers must possess to use AI systems for decision-making, and which information and data can increase the interconnections that are useful for the business process. Similarly, Varma et al. (2024) argue that the evolution of research in the management domain of AI has been active predominantly in the so-called post AI spring, as the upward trend in management research starts in the period of 2014-2015. They also identify the underdeveloped and emerging topics, among others, the analysis of business functions increasingly adopting AI practices. They also argue that the management literature is far from developing a comprehensive theory on AI in management. Similarly, some authors (see, e.g., Raisch and Krakowski, 2021) argue that there is a substantial lack of research by management scholars on the actual use of AI in organizations, and, overall, that the existing AI research lacks the ability to develop meaningful theory and to provide practice with sound advice. Moreover, this issue is further exacerbated when turning to the public sector. Although the adoption of AI has also been widely introduced in the public sector, the research on the managerial aspects of the introduction has been scarce in the public sector literature (Sousa et al., 2019). The existing research has identified several main gaps in the literature. The first gap is the so-called knowledge gap between the status of AI's current implementation in the public sector and public managers' skills and competencies that must be developed to understand the technology and the current academic debate. The second is the so-called practical knowledge gap, as public managers' professional behaviour and their administrative practices far advance what is currently been covered in the public management implementation research field. And the third gap may be labelled as the methodological gap, which results from the disconnection between existing e-government researchers and their public management counterparts. The first group publishes almost entirely in their field journals, whereas the second group has largely ignored digital transformation research until the pandemic (Mergel et al., 2023).

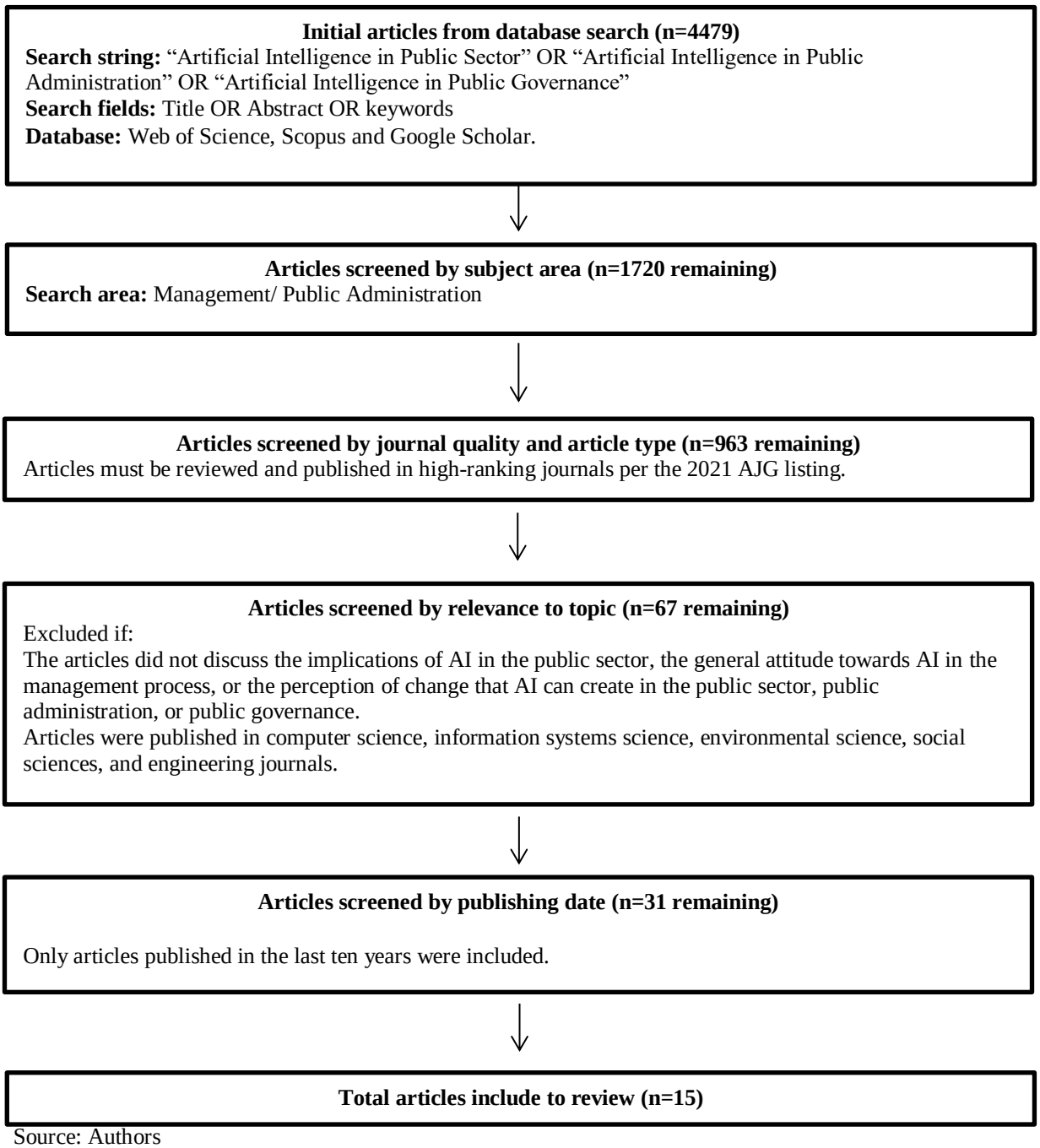
3 Methodology

For this study, we follow the logic of scoping literature review, which aims to establish a comprehensive review of published literature and identify the key variables that can predict the relationships between variables and topics (Fiaz and Qureshi, 2021). A scoping review refers to evidence synthesis with the objective to identify and map relevant evidence that meets pre-determined inclusion criteria regarding the topic, field, context, or concept under review. The review question guiding a scoping review is typically broader than that of a traditional systematic review, and its purpose is to identify gaps in knowledge and research or to investigate research conduct, thus often serving as predecessors of systematic reviews or simply as identifiers of potential research questions (Peters et al., 2021; Munn et al., 2018).

In this context, the paper thus focuses on the analysis of the main issues addressed by scholarly debates on the two-way relations between artificial intelligence and public management. A data-gathering procedure is utilized to collect the data for this research. The relevant articles were searched by using a five-step process outlined in Figure 1. First, we searched the Web of Science, Scopus and Google Scholar databases using the presented search terms. We limited our results to articles published in management and public administration areas within the last decade, thus corresponding to the period of the post AI spring. This initial search yielded 1,720 articles (screening period till January 2024). Second, articles were screened for journal quality. To ensure an inclusive sample focusing on managerial work, we included articles published in

high-ranking journals per the 2021 AJG listing. In the third and fourth step, we manually screened the titles and abstracts of the remaining articles (n = 67) to ensure that they had a tight focus on the micro-level implications of AI use in relevant management, public sector, public sector and public governance outlets, exclusion criteria. This process resulted in 31 relevant articles. After manually reading the final set of articles, we excluded half (republished articles, wrong publishing date, book chapter, etc.). We only included 15 review or conceptual-only and empirical articles to maintain our focus.

Figure 1 Flow Diagram of Search Process



Source: Authors

Furthermore, we employed a data extraction form to obtain information from the articles, encompassing their aims, theoretical frameworks, research methodologies, and conclusions. Adopting an inductive methodology, we pinpointed themes and classifications, subsequently

making deductions about the articles' inherent subjects in the showcased review (Woo et al., 2017). Rather than examining the articles through a pre-established categorization framework, the inductive method facilitated the natural emergence of themes via thorough engagement with the body of literature (Lightfoot et al., 2013). The data extraction template served as a foundation for classifying articles based on their central themes. Each article was subsequently read, with themes evolving through successive rounds of iteration and fine-tuning. However, further immersion in the articles led us to identify nuanced distinctions across the work. Some articles explicitly discussed AI adaptation and implementation in public organizations (Theme 1), while others focused on AI policy and on ethical considerations (Themes 2 and 3). Overall, the sample is comprised of four themes. Each theme and example constitutive articles are presented in Table 1.

Table 1 Key Themes on Artificial Intelligence in the Public Sector

Source	Theme	Main Results
Sienkiewicz-Małyjurek, K. (2023). Whether AI adoption challenges matter for public managers? The case of Polish cities. *Government Information Quarterly*, 101828. Madan, R. and Ashok, M. (2023). AI adoption and diffusion in public administration: A systematic literature review and future research agenda. *Government Information Quarterly*, *40*(1), 101774. Maragno, G., Tangi, L., Gastaldi, L. and Benedetti, M. (2023). Exploring the factors, affordances and constraints outlining the implementation of Artificial Intelligence in public sector organizations. *International Journal of Information Management*, *73*, 102686. Neumann, O., Guirguis, K. and Steiner, R. (2023). Exploring artificial intelligence adoption in public organizations: a comparative case study. *Public Management Review*, 1-28. Mergel, I., Dickinson, H., Stenvall, J. and Gasco, M. (2023). Implementing AI in the public sector. *Public Management Review*, 1-13.	AI Adoption and Implementation Challenges in Public Organizations	These articles collectively identify the key factors, stages, and challenges in AI adoption and implementation in public organizations. They emphasize the need for strategic approaches, the understanding of the technological and organizational interplay, and address practical challenges.
Kuziemski, M. and Misuraca, G. (2020). AI governance in the public sector: Three tales from the frontiers of automated decision-making in democratic settings. *Telecommunications policy*, *44*(6), 101976. Koskimies, E. and Kinder, T. (2022). Mutuality in AI-enabled new public service solutions. *Public Management Review*, 1-26. Mikhaylov, S. J., Esteve, M. and Campion, A. (2018). Artificial intelligence for the public sector: opportunities and challenges of cross-sector collaboration. *Philosophical transactions of the royal society a: mathematical, physical and engineering sciences*, *376*(2128), 20170357.	AI Governance and Ethical Considerations in the Public Sector	These articles explore how AI governance varies across democratic contexts, emphasizing the importance of ethical considerations, policy implications, and the need for mutuality and trust in AI-enabled public service solutions.
O'Shaughnessy, M. R., Schiff, D. S., Varshney, L. R., Rozell, C. J. and Davenport, M. A. (2023). What governs attitudes toward artificial intelligence adoption and governance? *Science and Public Policy*, *50*(2), 161-176.		These articles focus on the need for comprehensive AI policies, systematic research, understanding public attitudes, and

Wirtz, B. W., Langer, P. F. and Fenner, C. (2021). Artificial intelligence in the public sector-a research agenda. *International Journal of Public Administration*, *44*(13), 1103-1128. van Noordt, C. and Misuraca, G. (2022). Artificial intelligence for the public sector: results of landscaping the use of AI in government across the European Union. *Government Information Quarterly*, *39*(3), 101714. Zuiderwijk, A., Chen, Y. C. and Salem, F. (2021). Implications of the use of artificial intelligence in public governance: A systematic literature review and a research agenda. *Government Information Quarterly*, *38*(3), 101577.	AI Policy and Strategic Development	setting a research agenda for AI in public administration. They highlight the importance of addressing AI-related challenges, identifying key areas of AI use, and understanding public sentiment towards AI.
van Noordt, C. and Misuraca, G. (2022). Artificial intelligence for the public sector: results of landscaping the use of AI in government across the European Union. *Government Information Quarterly*, *39*(3), 101714. Wirtz, B. W., Weyerer, J. C. and Geyer, C. (2019). Artificial intelligence and the public sector—applications and challenges. *International Journal of Public Administration*, *42*(7), 596-615. Willems, J., Schmid, M. J., Vanderelst, D., Vogel, D. and Ebinger, F. (2022). AI-driven public services and the privacy paradox: do citizens really care about their privacy. *Public Management Review*, 1-19.	AI Impact Assessment and Application Challenges	These articles provide insights into the need for a comprehensive framework to assess AI's impact on public services, discuss the unique challenges and opportunities in AI integration in public services, and address the privacy paradox in AI-driven public services.

Source: Authors

4 Results and discussion

In subsequent sections, the thematic analysis of the literature review on AI in the public sector has delineated four pivotal themes, reflecting a comprehensive spectrum of research focuses within the domain. These themes were discovered by analysing empirical and theoretical articles from the last decade and providing insights into the multifaceted dimensions of AI's integration into public sector management and governance.

4.1 AI Adoption and Implementation Challenges in Public Organizations

Research over the last decade has delved into the complexities that public organizations face in adopting and implementing AI technologies. Studies have found that the path to integrating AI involves navigating through many challenges, from technological barriers to organizational resistance. The literature suggests a strong need for strategic planning that addresses the technical aspects of AI integration and considers the organizational culture and readiness (Sienkiewicz-Małyjurek, 2023; Madan and Ashok, 2023). Moreover, the significance of aligning AI initiatives with the broader goals and values of public sector organizations is emphasized, pointing to the critical balance between technology adoption and organizational ethos (Maragno et al., 2023; Neumann et al., 2023; Mergel et al., 2023). Furthermore, according to Yolvi et al. (2022) introducing AI in the public sector opens new scenarios for practitioners and researchers. Notably, nations such as China and the United States have acknowledged the

strategic importance of AI in enhancing the public sector's effectiveness and its competitive edge in the global market. Understanding and navigating this new terrain is crucial. AI's potential to transform public administration is significant. For instance, Galloway and Swiatek noted that AI can assist public relations professionals in managing public emotions while implementing new technologies, leading to smoother transitions and acceptance (Galloway and Swiatek, 2018). Furthermore, AI enables the automation of routine processes, expedites data processing, elevates service quality, and boosts productivity in public administration. Local governments are also beginning to harness AI through predictive analytics and decision support systems. These applications streamline government operations and free up valuable time for public employees, allowing them to foster stronger relationships with citizens. Given the general public's lukewarm satisfaction with digital governmental services, AI technologies like machine learning, rule-based systems, natural language processing, and speech recognition can significantly enhance citizen engagement and service delivery. These technologies have far-reaching implications for improving the internal operations of government agencies, enhancing interactions between government and citizens, and refining regulatory roles (Dwivedi et al., 2019).

A concrete illustration of AI's application in public administration is demonstrated by a study conducted by Abbasi and El Hanandeh, which focused on municipal solid waste (MSW) management in an Australian town. This study utilized advanced AI forecasting systems to compare the accuracy of different AI algorithms in predicting waste generation rates. The findings revealed that AI not only enhances decision-making capabilities but also outperforms traditional methods in planning and managing MSW (Abbasi and El Hanandeh, 2016). In another instance, Kouziokas's research on improving public transport safety and quality in Greece through AI showcases the adoption of artificial neural networks to predict high-crime areas within transport sectors. This approach uses geographic information systems for spatial analysis to pinpoint crime hotspots, employing fast-learning algorithms like the scaled conjugate gradient method to optimize neural network training. The high accuracy of these predictions supports the development of safer transport policies (Kouziokas, 2017).

Further illustrating AI's benefits, Abduljabbar et al. explored its application in addressing transportation challenges such as increasing travel demands, carbon dioxide emissions, safety concerns, and environmental impact. Their study shows that AI can effectively address complex transportation issues by leveraging extensive data on transportation system characteristics and employing AI methodologies like neural networks and genetic algorithms. Adopting AI in the management of connected and autonomous vehicles significantly enhances efficiency and safety, thereby improving overall productivity and garnering public approval for these innovations (Abduljabbar et al., 2019).

Table 2 Literature review – Reference list

Construct	Source
AI Adoption and Implementation Challenges in Public Organizations	Sienkiewicz-Małyjurek, K. (2023). Whether AI adoption challenges matter for public managers? The case of Polish cities. *Government Information Quarterly*, 101828. Madan, R. and Ashok, M. (2023). AI adoption and diffusion in public administration: A systematic literature review and future research agenda. *Government Information Quarterly*, *40*(1), 101774. Maragno, G., Tangi, L., Gastaldi, L. and Benedetti, M. (2023). Exploring the factors, affordances and constraints outlining the implementation of Artificial Intelligence in public sector organizations. *International Journal of Information Management*, *73*, 102686. Neumann, O., Guirguis, K. and Steiner, R. (2023). Exploring artificial intelligence adoption in public organizations: a comparative case study. *Public Management Review*, 1-28. Mergel, I., Dickinson, H., Stenvall, J. and Gasco, M. (2023). Implementing AI in the public sector. *Public Management Review*, 1-13.

Source: Authors

4.2 AI Governance and Ethical Considerations in the Public Sector

Exploring AI governance and its ethical implications is becoming increasingly critical in public administration. Scholars emphasize the challenges of ensuring that AI governance frameworks advance technological efficiencies, uphold democratic values and ethical standards, and protect individual privacy rights. The literature calls for a balanced approach that promotes both the efficient use of AI in public service and safeguarding citizens' rights and privacy. Critical discussions revolve around developing policies and guidelines that align AI applications with public values and legal frameworks, ensuring a symbiotic relationship between technological progress and ethical governance (Kuziemski and Misuraca, 2020; Koskimies and Kinder, 2022; Cath et al., 2018; Wirtz et al., 2019).

Moreover, the rapid advancement of AI technologies in public sectors introduces significant efficiencies in service delivery and operational processes. However, this technological gain often comes with challenges in balancing it against the critical need to protect privacy rights, calling for a robust discourse on ethical considerations in AI applications. Authors like Cath et al. (2018) advocate for AI governance frameworks incorporating strict regulatory measures to pre-emptively address privacy concerns, ensuring that AI applications respect user confidentiality and comply with data protection laws. Similarly, Wirtz et al. (2019) discuss the transformative potential of AI in public sector interactions with citizens, emphasizing the importance of transparent policies that foster trust and prevent misuse. These discussions underline the necessity of integrating ethical considerations into AI policymaking, indispensable for maintaining public trust and legal compliance in the digital governance era.

Table 3 Literature review – Reference list

Construct	Source
AI Governance and Ethical Considerations in the Public Sector	Kuziemski, M. and Misuraca, G. (2020). AI governance in the public sector: Three tales from the frontiers of automated decision-making in democratic settings. *Telecommunications policy*, *44*(6), 101976. Koskimies, E. and Kinder, T. (2022). Mutuality in AI-enabled new public service solutions. *Public Management Review*, 1-26. Mikhaylov, S. J., Esteve, M. and Campion, A. (2018). Artificial intelligence for the public sector: opportunities and challenges of cross-sector collaboration. *Philosophical transactions of the royal society a: mathematical, physical and engineering sciences*, *376*(2128), 20170357.

Source: Authors

4.3 AI Policy and Strategic Development

This theme encapsulates the scholarly efforts to outline comprehensive AI policies and strategic directions. The findings suggest an acute awareness among researchers and policymakers of the necessity for well-crafted AI policies informed by systematic research and public sentiments. Such policies are pivotal in navigating AI-related challenges and leveraging AI's potential to improve public administration. Emphasizing the importance of a research agenda for AI in public administration, the literature calls for a strategic approach that aligns AI development with public sector priorities and societal needs (O'Shaughnessy et al., 2023; Wirtz et al., 2021; van Noordt and Misuraca, 2022; Zuiderwijk et al., 2021).

Table 4 Literature review – Reference list

Construct	Source
AI Policy and Strategic Development	O'Shaughnessy, M. R., Schiff, D. S., Varshney, L. R., Rozell, C. J., and Davenport, M. A. (2023). What governs attitudes toward artificial intelligence adoption and governance? *Science and Public Policy*, *50*(2), 161-176. Wirtz, B. W., Langer, P. F. and Fenner, C. (2021). Artificial intelligence in the public sector-a research agenda. *International Journal of Public Administration*, *44*(13), 1103-1128. van Noordt, C. and Misuraca, G. (2022). Artificial intelligence for the public sector: results of landscaping the use of AI in government across the European Union. *Government Information Quarterly*, *39*(3), 101714. Zuiderwijk, A., Chen, Y. C. and Salem, F. (2021). Implications of the use of artificial intelligence in public governance: A systematic literature review and a research agenda. *Government Information Quarterly*, *38*(3), 101577.

Source: Authors

4.4 AI Impact Assessment and Application Challenges

The necessity for frameworks to assess the impact of AI in public services and the challenges related to its application emerges as a critical area of focus. The literature provides insights into the need for comprehensive evaluations of AI's impact, addressing both the unique challenges and opportunities presented by AI integration in public services. This includes tackling the privacy paradox in AI-driven public services, where the potential conflict between leveraging

AI benefits and protecting individual privacy rights is examined (van Noordt and Misuraca, 2022; Wirtz et al., 2019; Willems et al., 2022).

Table 6 Literature review – Reference list

Construct	Source
AI Impact Assessment and Application Challenges	van Noordt, C. and Misuraca, G. (2022). Artificial intelligence for the public sector: results of landscaping the use of AI in government across the European Union. *Government Information Quarterly*, *39*(3), 101714. Wirtz, B. W., Weyerer, J. C. and Geyer, C. (2019). Artificial intelligence and the public sector—applications and challenges. *International Journal of Public Administration*, *42*(7), 596-615. Willems, J., Schmid, M. J., Vanderelst, D., Vogel, D. and Ebinger, F. (2022). AI-driven public services and the privacy paradox: do citizens really care about their privacy? *Public Management Review*, 1-19.

Source: Authors

4.5 AI and Public Management Research: Now and Next to Follow

Initially known as a ground-breaking tool, AI has matured into an integral public management and governance element. This progression from novelty to necessity encapsulates a journey of adaptation, learning, and ethical integration, blending technological advancement with core human principles. Integrating these insights, the results revealed a landscape where the integration of AI in the public sector is not just about technological adoption but also about navigating the complex interplay between innovation, human judgment, and ethical governance. The evolution from viewing AI as a tool for automation to recognizing its role in augmenting human capabilities reflects a deeper understanding of AI's potential to contribute to public management. This shift underscores the need for a balanced approach that harnesses AI's analytical strengths while preserving the irreplaceable value of human intuition, creativity, and ethical oversight.

Ultimately, the successful integration of AI into public sector management requires addressing both the opportunities and challenges identified in the thematic analysis, informed by the historical and contemporary insights from the introduction. This entails developing strategies that leverage AI's capabilities for enhancing efficiency and decision-making and ensuring that AI deployment is aligned with ethical standards and public values and the goal of augmenting rather than replacing human expertise. Moreover, the decision to focus on literature for at most ten years is predicated on the rapidly evolving nature of AI technology and its applications. This temporal limitation ensures that the insights and findings are relevant to current technological capabilities, societal expectations, and regulatory frameworks. It also aligns to capture the most recent scholarly discussions and empirical findings, which are pivotal in informing contemporary policy decisions and strategic directions. For instance, Smith and Doe (2023) highlight the significance of staying abreast with technological advancements to grasp the full spectrum of AI's potential and limitations within the current societal and regulatory context. Similarly et al., (2024) underscore the importance of recent research in shedding light on the latest trends and challenges in the technology field, thereby informing policy and strategic directions with up-to-date evidence. These perspectives reinforce the value of focusing on the current literature to ensure that academic and practical engagements with AI technology are relevant and informed (Smith and Doe, 2023; Johnson and Young, 2024). Moreover, the past decade has also seen the alignment of AI development with the United Nations Sustainable

Development Goals (SDGs). This alignment has directed recent AI research towards addressing global health, environment, and governance challenges, among others, making recent literature more relevant to contemporary policy objectives (Vinuesa et al., 2020). Hence, what is interesting, there is obviously a lack of studies that analyse the role of artificial intelligence in performing managerial functions in the public sector. We might label this gap as management functions gap. Although this gap might exist also in the generic management literature, further research is highly warranted within the domain of public sector management. Namely, there are differences between the private and public sector, which are derived mainly from the use of public authority by the public sector, inability of the public sector to act arbitrary, difficulties in managing and measuring performance as the public sector intends primarily to create public value, and political and organisational constraints and complexities, which are far more present within the public sector (Hughes, 1994; Moore, 1995). As Boyne (2002) argued very conservatively, public management is characterized by more bureaucracy, a stronger desire to promote public welfare, and lower organizational commitment in comparison to private management, but there are also differences related to decision making processes and styles of strategic management, among others. Alford and Greve (2017) pictured this in a way that the alignment for public managers is not so much about finding the perfect or optimal solutions, but rather to make clear and to understand what the trade-offs are in certain decisions and approaches, which presumes differences in performing managerial functions and necessity to understand different contexts of operations. However, often the mainstream research literature assumes that public-private differences are absent or minimal when compared to different organizational characteristics, not just on the often ideologically based claims of in-built inefficiency, existence of rent-seeking etc. (Rainey, 2009; Meier and O'Toole, 2011). Thus, differences between sectors exists, and this increases the importance of sector-specific research endeavours in management science, to avoid possible generalizations, which, as noted, often exist in generic management literature.

What can we elaborate on the other possible future research directions? Although we argue for more research to be conducted on the effect of AI on performing management functions in the public sector, we also acknowledge some other prepositions. For instance, if we follow the idea of Noponen (2019), there might be a difference in how AI will affect management at different levels. According to his evidence, AI may augment highest level senior managers more than operative and middle managers, whose tasks could be more prone for automation. In addition, he argues for the address of two perspectives of AI's impact, either a revolutionary or an evolutionary one. The first one transforms the tasks, the second one complements the tasks, and in this context the skills for performing such tasks should become more important. In this context, routine administrative tasks might be automated, but leadership tasks not. Next, it might be of relevance, in particular, given the specificities of the public sector, to research the possibilities of using AI in performance management and measurement, in particular as the sector and its organisations tend to be large with access to large amounts of data and need to make sense of the available data (Varma et al., 2024).

5 Conclusion

The research explored the discourse on AI's role and relevance within public sector management, revealing four critical themes: adoption and implementation challenges, governance and ethical considerations, policy and strategic development, and impact assessment and application challenges. These findings underscore the complexity of integrating AI into public management, highlighting the need for strategic, ethical, and policy-oriented

approaches to harness AI's potential while addressing implementation challenges and ethical concerns. It is essential to consider how AI can enhance managerial functions such as decision-making, resource allocation, and service delivery within the public sector, tailoring AI applications to meet the unique needs and objectives of public organizations.

One notable limitation is that the study relies on secondary literature, which may not fully capture the rapidly evolving field of AI. Additionally, there is a lack of empirical studies on AI's practical applications in the public sector, particularly in enhancing the distinct managerial functions in public sector. Therefore, future research should focus on longitudinal studies to understand AI's long-term impact on public management, empirical studies on AI's effectiveness in different public sector contexts, and the development of ethical frameworks to guide AI integration in public services. Investigating the specific ways in which AI can support public sector managerial functions will provide valuable insights into optimizing AI use for public good. To conclude, this study contributes to the understanding of AI's multifaceted role in public management and sets the stage for further exploration of its strategic, ethical, and practical implications.

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Cleantech Crowdfunding

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ABSTRACT

Cleantech is not a new term, but it is becoming increasingly important after the release of the European Union's (EU) Cleantech Investment Plan. The EU is investing heavily in cleantech in an attempt to decarbonize the European Union and to become more competitive than USA and Asia. However, traditional financing options cannot address such intensive capital requirements. It is estimated that there is an investment gap of around 50 billion euros for the development of some cleantech technologies. In addition, EU funding sources for innovation are at risk due to EU budget cuts. Hence, one of the alternative funding sources for cleantech is crowdfunding. This study seeks to explore whether cleantech crowdfunding has the potential to contribute to achieving the net zero agenda and to complement existing funding sources. The study examines EU equity crowdfunding platforms that support cleantech projects and identifies the factors that contribute to the success of the crowdfunding project. The results of the regression show that the number of investors, the promised IRR and the investment horizon are statistically significant for a project's success. More transparency and a global focus of the campaigns could help attract more investors and support the EU's cleantech agenda.

Keywords**:** *crowdfunding, cleantech, green finance*

JEL code**:** Q42, Q5

1 Introduction

Climate change poses a global concern. People around the world are trying to help the planet through various initiatives. There are some important dates on the timeline of global climate change. The adoption of the Kyoto Protocol (UNCCC) in 1997 can be marked as the first milestone in the fight against climate change (Olgic Drazenovic et al., 2023). The year 2015 can be described as the second milestone. That year, the member states of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement. This agreement set targets for greenhouse gas (GHG) emissions and limited the rise in temperature with the aim of achieving net zero emissions in the second half of this century. Moreover, the year 2015 is of fundamental importance for climate change initiatives, as the United Nations adopted the 2030 Agenda for Sustainable Development (SDG) in that same year. This agenda

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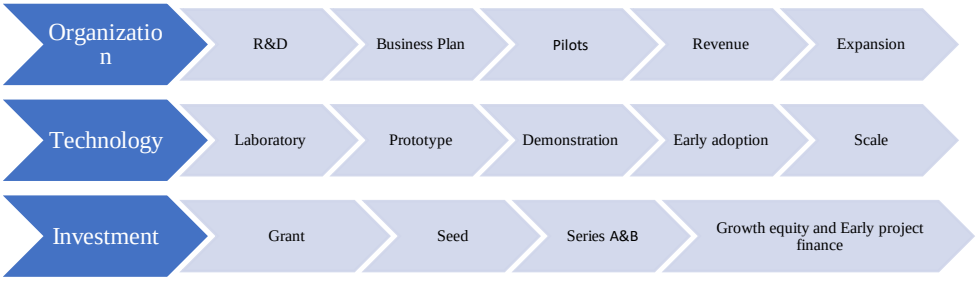
also addresses climate change. In addition, clean technologies (cleantech) are recognized as technologies that will play a pivotal role in achieving net zero emissions, in limiting temperature rise and in achieving the SDG targets (Xiang, 2022). Turning our attention to the European Union (EU), the next milestone is reached at the end of October 2023. This is when the European Union published its first report on investing in cleantech, revealing that cleantech is now a major priority in the EU (Mettler et al., 2023). But what is considered as cleantech? Cleantech refers to new business models and technologies that can help investors achieve higher financial returns while enabling positive external effects in terms of a cleaner environment. A wide range of products, services and processes can be considered cleantech. Clean technologies can significantly reduce or even eliminate the negative environmental impacts that some other technologies may have and can therefore make an important contribution to the net zero target. In addition, cleantech technologies improve the responsible use of natural resources. For example, advanced mining technologies can minimize environmental degradation (Opere, 2023). High dependence on natural resources degrades environmental quality, but clean energy and technological innovation help countries create a cleaner natural environment by reducing carbon emissions (Liu et al., 2023). Sectors covered by new clean technologies include agriculture, energy and power, materials and chemicals, transportation and logistics, resources and environment, and in recent years, artificial intelligence (AI) has been gaining momentum as a key technology (Cleantechforeurope; Cumming et al., 2017). Cumming et al. (2017) identify four main sectors: energy, transportation, water and minerals.

Cleantech projects can play a decisive role in achieving net zero emissions. Green investments are still considered risky and not very profitable. There are various public and private actors offering green financing (Babic, 2024). In the initial R&D phases of technology development, funding is provided by public research institutes or private companies in the form of grants. In the early phase of technology commercialization, private investors such as business angels or venture capitalists enter the scene. Another option in the seed-up phase is crowdfunding, a relatively new form of financing. In the later phases, banks, private equity and the entrepreneurs' own funds are used as financing instruments. Institutional investors finance complementary assets such as infrastructure (Polzin, 2017). The life cycle of cleantech innovations is illustrated in Figure 1. As we can see, there are several phases in the development of clean technologies, which are time-consuming. It usually takes many years before a clean technology can be introduced and used. It usually takes between 5 to 20 years from laboratory to series production. The long development process does not suit venture capitalists. Namely, they are not interested in investing in clean technologies as they require a different timeframe for projects (Cleantechforeurope). Therefore, developers of such technologies usually turn to alternative financing models, such as crowdfunding (Otte and Maehle, 2022). Furthermore, policy makers can play a crucial role in the development of cleantech. They can phase out old technologies and create demand for new clean technologies (Cleantechforeurope; Polzin, 2017).

Figure 1 Growth of cleantech innovation



Source: Compiled and adapted from https://www.cleantechforeurope.com/explainers/what-is-cleantech

2 Crowdfunding as an alternative financing tool

Crowdfunding is an alternative way of raising funds to finance companies or projects via online platforms. The money is raised from a "crowd" which is optimistic about new business ideas (European Commission). Many individuals make small contributions and finance entrepreneurs, start-ups and small and medium-sized enterprises. Even large and established companies use crowdfunding to test their new ideas (Pope, 2023). The platforms usually finance new business ideas according to the "all-or-nothing" principle. If the target amount is reached within a certain period of time, a project is funded. If the target amount is not reached, the "crowd" gets its investment back (European Commission). Crowdfunding comes in various forms (Table 1): equity crowdfunding, reward-based, donation-based, peer-to-peer lending, debt-securities crowdfunding, profit-sharing, and hybrid models (European Commission). Depending on the type of crowdfunding method, the "crowd" that invests in new ideas can be described differently. If the platform is based on donations, the "crowd" is referred to as donors. For platforms based on rewards, we speak of backers. If, on the other hand, the platform offers a stake in the company, the "crowd" is referred to as investors. In this paper, the "crowd" is referred to as investors according to all platform types.

Table 1 Types of crowdfunding

Crowdfunding method	Description
Equity	Investors receive an ownership stake in a company
Reward-based	Investors receive a non-financial reward
Donation-based	Investors make charitable contributions and do not expect to receive any financial or non-financial reward
Peer-to-peer lending	Investors lend money and receive interest in return. Repayment can be in the form of bullet repayment, French or Italian style amortization, multibullet, amortization with balloon or dynamic repayment
Debt-securities	Investors invest in different debt instruments issued by the venture. Debt instruments can be a simple bond, minibonds or convertible bonds
Profit-sharing	Investors will have a stake in the future profits of a company
Hybrid	A venture that combines elements of a few other crowdfunding methods

Source: Adapted from: https://single-market-economy.ec.europa.eu/access-finance/guide-crowdfunding/what-crowdfunding/crowdfunding-explained_en; https://www.lumo-france.com/vos-questions-nos-reponses/faq; https://helpdesk.evenfi.com/en/article/types-of-loan-repayment-1wg6wsx/

Crowdfunding as an alternative financing instrument is not equally developed worldwide. According to Statista's latest report (2024), the top 5 countries in the world by value of crowdfunding transactions are the United States, Japan, South Korea, the United Kingdom and Germany. As we can see, only one country in the European Union is among the countries with the highest value of transactions. So there is still room for improvement and development of this type of financing. In addition, the EU is trying to achieve a net-zero emissions target and is making the development of clean technologies its priority. Due to scarce traditional financing options for new technologies, crowdfunding can become a recognized financing instrument. Policy measures can help to increase the demand for new clean technologies and raise awareness of crowdfunding in the EU. As we can see from Table 1, there are different crowdfunding methods. If we look at the cleantech campaigns, we can see that in most cases the projects offer debt or equity. In this study, we focus on equity crowdfunding and examine what the different platforms offer potential investors. In equity crowdfunding, investors receive shares as a stake in the capital of a company. In crowdfunding, the shares are usually not listed on a stock exchange and investors cannot trade them on organised stock exchanges. Depending

on the crowdfunding platform, there are secondary markets for equity crowdfunding shares. Unlisted shares are issued as part of the fundraising round and are usually distributed to business angels and investment funds. Nowadays, individual investors can also invest in new business ideas via crowdfunding platforms and receive unlisted shares in return (LitaCo). Crowdfunding platforms such as Lumo Investments limit investors' investments in projects based on their place of residence. If the project has been designated by the French Energy Regulatory Commission (la Comission de Regulation de l'Energie – CRE), investors must be resident in that region or in neighbouring regions (Enerfip). For the communication and management of investors, companies participating in equity crowdfunding may set up an intermediary company established via the platform. Each capital increase is subscribed by this intermediary (Lumo2). This intermediary company is known as a special purpose vehicle (SPV). Investors can exit the investment by acquiring the start-up through another company or an investment fund or when the start-up eventually grows enough and makes an Initial Public Offering (IPO) and is listed on a stock exchange. Investors receive capital gains and/or dividends and, depending on the platform, the investors' residences and the selected projects, these are taxed or tax-advantaged (Doorway1). Crowdfunding campaigns require a minimum investment amount. If they do not succeed, they can be cancelled. In this case, the funds paid in are refunded to the investors. Campaigns can be successfully funded or even overfunded. If the company opts for overfunding, it accepts more investment and releases more equity in return (Crowdcube).

This study attempts to determine the state of cleantech crowdfunding in the European Union. The motivation for this study stems from the fact that cleantech has come into focus following the release of the Cleantech Investment Plan. However, the demand for funding needed to develop new and innovative clean technologies is enormous and there are various public and private sources available at different stages of technology development. Due to the longevity of the cleantech technology development process, not all funding options are readily available. Therefore, the potential of an alternative source of funding – namely equity crowdfunding - will be investigated. In order to assess the current state and potential of cleantech financing via equity crowdfunding platforms in the EU, this study focuses on understanding and interpreting data from various equity crowdfunding platforms. The study examines successfully funded cleantech projects and their characteristics and compares the results between crowdfunding platforms in the EU. The results suggest that cleantech crowdfunding practices can still be improved in order for the European Union to meet its greenhouse gas emission reduction targets. This study is structured as follows: The second part reviews the current literature and its findings in relation to the state and success of sustainable crowdfunding campaigns; the third part presents the research construct and its findings; and the fourth part provides concluding remarks.

3 Literature review

Various aspects of crowdfunding have been researched in recent years. Most of this research relates to the factors that lead to a successful crowdfunding campaign. However, the topic of sustainability and its interplay with crowdfunding is becoming increasingly important. Hornuf and Siemroth (2023) examine the success of crowdfunding campaigns via newsletters and the environmental and financial framing according to investors' age and gender. The results show that crowdfunders respond to environmental framing. When age is taken into account, older crowdfunders respond to financial framing. When gender is taken into account, female investors respond more to a financial framing than men. Sustainability in social media coverage of crowdfunding is the focus of Laurell et al. (2019). The results show that crowdfunding

content on social media contains a negligible number of posts on sustainability. The main promoters of sustainability in crowdfunding campaigns are professional actors. Bento et al. (2019b) find that a sustainable mission of the campaign has a positive impact on its outcome. Berns et al. (2022) attempt to understand the success factors in sustainability-oriented projects and examine the campaigns of 3D printers. The findings suggest that entrepreneurs should be aware of institutional trends on specific crowdfunding platforms and look for the one that best fits their project type and funding needs. Visuals offered by the campaign and the timeline are the factors that contribute to the amount and percentage raised, rather than the success of the campaign. Dabbous et al. (2024) examine how crowdfunding, eco-innovations and digitalization contribute to the sustainability of countries. The results show that high levels of digitalization, crowdfunding and financial development contribute to a country's sustainable competitiveness. Kim and Hall (2021) examine crowdfunding in the context of the SDGs. Crowdfunders beliefs are important for understanding their participation behaviour and evaluation of SDG crowdfunding projects. Individuals' feelings about sustainability are critical to their investment decisions in SDG crowdfunding. Not only crowdfunding projects were examined. Crowdfunding platforms were also examined and their relationship to sustainability, environmental, social and governance characteristics. Crowdfunding platforms with higher ESG criteria have a higher survival rate (Cumming et al., 2024). In addition, there is a growing body of evidence for crowdfunding projects in the renewable energy and cleantech sectors (Alsgar et al., 2023; Bento et al., 2019a; Bergman et al., 2021; Mollick, 2014; Bürer and Wüstenhagen 2009; Cumming et al., 2017; De Crescenzo et al., 2020; Guillochon, 2022; Otte and Maehle, 2022; Pabst et al., 2021).

Cumming et al. (2017) find that cleantech crowdfunding is specific to countries with certain characteristics, such as countries with low individualism. When the market shows a rising trend in oil prices, crowdfunding for new alternative energy technologies increases accordingly. Bento et al. (2019a) examine the risk and return profiles of crowdfunding. Based on a sample of 365 European cleantech crowdfunding projects, they find that project returns are negatively associated with risks. A mispricing occurs when country risks are taken into account. Bento et al. (2019a) offer behavioural characteristics of investors, such as bounded rationality and their cultural dimension, as possible explanations. Projects that offer better risk-adjusted returns are those that attract higher investor contributions (Bento et al., 2019a). Country risk has been shown to be important in crowdfunding campaigns in general, not just in those related to cleantech. Alsgar et al. (2023) examine geopolitical risks associated with campaigns in developing markets. They examine reward-based crowdfunding and find that geopolitical risks are negatively related to crowdfunding success. In the presence of geopolitical risks, backers are not confident that they will receive the rewards associated with the project.

Otte and Maehle (2022) study the interaction of factors that contribute to the success of cleantech crowdfunding campaigns. Communication with backers is very important for sustainable campaigns. A combination of frequent project updates with an emotional appeal and a short campaign duration guarantees a fully funded crowdfunding campaign. Project updates are important as they serve as a signal of the quality of the project. Investors often perceive these types of projects as riskier, and frequent and meaningful new information can ease the uncertainty. Founders try to create a sense of increased well-being. The enhanced emotional appeal of the crowdfunding campaign will lead to positive emotions related to the project and can contribute to the success of the campaign. The campaign needs to be shorter to be successful. Unsuccessful campaigns usually last between 33 and 60 days (Otte and Maehle, 2022). Communication with investors can be seen through video pitches, which prove to be value-enhancing in blockchain crowdfunding (Kolbe et al., 2022). Using a sample of French

crowdfunding campaigns for renewable energy, Guillochon (2022) explores the influence of media coverage and geographical restrictions on the number of campaign participants. It was proven that the more media coverage a campaign receives, the more investors it attracts. It is important that founders use a mix of traditional and social media coverage and not focus on just one source. It would be better if campaigns were not geographically limited as they would last longer and attract fewer investors (Guillochon, 2022). Bergman et al. (2021) present findings of a survey concerning public perception regarding European crowdfunding for renewable energy projects. Surprisingly, 86.2% of respondents know something about crowdfunding and almost 50% have already invested via online platforms. A similar percentage of respondents have invested specifically in renewable energy projects. European investors invest an average of around EUR 2,500 and plan to continue investing in the coming years. Consequently, neither their knowledge nor their investments are negligible. Among the characteristics of renewable energy projects considered important by respondents are transparency and sustainable impact. Although the preferred crowdfunding method for renewable energy projects by the founders is debt financing, respondents indicated a preference for equity crowdfunding campaigns (Bergman et al., 2021). Crowdfunding is proving to be an attractive way to finance sustainable entrepreneurship. However, investors can often find a few similar sustainability projects at the same time. Such a situation poses a potential problem for achieving the financing target. Pabst et al. (2021) explore how third-party seals can help in allocating investors' contributions to different sustainability crowdfunding projects. Third-party seals serve as quality assurance and may be regional framed or may represent the European Union. The results show that projects with seals receive more contributions than projects that do not have a seal attached. It has also been shown that regional seals attract more trust and more contributions than EU seals (Pabst et al., 2021). De Crescenzo et al. (2020) explore success factors in UK equity crowdfunding campaigns. They chose to explore this method of crowdfunding since there is less research connected to it. Using a sample of 344 projects, they found that startups with a large number of founders are successful in raising the target amounts. Furthermore, a successful campaign contains many images that additionally describe the project. Failed projects were those that were not related to cleantech startups, had no female founders and contained fewer images.

Previous research regarding renewable and cleantech technologies stresses the importance of several factors in the success of crowdfunding, such as media coverage, team structure and regionality. The next section provides further insights into the state and success of EU crowdfunding for new and existing energy projects. It shows which factors are relevant for the funding success of a campaign.

4 Methodology

This research is based on a review of the existing literature on crowdfunding practices employed in the domain of renewable energy and cleantech projects. Hiebl (2023) presents three basic uses of literature reviews in qualitative accounting research, with a literature review covering a certain domain being one of them. We thus conduct a domain research on crowdfunding practices. This research acts as an exploratory study that seeks to identify current trends in clean crowdfunding practices. Likewise, by synthesizing existing findings, we seek to gain a deeper understanding of the factors that help cleantech campaigns to be successful. To strengthen the robustness of our findings, we collected publicly available data from several European crowdfunding platforms offering equity financing for new and existing clean technologies. Using an OLS regression analysis, we try to determine the factors relevant for the success of the projects.

4.1 Data and sample description

This paper investigates cleantech crowdfunding projects in the European Union. Although crowdfunding has boomed in the United States and the United Kingdom in recent years, this study examines the state of cleantech crowdfunding in the European Union, where such investments have been a recent priority. The study seeks to identify what project characteristics make clean equity crowdfunding successful. As Bergman et al. (2021) find that investors prefer equity crowdfunding for renewable energy projects and De Crescenzo et al. (2020) show that equity crowdfunding is still under-researched, we focus on cleantech and renewable energy campaigns on European equity crowdfunding platforms. Since the platforms usually combine cleantech projects with renewable energies, our sample is also structured in this way. It consists of projects that promote the development of new clean technologies and new installations of existing clean technologies. The study sample consists of data that were hand-collected from five European crowdfunding platforms offering equity financing options. The platforms we considered include WeAreStarting, Lita.Co, Lumo, Doorway and Enerfip. WeAreStarting is an equity crowdfunding platform based in Italy. Lita.Co is operated from France, Italy and Belgium and offers loan and equity crowdfunding options for impact projects. Lumo is a French lending and equity crowdfunding platform focused on projects that accelerate positive impact (Lumo3). Doorway is an Italian equity crowdfunding platform led by experienced investors and venture capitalists (Doorway2). Enerfip is a French equity and debt crowdfunding platform focused on renewable energy projects (Enerfip2). Several other EU crowdfunding platforms support cleantech innovations. However, most of them only display the project data for accredited investors and/or the cleantech projects are described in languages other than English. Therefore, we have not included them in our sample. The total number of projects that fit into the platform classification of cleantech and energy projects offering equity to investors is 72. Out of these 72, 10 projects were analysed from the WeAreStarting platform, 6 successfully funded cleantech projects from Lita.Co and 6 projects were considered from the Lumo platform. Doorway has only 3 cleantech projects while data from the crowdfunding platform Enerfip was taken into account for 47 projects from the equity sector. The project data from these five platforms was collected manually. The data collected represents factors identified in previous research as relevant to the success of the crowdfunding campaign. In particular, the information collected includes the target amount of the campaign, the amount raised by the campaign, the number of investors who supported the campaign, the minimum investment amount, the total number and composition of the founding team, the expected internal rate of return of a campaign and the duration of the project. Data availability varies from platform to platform and there are missing values for each variable. We treated the missing values and assumed the mean values as missing observations. The date and duration of the equity crowdfunding campaign were not publicly available and therefore could not be included in the study. Limited date information was only available on two platforms.

4.2 Empirical findings

Publicly available data were hand-collected from the five crowdfunding platforms (WeAreStarting, Lita.Co, Lumo, Doorway, and Enerfip. WeAreStarting). Summarised statistics on the study sample can be found in Table 2.

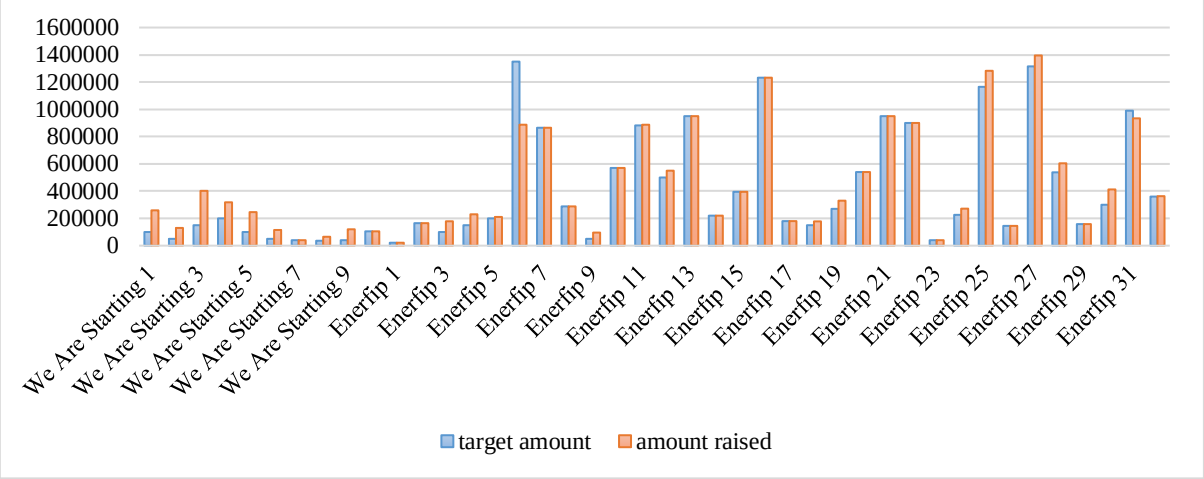
Table 2 Summary statistic

Variable	Obs.	Mean	Std. Dev.	Min	Max
Target amount	60	413557.60	404514.80	21500	1665841
Amount raised	69	371590.40	374950.40	350	1665840
Investors	63	131.75	143.44	2	633
Minimum inv.	57	97.37	221.77	10	1000
No. of team members	20	4.15	2.74	1	11
No. of females	20	0.60	1.10	0	4
Expected IRR	53	5.16	.80	4.50	10
Investment horizon (years)	53	4.59	3.60	3.50	30

Source: Author's calculations

The publicly available data varies depending on the platform in question. For each of the 72 clean equity crowdfunding projects, the target amount that the campaign aimed to gather from the crowd is observed. The amount raised represents the actual amount collected in the campaign and may signal that the project is not fully funded, that it has reached the target amount or is even overfunded. We see that the amount needed to support a clean project can vary significantly, from EUR 21,500 to EUR 1,665,841. The amounts raised vary even more. This study attempts to explore more in-depth how the target and amount collected vary between our five sample platforms. Figure 2 displays the results for the WeAreStarting and Enerfip platforms. As you can see, the target amount differs considerably depending on the platform. Entrepreneurs on the WeAreStarting platform try to raise much lower amounts for their projects than entrepreneurs on the Enerfip platform. Projects on the WeAreStarting platform are overfunded in most cases, whereas projects on Enerfip are only overfunded in a few cases. Since the entrepreneurs on Enerfip are trying to collect significantly higher amounts of capital, these results are not very surprising.

Figure 2 Comparison of target and actual amount of capital raised on the two platforms

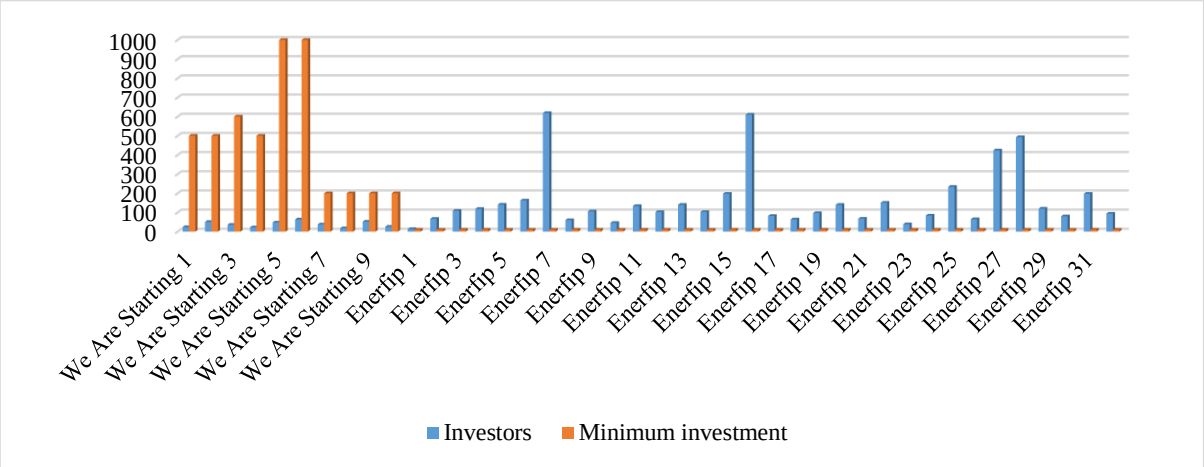


Source: https://www.wearestarting.it/invest-equity, https://fr.enerfip.eu/placer-son-argent/

The same type of clean projects can be fully funded in one region and reach the maximum amounts, or they can be funded in other regions without reaching the ceiling amounts (e.g. ground-mounted photovoltaics). The reason behind these findings could be that projects that reached the ceiling amount were targeted to collect lower amounts of capital than projects that were funded but did not reach the ceiling amount. The projects that reached the ceiling amount were generally those that had a funding target of less than €200,000. Among the projects that attempted to collect more than €800,000, the projects that were successfully funded and reached

the ceiling amount had many comments and answers from the founders to investors' queries. Projects which had lower target amounts also had a lower number of comments from investors, 2 on average. Not all sample platforms provide insight into news and updates on projects, which can be a drawback, as documented in previous research. The projects in Figure 2 are displayed in descending order by campaign closing date. Before 2022, the companies aimed to collect higher amounts (more than EUR 500,000) and were giving a higher stake in the company. Due to the geopolitical situation and the associated higher country risk, the target amounts have been reduced in the last two years, but the success of the campaigns has not been jeopardized. Geopolitical risk only poses a threat of failure in developing markets, and all our sample platforms are founded in developed countries. Nowadays, more projects reach the funding objective. The only project that has not been fully funded is the one aiming for more than EUR 1,000,000. In the last two years, the number of investment opportunities offering equity participation to investors has increased significantly compared to the period a few years ago.

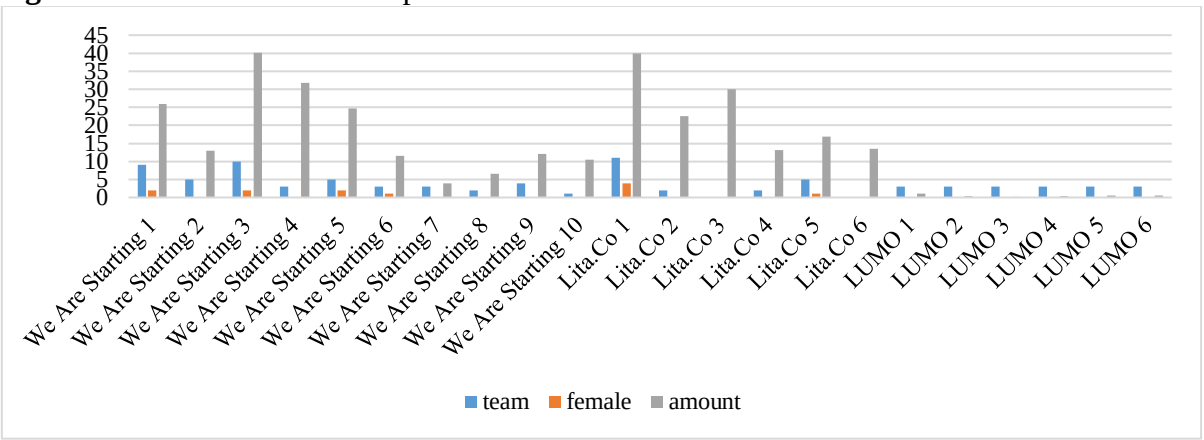
Figure 3 Number of investors about minimum investment amount



Source: https://www.wearestarting.it/invest-equity, https://fr.enerfip.eu/placer-son-argent/

Different platforms have different policies regarding the minimum investment amount. As can be seen from Table 2, this amount varies between 10 and 1,000 euros while the number of investors goes from 2 to 633. Figure 3 shows that projects with a higher minimum investment amount have fewer investors than projects that require a lower minimum investment.

Figure 4 Team structure and capital raised



Source: https://www.wearestarting.it/invest-equity, https://www.lumo-france.com/projets-finances
https://be.lita.co/en/projects?aasm_state=succeeded&locale=en

Another important determinant of project success is the size of the team and its composition. De Crescenzo et al. (2020) find that larger teams with female members have a higher success rate. Figure 4 shows the amount of capital raised by various cleantech projects and the team structure. Again, there is no full transparency regarding team members on all sample platforms. The findings show that teams with more members and a female presence were able to raise higher amounts. The first objective of this study is to determine whether there is a correlation between the collected variables (target amount, amount raised, number of investors, minimum investment amount, team size, number of females in the team, IRR, investment horizon) which can be indicators of a successful crowdfunding campaign. All platforms offer different publicly available information and there are missing values for each of the variables. The correlation results are displayed in Table 3. As it can be seen, there is a high correlation between the target amount and the amount raised by the project. There is also a high correlation between the number of investors and the target amount as well as the amount raised. There is a negative correlation between the minimum investment amount and the number of investors as well as between the target amount and the amount collected by the campaign.

Table 3 Correlation matrix

	Target amount	Amount raised	NumInv	MinInv	Team	Female	IRR	Inv. horizon
Target amount	1.0000							
Amount raised	0.91***	1.0000						
NumInv	0.65***	0.72***	1.0000					
MinInv	-0.3***	-0.21*	-0.26***	1.00				
Team	-0.0789	0.73***	0.2201	0.2501	1.000			
Female	-0.0521	0.75***	0.3786	0.3537	0.9***	1.000		
IRR	-0.0440	-0.0424	0.1361	-0.012	0.2820	0.3679	1.000	
Investment horizon	-0.0794	-0.0651	0.0810	0.0567	-0.282	-0.3679	-0.045	1.0000

Note: *, **, *** denotes statistical significance at 10%, 5%, and 1% levels, respectively
Source: Author's calculations

Next, an OLS regression analysis is performed. Project success, as measured by the amount of funds raised by the campaign, is tested against expected internal rate of return, the number of investors, the minimum investment required for the project and the project duration using the following regression (1):

$$Amount\ raised_i = \alpha_i + \beta_1 IRR_i + \beta_2 MinInv_i + \beta_3 NumInv_i + \beta_4 Investment\ horizon_{\ i} + \mu_i \quad (1)$$

Where IRR is the expected internal rate of return of a project i; MinInv is the minimum amount that backers can pay to support the project; NumInv is the number of investors who have backed project i; and the investment horizon is the life expectancy of project i. The regression equation includes factors that were identified in previous research as the factors that can lead to the success of a campaign. Due to the limited amount of publicly available information on the sample platforms, the regression model does not include all factors identified by previous research as relevant to the success of a campaign. Moreover, the target amount is not considered due to the high correlation with the amount raised. α stands for the intercept, β are coefficients and μ is the error term. The model is estimated using ordinary least squares regression with robust standard errors. The regression output is displayed in Table 4.

The model is statistically significant, and it explains 55.81% of the variance. The number of investors increases the amount collected by the campaign. Perhaps the results would be even

better if some projects were not geographically restricted. A longer investment horizon and a higher promised return reduce the amount of funding. These results could be due to the nature of cleantech projects. They are very risky and investors feel more comfortable if the investment horizon is shorter. They do not want to keep their uncertain position for longer periods of time.

Table 4 Regression output

Model	
Variable	*Amount raised*
IRR	-80775.16** (36542.08)
MinInv	-19.09915 (94.99892)
NumInv	2052.709*** (316.3996)
Investment horizon	-15708.5*** (3195.102)
Const_	591785.7*** (201232.6)
Number of observations	72
F (4, 67)	12.24***
R-squared	0.5581

Note: *, **, *** denote statistical significance at the 10%, 5%, and 1% level respectively. Robust standard errors are presented in the parenthesis
Source: Author's calculation

5 Discussion and conclusion

The results of this research show that the number of investors, the promised IRR and the investment horizon are statistically significant for equity crowdfunding of new and existing clean energy projects. It is possible that projects could attract more investors if the campaigns were not geographically restricted, which is consistent with the findings of Guillochon (2022). When the investment horizon is longer, investors feel more anxiety and this has a decreasing effect on the amount of funding, which is consistent with the results obtained by Bento et al. (2019a).

The limitation of this study is the small sample size. The sample size could not be larger now, given the limited transparency in terms of project information. EU equity crowdfunding platforms offering cleantech projects only publish a limited amount of information. There are several platforms that only focus on local investors and do not provide information in English. This suggests that the crowdfunding campaigns are targeted at qualified investors or try to attract regional capital. On the other hand, the fact that a potential investor has to disclose their personal information in order to be approved by the platform means that the founders of the project have quality assurance regarding their investors. Policy implication of such findings can lead to higher transparency of project details, not only for the registered "crowd". In this way, many more investors could be drawn to invest in projects and cleantech could receive much more funding.

Furthermore, most of the sample platforms do not provide public insight into news and updates regarding projects. When analysing the US and UK equity crowdfunding platforms, the founders provide continuous updates and are in constant communication with investors or even potential investors. Media coverage and updates are important factors for project success (Otte and Maehle, 2022) and therefore that can be an important practical improvement that crowdfunding platforms in the European Union could make. More transparency for potential and current investors could contribute to the success of the campaigns. In addition, the same type of clean projects may have different success rates depending on the geographical region.

Perhaps the projects could be more global in nature and thus attract more funding. For the EU cleantech initiative to be successful, crowdfunding for cleantech projects needs to be more transparent and not just regionally focused. Moreover, media coverage needs to be advanced. This could reduce the uncertainty connected to the project and attract more investors.

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The Project Manager of the Future – Will the Role Continue to Exist?

***Agnes Wittrich*[1]**

ABSTRACT

The society is facing a steadily increasing grade of projectification driven by digitalization, growing complexity and need for innovation. Digitalization is driven forward by projects, so that a boost in project management is expected in the next years. The classic role model of the project manager is threatened to be divided between self-organized empowered teams, and agile role models. The paper aims to forecast whether the role of the project manager will still exist in the next decade. The research has been approached from a theoretical and a practical perspective. The research object is the project manager of the future, analyzed from the perspective of digital transformation. For the theoretical study, the systematic literature review has been applied. The practical study aims to underline the research findings of the theoretical study on the future of the project manager's role. The answer to the research question is ascertained by practical perspectives of project practitioners from different industries. The research survey method has been used. The results are beneficial for business organizations as they may serve for developing leadership, and digital transformation models for project management roles, for project practitioners who can focus on their competences development for the future, and for educational institutions to re-think and design their curricula.

Key words: *project manager, role, future, digital transformation*

JEL classification: *M10, M16*

1 Introduction

Projects and project management have become essential in each sector of the economy, including non-profit organizations, and public administration. In almost all operational functions work is performed within and with the help of projects (Wagner, 2014). The German Society for Project Management [GPM Deutsche Gesellschaft für Projektmanagement] commissioned 2021 a study to systematically investigate the projectification and the dissemination degree of project work in the German society (GPM Deutsche Gesellschaft für Projektmanagement, 2021). Projectification as a term was introduced in 1995 by Midler in a pioneering article about the increasing significance of projects for the French car manufacturer Renault and the organizational and cultural changes it has caused (Midler, 1995). From today´s perspective it can be described as the fusion between project and organizational transformation. Digitalization, growing complexity and need for innovation have been identified as key driversin the expansion of projectification (GPM Deutsche Gesellschaft für

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Projektmanagement, 2021). Therefore, since digitalization is driven forward by projects, a boost in project management is expected in the next decade.

Project management in organizations is currently facing challenges such as digital transformation, increasing complexity, globalization, the pandemic, etc. The literature review has shown that project management in organizations is still focused on predictable situations. Although an increasing number of companies are adopting an agile approach to manage projects, it may not be enough to meet the challenges of the future. Current developments are questioning the classic model of a project manager. The project manager is threatened of being decomposed by automated systems, self-organized empowered teams, and agile role models. The main objective of the research is to identify the key changes in the role of future project managers regarding their long-term existence over a ten to fifteen-years horizon. It aims to predict whether the project manager role will continue to exist in the future. A partial objective of the research is to analyse to what extent the influence of the project manager, due to the growing complexity, will become significant in the business-critical digitization projects. It aims to answer, if the project manager becomes the control centre as a generalist, and the coordination point for the project participants, this will create the optimum conditions for interdisciplinary virtual global teams, often from different organizations, to network and perform. Considering the effects of digitization on workflow and project management in a heterogeneous, global, and largely virtual work environment the research question [RQ] and related null [H_0] and alternative [H_a] hypotheses have been defined.

RQ: In what way will the role of the project manager develop in ten to fifteen years?

H_0: The role of the project manager will expire. Self-organizing, empowered project teams will replace it.

Ha: The project manager will become a leader with a change implementing function and a value provider to the organization.

2 Literature review

Digital transformation stands as a generic term to describe the expanding use of networked, web-based, and automated technologies in the society. It is frequently associated with the descriptive concepts of Industry 4.0 and the fourth industrial revolution, with different meanings behind them. Industry 4.0 refers to “a marketing term that is also used in science communication and stands for a “Project of the future” (according to the high-tech strategy website) of the German federal government. The so-called fourth industrial revolution, to which the number refers, is characterized by individualisation (even in the series production) or hybridization of products (coupling of production and service) and the integration of customers and business partners in business and value-added processes” (Bendel, 2021). The industrial revolution might be seen as a huge complex, multi-national and transdisciplinary project, with the goal of process digitization and networking. To manage the complexity, project management goes beyond focussing on the manner in which to control the rigid “magic triangle” of scope, time, budget. It ensures the transformation of ideas in deliverables that produce an added value for the business and the achievement of project targets that match the strategic goals of customers and the company itself. The emerging technology trends of the fourth industrial revolution which will shape the way of thinking, working, and living in the next decade will also impact the way project management is conducted. Pajares et al. (2017) describe the key features of the projects of the fourth industrial revolution focusing on those that could affect the management style in managing these kinds of projects. They refer to them as Internet of Things [IoT] projects which can involve different technologies. According to their

point of view, technological revolution is caused by the maturity of several technologies and its empowerment by means of connectivity. The phenomenon of the significant reduction in the products' life cycles in the last decades makes time one of the key factors in project management, according to Pajares et al. probably more important than cost and scope. Project success will be associated with the market success of a new product or service rather than realizing deliverables measured by the requirements of the "magic triangle" of scope, time, and costs.

In a report published in 2017, ARUP dealt with the evolution of project management until 2045 with focus on construction projects. The "Future of Project Management" considers emerging trends and drivers, combines best practices and visual thinking to imagine the future through the eyes of its clients and creates a roadmap for research and academia. The ARUP concept, which could be extended to a wider scale of project types in different environments, predicts that social responsibility of individuals and companies to act in the best interest of their ecosystem will continue to grow in importance, becoming a dedicated chapter of the Project Management Body of Knowledge [PMBoK]. It can also be predicted that the project management institutions will continue to consolidate their position and develop their standards in accordance with the global technological, economic, and social changes. The project management profession will continue to grow in importance and consolidate its position in the society. Project management becomes part of the national curriculum in several countries. The project management institutions have the possibility to encourage research in the field of project management, and to enable and promote the collaboration between industry and academia.

Project management 4.0 takes advantage of real-time monitoring and real-time cost progress indicators in the execution. Elaboration of progress reports and quality control of deliverables will be automated, which facilitates time saving. The communication processes within and between projects will be accelerated; connectivity is increasing and removing physical and personal interchange of information. Communication between a human and a machine, as well as between a machine and a machine will be deployed in the execution process. Simulation of the execution enables forecast and identification of risks, which are evaluated applying techniques based on using large volumes of data from other projects. Regarding team collaboration and work, the use of virtual teams will be generalized, gamification will be applied in the development of human resources and collective intelligence will facilitate problem solving and efficient management of projects (Siminon et al., 2018). The downside of teams' virtualization is the decrease in social interaction between project members. Automation and increasing connectivity may save an individual's time, which can be invested in creativity, knowledge accumulation and potential expansion. Virtual environments allow for cooperation beyond borders and the use of collective intelligence to solve issues in brief time. But the human aspect of teamwork will continuously fade. A large-scale study performed by KPMG in collaboration with the Australian Institute of Project Management [AIPM] and the International Project Management Association [IPMA] with over five hundred participants from fifty-seven countries shows that the future of project management is anchored more in the strategic orientation than in the methodical handling of projects. The methods of project management are progressively being used to overcome an increasing number of business challenges. This demonstrates the essentiality of project delivery for modern organizations as a tool to implement strategic changes and increase profitability. The study shows that sixty-three percent of the companies surveyed conduct projects with essential change management skills. This is in line with the finding that thirty percent of companies believe that their change management skills are remarkably effective. The future of project management is "as a connected facilitator of change and return of investment" (KPMG et al., 2019). VUCA combines four distinct types

of challenges that demand four distinct types of response. The description by Bennett and Lemoine (2014) of the four elements of the VUCA term (Volatility, Uncertainty, Complexity, Ambiguity) can be transferred to project management, so that an approach for the future of the discipline can be derived. Project management in the future needs to re-organize and build-up specialists and resources focussing on their special needs dictated by the nature of their business. Organizations will invest in buying talents, and if required, build stockpile inventory, collect, interpret, and share information. On order to cope with ambiguity, the project management of the future needs to be experimental. To understand cause and effect, hypotheses have to be constructed and tested and experiments designed, so that lessons learned could be applied broadly. The future project management is aware of disruptive technologies, understands the potentialities of modern technologies, is capable of think ahead and acts proactively to produce added value for the organizations. Project performers of the future know their organizations and their strategic objectives, and are able to manage fast-occurring changes with solid business judgment and pragmatic handling of uncertainties.

3 Methodology

The research has been approached from a theoretical and a practical view. The main object of the research is the project manager of the future, explored in the perspective of digital transformation. The term *future* refers to a time horizon of ten to fifteen years. For the theoretical study, the systematic literature review methodology has been selected because it provides a process for identifying and critically appraising relevant research data for this paper. It aims to identify the empirical evidence that matches the pre-defined search criteria to answer the research question (Snyder, 2019). It has been performed according to an iterative process of four sequential phases: data collection, selection, evaluation, and synthesis (integration in own research). The reporting of the review has been guided in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis [PRISMA] Statement (Page et al., 2021). The review of the scientific literature focusing on the concepts of project management and manager in combination with digital transformation, outlined insights on the current state of the art research, indicated trends of further research and guided to interpretations of the research material. The search concentrated on peer-reviewed, scientifical publications between 2017 and 2023, limited to articles, books, book chapters, standards, conference papers and studies, in English and German. In the scientific source selection, Google Scholar has been set as the starting point for the research. Databases mostly used for management studies have been taken in consideration as further sources for gathering scientifical research data. The repositories for scientifical articles, studies and research results of the Project Management Institute, the International Project Management Association and the Association for Project Management have been identified as valuable data sources. The websites of groups and organizations which cover topics of, and websites of journals and blogs dedicated to project management, the project manager role and digital transformation have been revised. The following scientific databases which demonstrated to be comprehensive in terms of publications have been selected: ScienceDirect, JSTOR, SpringerLink and Google Scholar. The practical study aims to underline the research findings of the theoretical study on the impact digital transformation has on the future role of the project manager. The answer to the research question is ascertained by practical perspectives considering the expertise of project practitioners from different industries. The research survey method has been applied. The survey population was sampled from project management practitioners from various industries and levels of expertise. The procedure was written and cross-functional. As for the survey instrument, the questionnaire has been intentionally chosen and preferred to interviewing in

order to reach project professionals from a wide range of industries and global regions. Due to anonymity, a higher degree of openness in the responses was expected. The questionnaire consisted of an introductory part followed by twenty-three questions including multiple choice, multi-point rating scales and open-ended questions. To assess the hypotheses plausibility, the probability of obtaining the observed results has been estimated. The statistical hypothesis evaluation has been conducted in four sequential phases: data selection, statistical tests selection and execution, results evaluation, decision on acceptance or rejection of the respective null and alternative hypotheses. Data collected through the survey has been used to perform the statistical tests. The exact binomial test (Wagner-Menghin, 2005) has been applied to assess the statistical significance of deviations from a theoretically expected distribution of observations using sample data (Conover, 1999).

4 Empirical data (documentation background) and analysis

The findings of the literature review showed a tendency toward the alternative hypothesis [Ha1] as the answer to the research question. Project management is developing from a process- to a principle-oriented discipline, aiming to create values for organizations and the society at whole, thus becoming an instrument of contribution to a sustainable society. The research results indicate that the project manager role will continue to exist in the next ten to fifteen years. An expanding volume of projects is expected in the next years due to the increasing projectification of the society and the progressing of digital transformation realized through projects. This will lead to an increasing demand for qualified professionals, who enable the practical realization of projects, and consequently to the need for leaders, who hold project teams together, creating in this manner, the appropriate environment to produce value. The value-oriented project management has to be established in business and public life organizations primarily as a leadership task rather than a method. The rising level of projectification enhances the significance and the effects projects have on the society, the number of project specialists and thus the consequences of their act and behaviour on organizations. The project leader as a generalist becomes the guidance and control centre, which creates the optimum conditions for interdisciplinary virtual global teams, often from different organizations, to network and the coordination point for project participants. The role of the project manager will be transforming in the next years; the project manager will become leader, with a guidance function, and a change implementer.

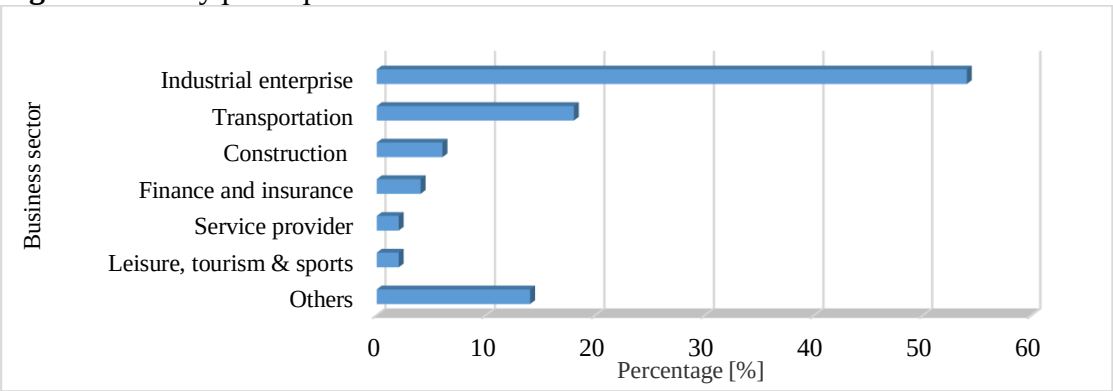
4.1 Study results

To reach project managers and practitioners from a wide range of industries and organizations of different sizes, a request for participation in the study and completion of the survey was posted on LinkedIn and Xing in dedicated project management groups. In addition, one hundred project and project management office leaders from the researcher’s professional environment were invited via e-mail to complete the survey. A total of fifty participants answered the questionnaire completely. Their responses could be included in the data evaluation and in the results presentation as they reveal respectively one hundred percent. Since the contacted professionals were asked to share the survey information and an anonymous link to the questionnaire within their networks, a final response rate cannot be determined.

4.1.1 Survey participants

The majority of the participants, fifty-four percent, was active in an industrial enterprise, followed by transportation with eighteen percent, construction with six percent, finance and insurance with four percent, and service provider and leisure, tourism and sports with two percent respectively. A share of fourteen percent belonged to other fields without nomination.

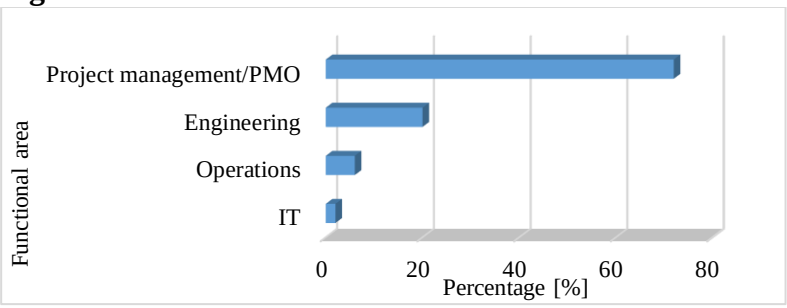
Figure 1 Survey participants' economic areas



Source: Author

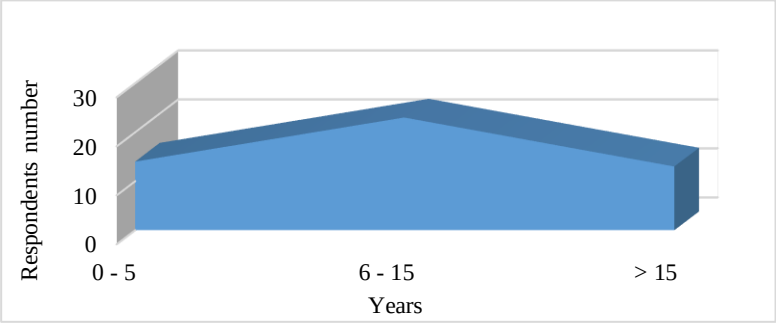
Project management and project management office, represented by seventy-two percent, is the participants' leading work functional area. Twenty percent work in engineering, followed by six percent in the field of operations and two percent in IT. Nearly half of the participants have several experience years in project management, balanced out by long and short-term experience.

Figure 2 Functional areas of work



Source: Author

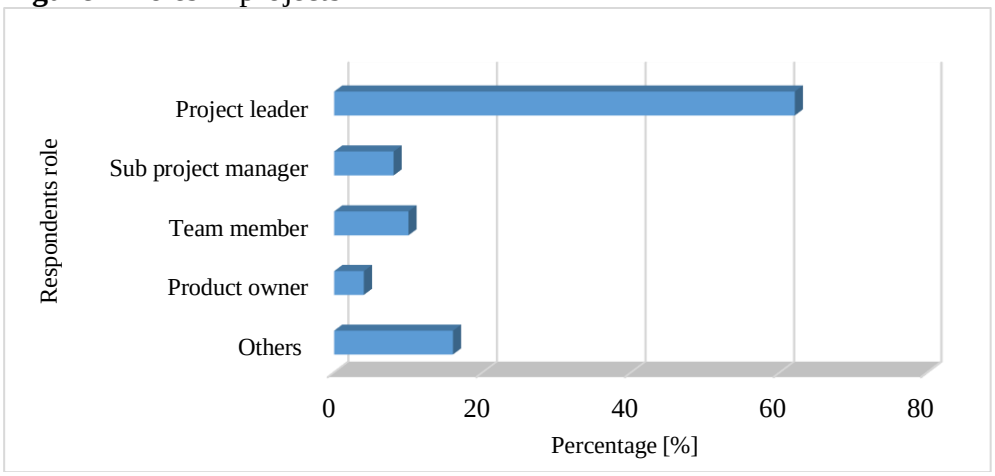
Figure 3 Project management experience years



Source: Author

The majority of the participants indicated that they have the role of project leaders (sixty-two percent), followed by eight percent of them having the role of subproject managers and ten percent, as project team members. They also specified multiple roles. For evaluation purpose, the first data was considered.

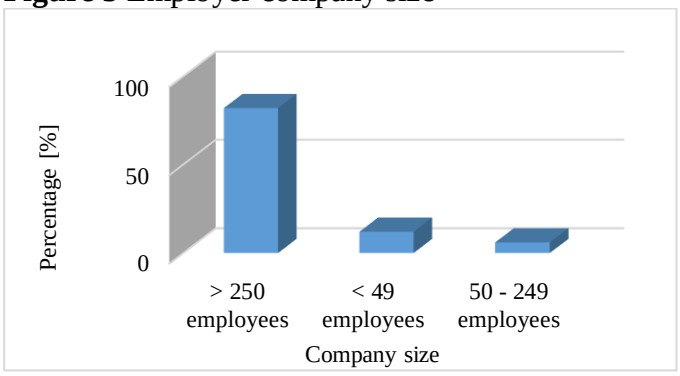
Figure 4 Roles in projects



Source: Author

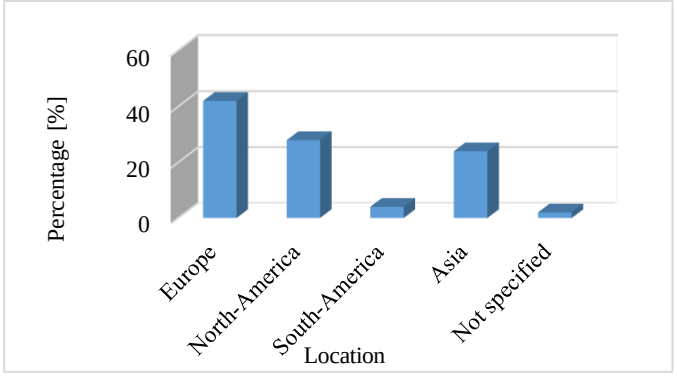
Predominant was the affiliation to large enterprises, with eighty-two percent in contrast to small and medium enterprises, with twelve and six percent respectively. Nearly half were located in Europe, followed by North America and Asia with a roughly equal percentage. South America was represented with two percent.

Figure 5 Employer company size



Source: Author

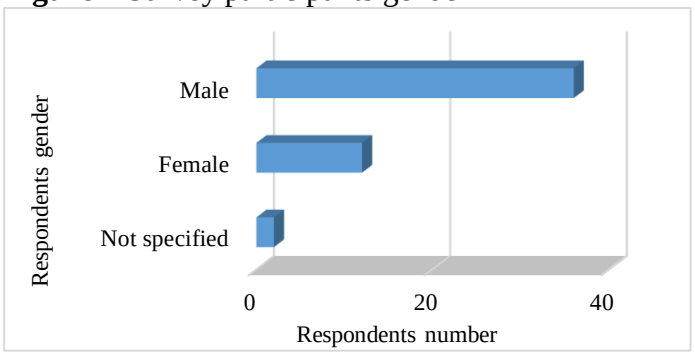
Figure 6 Employer company location



Source: Author

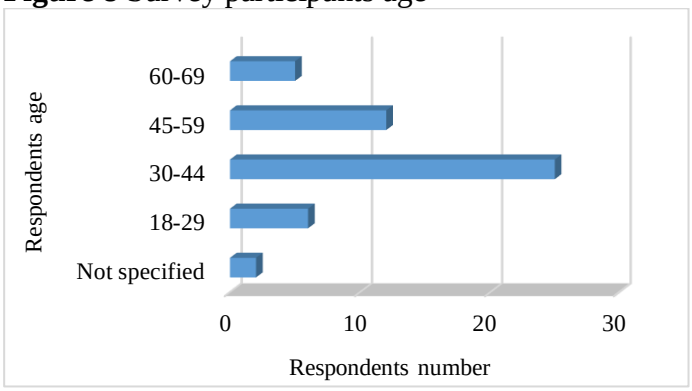
Seventy-two percent of the survey participants were male and twenty-four percent female. Half of the participants were aged between thirty and forty-nine, followed by those middle aged, and balanced out by young and senior professionals.

Figure 7 Survey participants gender



Source: Author

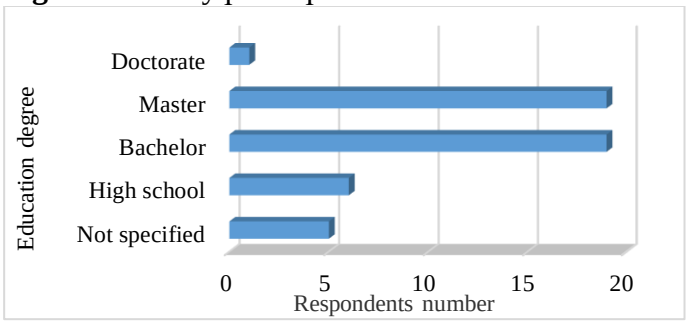
Figure 8 Survey participants age



Source: Author

Thirty-eight percent have stated to have a master and respectively a bachelor degree. One participant had a doctorate degree, whereas the remaining part stated to have a high school diploma.

Figure 9 Survey participants' education



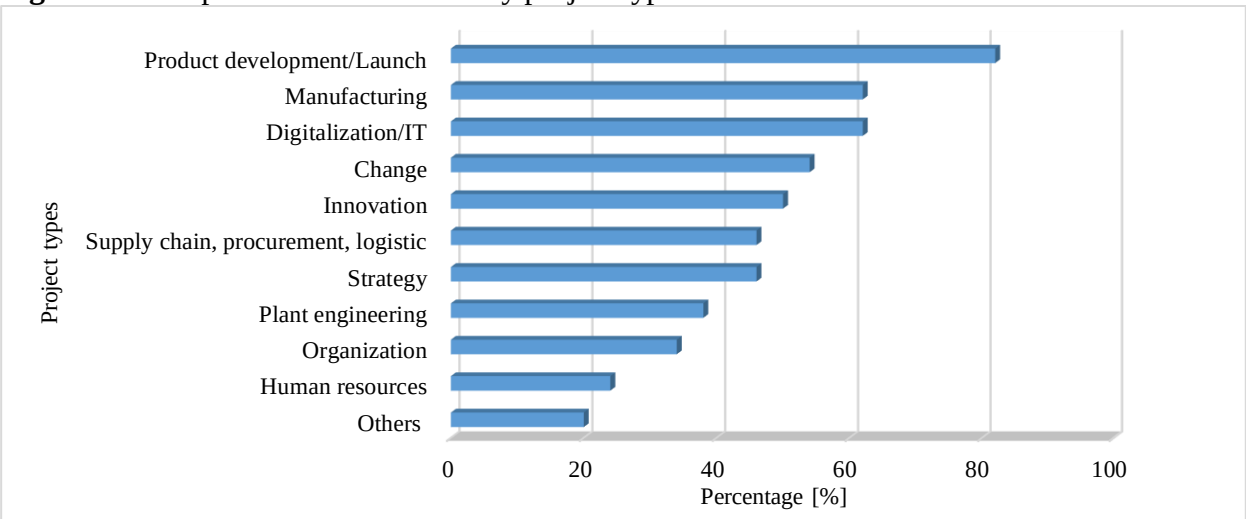
Source: Author

4.1.2 Projects and project management in practice

The analysis of this section's data reveals the significance of projects and of the project management function in the practical environment of the survey participants. The types of

performed projects provide insights into companies' business focus and trends. Consequently, the attention is concentrated on product development, manufacturing, digitalization, and information technology, driving change, closely followed by innovation, strategy and supply chain. Human resources and organizational projects have a share of around one-third.

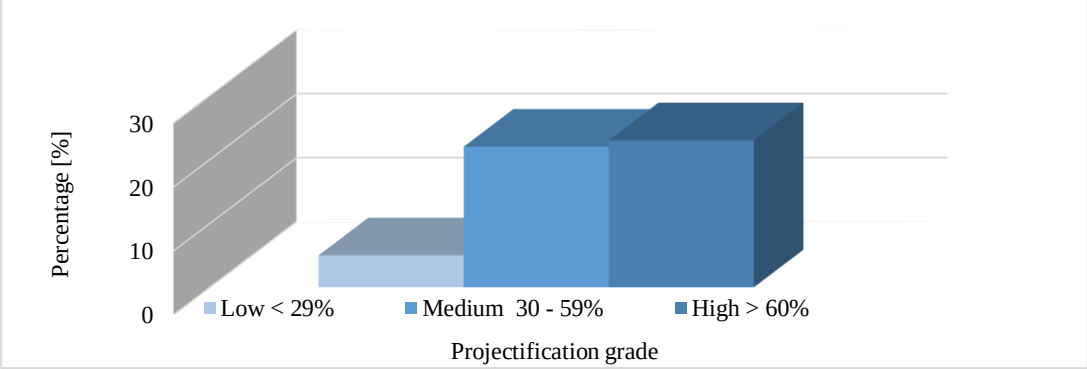
Figure 10 Companies business focus by project types



Source: Author

The projectification level defined as the share of work performed by and within projects was assessed by almost half of the respondents as high, with over sixty percent, whereas the other half estimated it as middle on a range between thirty and fifty-nine percent.

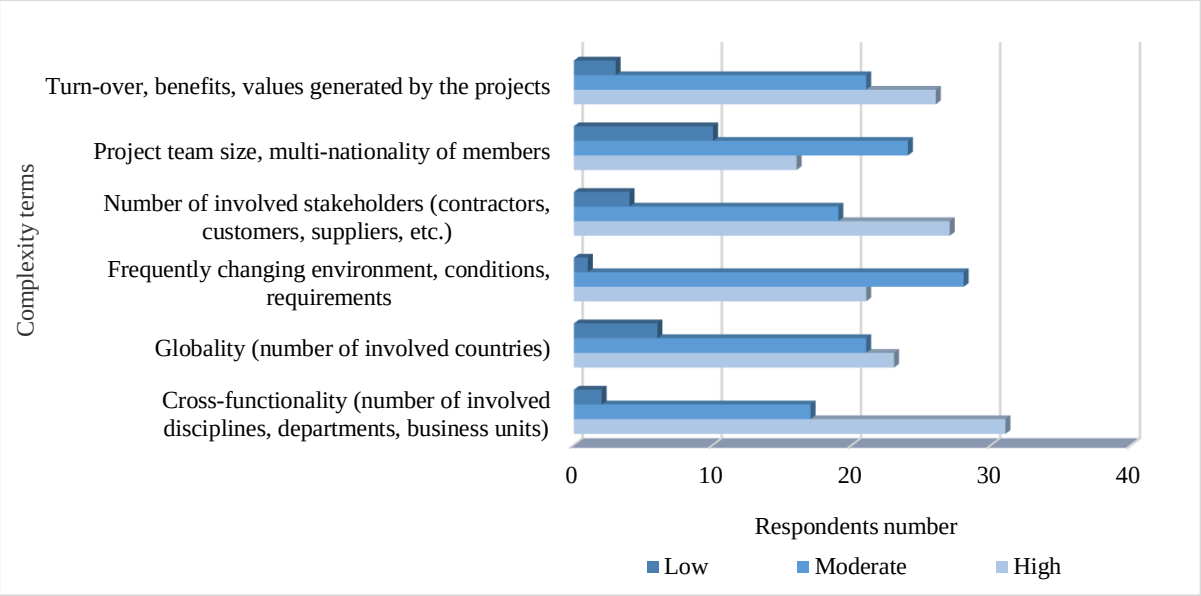
Figure 11 Companies estimated projectification grade



Source: Author

High complexity within performed projects in the organization has been estimated in terms of cross-functionality in terms of business units and disciplines involved, the number of stakeholders, contractors, and suppliers, and in relation to generated benefits and values. Frequently changing environment, conditions, requirements, globality, size and multi-nationality of project teams have been estimated as moderately complex.

Figure 12 Terms of complexity



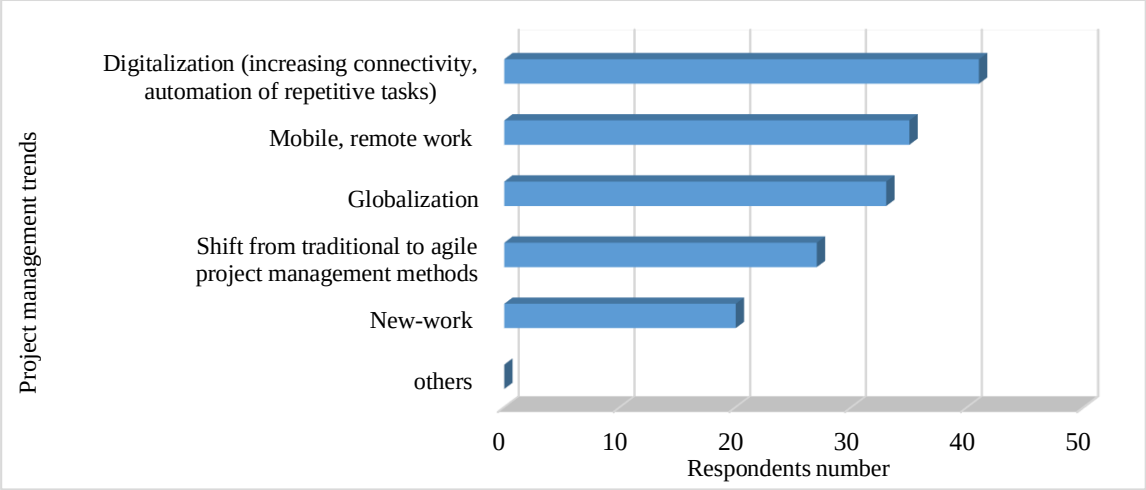
Source: Author

Regarding the handling of the complexity and uncertainty in projects, seventy-four percent of the respondents provided specific information. Communication within the team and with stakeholders has been named by the majority (forty-five percent). This includes regular project team meetings, reviews, proactive involvement of stakeholders, enabled collaboration in teams, involving and collaborating with relevant entities from the organization to provide solutions. Establishing communication plans, enabling and creating multiple channels, and the use of tools for quick information distribution support interactions in projects. A consistent application of risk management in projects, including regular risk evaluation, planning and mitigation has been identified likewise to handle complexity in projects. Further instruments have been identified in the application of project management methodologies, agile and hybrid approaches, adherence to standards and further education. Complexity and uncertainty can be faced situationally, demanding additional responsibilities from project managers. The most commonly used project management methodology is the traditional (waterfall), followed by the hybrid approach and agile scrum. A very small percentage of respective six, two apply agile Kanban or none of the mentioned methods. The adherence to standards in managing projects is balanced. The PMBOK® Guide (Project Management Institute) is the most applied standard at the same level with other, not specifically named, closely followed by the International Standard Organization, ISO 21500:2021(en) Project, programme and portfolio management and the International Project Management Association. A low proportion apply PRINCE 2.

4.1.3 Future scenarios

Digitalization in form of connectivity and automation of repetitive works, mobile and remote work and globalization have been perceived as major trends in project management, followed by the shift from traditional to agile project management methods and new-work. Consequently, these were estimated as the trends with highest impact on the evolvement of project management in the next ten to fifteen years. Getting more activities done with artificial intelligence will reduce costs and will free space for project manager’s leadership.

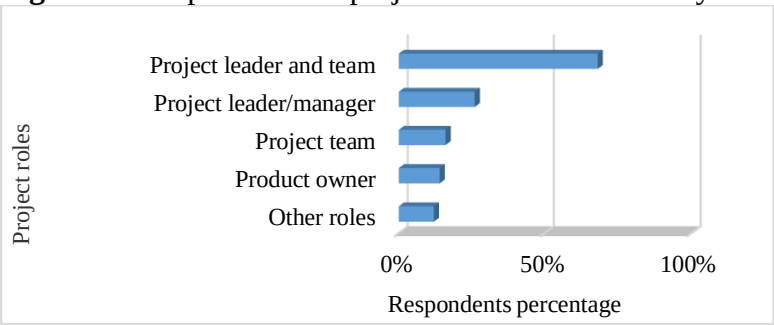
Figure 13 Perceived trends in project management



Source: Author

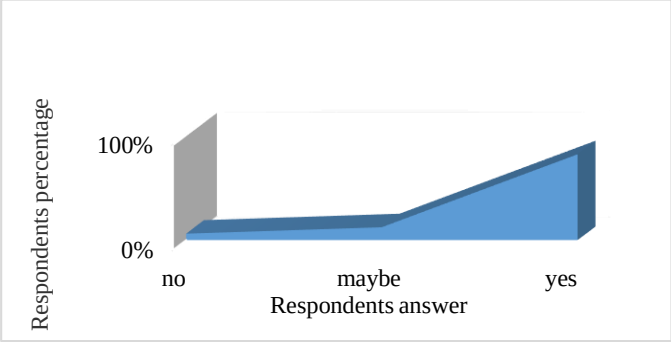
Digitalization is progressed in the survey participants' organizations to almost the same extent through projects, line operations, and in combination of both, in contrast to two percent where no activities of this type take place. The existence of the project manager role has been confirmed by a rate of eighty-two percent of professionals surveyed, while six percent denied it. The project leader and team ensure, by mutual responsibility, successful project completion.

Figure 14 Responsible for project success in 10 to 15 years



Source: Author

Figure 15 Existence of project manager role in 10 to 15 years



Source: Author

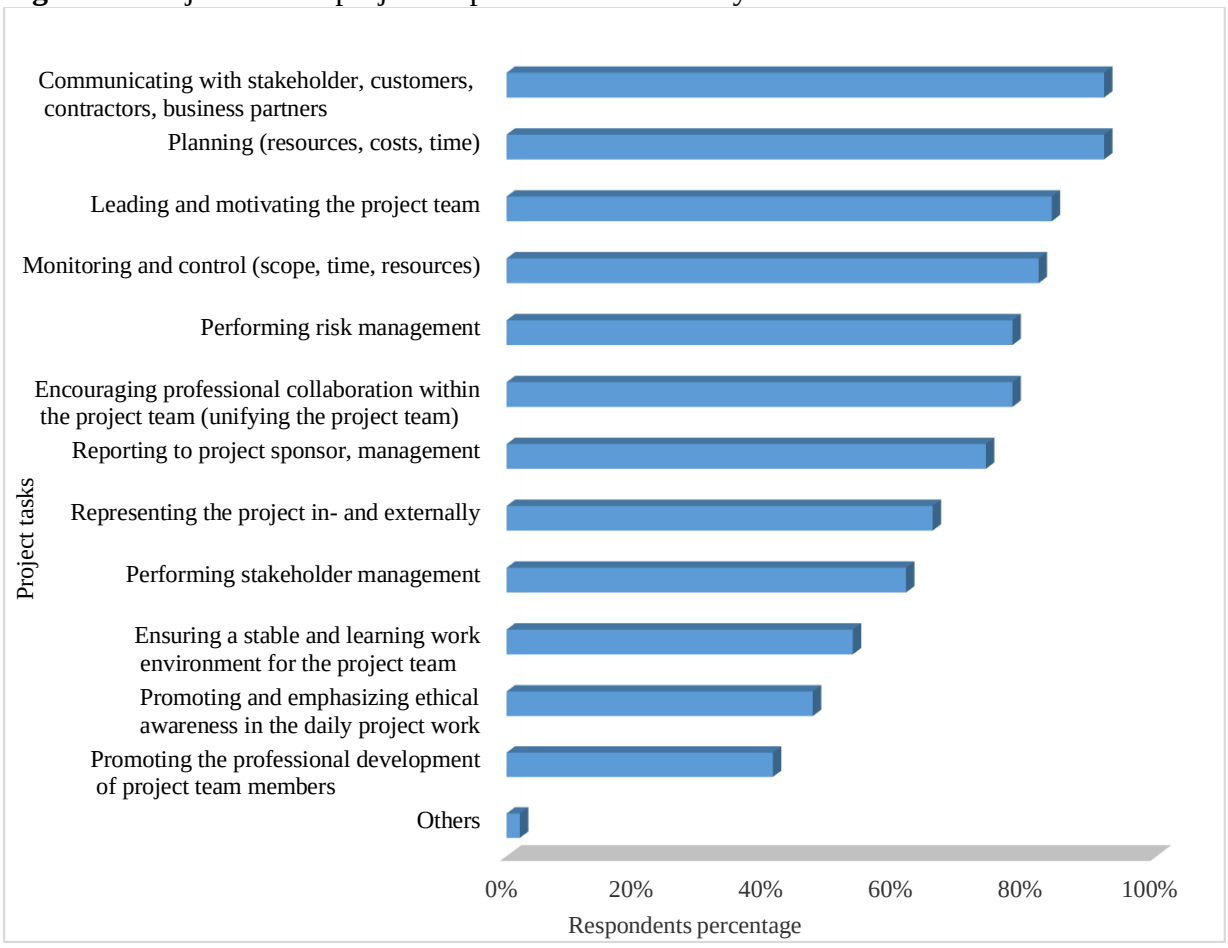
Leading success criteria for project completion include completion within time, budget, scope, generating material benefits for the organization, stakeholder satisfaction and sustainability.

Figure 16 Project completion success criteria in 10 to 15 years

Source: Author

Communication with stakeholders and business partners is expected to be the key task besides planning of resources.

Figure 17 Major tasks of project responsible in 10 to 15 years



Source: Author

Seventy percent of the respondents confirmed their involvement in projects in the next ten to fifteen years. They described their roles as project leaders responsible for achieving project success within the planned time, budget and scope, using available digitalized project methods, communicating regularly with the sponsor and reporting on progress to project management office leaders, consultants and program managers overseeing multiple global projects. Project work is assessed as essential in the future due to increasing number of projects. Respondents concluded that project management will be one of the future jobs in different types of sectors and enterprises. The development and education of project specialists will be essential for the future of companies, their success and customers' satisfaction

4.2 Statistical hypothesis evaluation results

As relevant input data for the statistical tests, the responses to the survey questions directly related to the research questions have been selected.
For the performance of the binomial test, the following considerations have been made:

0. Three answers "yes/no/maybe" were possible.
1. To figure out the ratio of "yes" responses compared to a random distribution.
2. To make the test more rigorous, only "yes" responses have been evaluated as success.
3. A total of fifty participants completed the survey, forty-eight gave concrete responses, two have abstained from answering.
4. The forty "yes" responses (corresponding to eighty-three percent) were tested against a binomial distribution.

With ninety-five percent confidence level, the ratio of "yes" answers lies between seventy-two and one hundred percent. The probability-value lower than 0.001 is highly significant. Therefore, the alternative hypothesis is accepted, the null hypothesis is rejected.

Table 1 Binomial test results

Evaluation test	Number of trials	Number of successes	Level of confidence [%]	Confidence interval [%]	p-value
Binomial	48	40	95	0.71931 - 1.00000	1.653e-06

Source: Author

The role of the project manager will continue to exist in ten to fifteen years and the project manager's role will transform to a leader with guidance, change implementing and value-providing function for the organization.

5 Results and discussion

The middle ranking of the project manager job by the World Economic Forum (The Future Job Reports, 2023), directs to a favourable prognosis for the maturity and life cycle of the profession. Professionalization and upgrading through leadership authority within business organizations are emerging as results of the role transformation in the future. Increasing complexity and globality of projects require guidance. The research on experienced project practitioners observed the transition from management to leadership in complex projects, from handling resources to orchestrating the dialogue between people at the right time about the right

issue. Stakeholder management shifts to collaborative meaning- creation in alignment with them. Further transitions include relying on practical wisdom to master complex challenges, developing power sources and pathways through power dynamics, and negotiating project success. Leading projects offers potentialities for human resource development. Considering the continuous grow of projectification and projects volume in the society, and the growing need for qualified staff, the necessity arises within the transformation process to re-assess the importance of project management in the organization. This includes a mind-set change towards the role of a project leader and no longer reducing it to a method implementer.

Project managers need more empowerment, project teams should be drivers in terms of culture, race, gender and age. More agility in thinking and problem solving as well as constant knowledge upgrading with respect to the industry and market are required. The set-up of a career plan for project managers will support retainment of talents in organizations. Respondents concluded that project management will be one of the future jobs in different types of sectors and enterprises. The development and education of project specialists will be essential for the future of companies, their success and customers' satisfaction. Project management should be promoted in elementary schools for young people, it should be popularized instead of elitized, seeing it as culture and not as discipline. In some considerations, project management is dependent of the brand, where specific knowledge and technical competency are needed. It becomes more complicated as digitization and global projects become more routine, requiring an international standardization. The project management of the future is characterized by the utilization of automated methods and techniques supported by innovative, continuously evolving tools, which will facilitate and accelerate the daily project work. For this, the discipline needs to retain a high degree of flexibility and connect traditional methods with the comprehension of new markets, the deep knowledge about products and services of its own companies, and the way these are used by their customers. Project goals are not only reduced to profit realization, which remains a major purpose to ensure long-term survival of organizations, they concentrate on sustainability and responsibility for their impact on the society. Project management is developing from a rational, strictly process - to a principle-oriented discipline, focussed on providing values for the society at whole. It is becoming more and more multidisciplinary, spreading across several international locations and partners. The increasing product and project complexity implies a growing importance of project management, because of the increasing volume of and added value creation through projects. Teams become progressively agile and empowered, individuals see themselves more and more as problem solvers instead of orders receivers and executers. From this perspective, it can be predicted that agile and perhaps hybrid approaches will dominate the project management environment and replace gradually the traditional, waterfall methodology.

Research indicates that the project manager will continue to exist in the next ten years. The role will transform from managing to guidance, change implementing and value creating for organisations and the society. Their core responsibilities will move in a direction beyond a singular project toward project networks with overall coordinating and financial controlling functions. Assuming a point in time in the next decade. Projects are interconnected, realized by specialized, self-organized and empowered teams, and governed by project leaders. The role of the project manager has grown into a project leader in control of the increasing complexity, with a holistic and systemic view on the project at whole, aiming and ensuring the delivery of values by the project for the organisation and the society. In their transition from a functional to a project character, as a result of projectification increase, organizations need to rely on the leadership of their project managers and give them authority to discharge their assigned role. The main contribution of the research lies in forecasting the long-term existence of the future

project manager role. It shows that project success is a matter of project manager's leadership and competence and the implementation of new methods, tools, or software. This observation invokes organisations to re-think their attitude towards the empowerment of the role. The forecast on the continuing existence of the project manager role in the next ten to fifteen years will encourage employers to specifically recruit and invest in development paths toward leadership, qualification, and digital transformation models of the project manager role. The contributions can be relevant for the providers of project management standards. The research results provide an added value for aspiring and performing project managers to focus on the development of their required competences for the future and to support their build-up. Project management is disclosed to be one of the future professions in different types of sectors and enterprises. Development and education of project specialists becomes essential for the future of companies, their success and customers' satisfaction.

6 Conclusions

Research and practice observed a steadily increasing projectification degree of the society, which is expected to continue in the next years. Digitalization, growing complexity, and the need for innovation are the key drivers. Digital transformation and organizational change are accomplished by projects, and further indication of a growing volume of projects and consequently an increasing demand for project management professionals in the future. Project leaders and their teams are confronted with new technologies and business models, which implies dealing with disruption and applying new ways of leadership, collaboration and communication. Controlling complexity, coping with digital transformation goes beyond the mastering of methods, techniques or tools and requires the ability to satisfy stakeholders, to motivate teams, to understand and exemplify the strategic meaning of projects for the organization and the society at whole. Projects and project management are enabling change and realization of innovative ideas. Project teams are a changemaker which do not act in isolation being confronted with the global challenges. It is essential for organizations and their project leaders to be aware of where the world is moving, to be able to adapt and prepare for change, and to figure out their contribution to the global transformation process.

The present study revealed the lasting existence of the project manager role in the next ten to fifteen years. The role will transform from management to leadership, change implementation and value creation for organizations and the society. Its core responsibilities will move in a direction beyond a single project towards project networks with overall coordination and financial controlling functions. The major tasks of project managers in the future will shift to communication with stakeholders, planning resources, leadership, and motivation of the project team. Managerial abilities, problem solving, and decision-making techniques complete their key skills. Organizations need to re-assess, and if required, re-design their strategy regarding project management application. This refers to the methods and tools they select, to their awareness of disruptive technologies, their understanding of the new technologies potentialities, their capability to think ahead and act proactively to produce added value since automation including artificial intelligence, machine learning, robotics, Internet of Things, impact increasingly the work environment. In their transition from a functional to a project character, as a result of projectification increase, organizations need to rely on the leadership of their project managers and give them authority to discharge their assigned role. They play a key role in providing an environment that facilitates continuous learning, ethical sensitivity by enabling an open culture, and in clearly communicating and living ethical principles, accepting errors and failures.

The study has limitations due to the focus on the project manager in terms of the evolvement of the role. Research on future evolvement of additional roles in project management was not included. The limited number of participants in the survey restricted the access to a larger, more diverse project environment which would allow for a collection of more comprehensive data for the practical study.
The majority of the practical study participants were project leaders in large industrial manufacturing enterprises. The perspectives in the practical study are limited and exclude those of further roles in and beyond project management. The generalisability of the findings is rather limited since the study included only large, manufacturing companies in western countries, mainly in Europe and North America. The perspective of small and medium organizations, in public and non-producing sectors, in European, North American, and additionally in South American, Asian, Middle East and African countries should be investigated in the future. The survey participants considered that the increasing projectification of the society has no positive effects on employees and organizations. As an increasing projectification level is to be expected in the coming years, the reasons for the unfavourable prognosis should be examined more closely. Additional research on increasing projectification itself, its impact on economic and public life, and on the roles involved is recommended. The study emphasized the demand for project management professionalization. To achieve this, research needs to be carried out on the topic itself, on the positive influencing factors and on the existing obstacles in society.

Project management theory and practice requires continuous questioning in the light of lived practitioner´s experience. Research is required on further roles in project management, the impact of digitalization, their transformation and their key competencies. Competencies in project management should be continuously expanded as the subject of future research. Additionally, research is required on talent and career development of project professionals, considering evolutionary factors like increasing projectification, globalization, ongoing digitalization and their impacts. A certain degree of effort has to be invested in further research on academic education to include project management in the basic curricula of technical, economic and social science faculties. How project success will be evaluated in the future, which success criteria will be defined in projects and the impact of digital transformation on these should be addressed in future research. The study is a call for project professionals to educate their sensitivity to capture and use change to re-fine their proficiencies, to recognize and exploit their own potential for the future development of project management. It is a motivation for organizations to provide an appropriate environment which enables learning and professional development. A more intensive collaboration between academia and business organizations would provide a fertile soil to promote research, further development of the discipline and continuous application of the results in practice.

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Connecting the Dots in Lean Implementation- Insights from Qualitative Data Analysis in Croatian Lean Companies

Lara Jelenc[1]

ABSTRACT

Lean approach originated with the Toyota principles and philosophy of production, expended to lean methodology, lean thinking and lean culture just to name a few. The underlying principles of lean, focusing on cost reduction and waste elimination, increasing efficiency and effectiveness of business processes, gained a revival role in Industry 4.0 and started to focus even more on the agile and innovation approach with the mission of business processes continuous improvement. Although present in the literature for the past five decades, lean implementation faces lower levels of success. The reasons could be grouped by identifying challenges, obstacles and key success factors applying a contingent approach to business depending on the industry, country, level of knowledge and readiness for lean implementation. This paper uses qualitative methods, more specifically the thematic method of analysis in order not just to identify the existing dots- key factors in the literature on lean implementation but to offer a way how to connect them. The proposed model is based on the qualitative analysis of 17 lean managers from 11 Croatian lean companies. The model incorporates two hierarchy levels, four iteration processes and five steps in lean implementation. The paper is in line with the findings of the literature on change management adjusted to the case of lean implementation. The model could be used for educational purposes in lean training and business improvement interventions. The next research step is to further build validation of the model by testing it within and across different cultures and industries.

Key words: *lean, lean implementation, qualitative methods, thematic analysis, Croatian lean companies*

JEL classification: *L15, L23, L69, M11*

1 Introduction

Implementing lean brings the old business postulates of being efficient and effective into action in the full sense of the word. It was originally presented as the non-traditional way of production, contrasting the old process approached production. It was based on the work and trainings of Edward Deming (Deming, 1986) that were assigned to Japanese management after World War II, as part of the Marchall Plan helping in the reconstruction of Japan after the war. Emphasizing the elimination of non-value-added activities, it attracted the attention of mass producers mostly in car and process industry. As the lean became more implemented in other industries, it crossed the line by being implemented in services and management. The practical approach of using simple tools and methods in order to identify waste and eliminate it, named as lean manufacturing (Gupta and Jain, 2013), got coined in lean thinking (Womack and Jones, 2003), broaden to lean philosophy of management (Liker, 2004; Leite et al., 2022) or

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management styles and leveled up to the lean culture (Mann, 2005). Since its first publication in the West, introducing Toyota's way of production (Womack et al., 1990) it grabbed the attention of production management and engineers. It looked so simple and easy, yet the attempts to implement lean in European and American companies seemed to face a high rate of failure. The first reactions were that lean implementation is deeply rooted in the Japanese quality culture and therefore could not be transcribed to any other company outside Japan. Well, the Toyota factories in USA demonstrated the opposite. At certain point they were even better than the factories in Japan. Operational management accepted lean management as one of the possible ways of organizing production, emphasizing its essence – elimination of waste. Still, the problem facing high rate of failure in lean implementation remained present up to now (Hines et al., 2020).

This paper builds on the existing literature on the systemic understanding of barriers during lean implementation (Leite et al., 2020; Antony et al., 2021; Puram, 2022) and contributes to the development of a model which actually connects the dots needed for lean to be implemented properly and correctly. The current level of literature review offers different classifications and groupings, still at the superficial level of listing factors/barriers that stand in the way of successful lean implementation. This paper pushes down the line in the attempt to offer a model that could be used in action by practitioners during lean training and the performing of lean transformations. It is embedded in the business process, enabling communication between two hierarchy levels, making connections between several stages of the change management process. The model is informed by change management literature and transfers knowledge to the management of lean implementation.

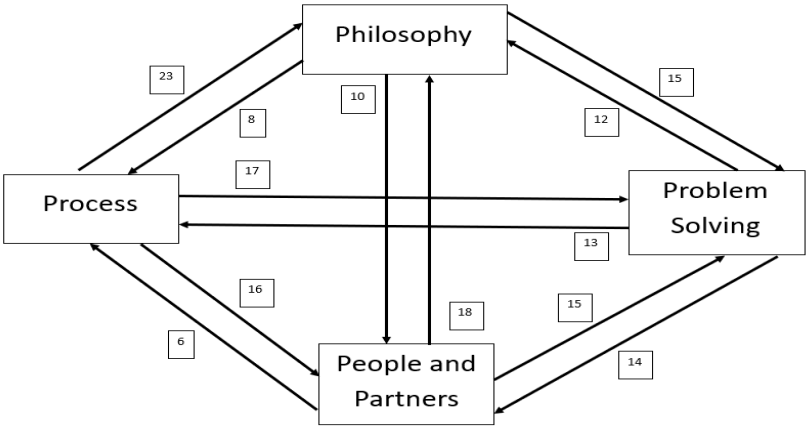
2 Literature review

Literature review on lean developed in several waves. The first wave was about discovering the lean itself within the Toyota way of production (Womack and Jones, 2003; Liker, 2004). These were the educational and training materials that had the role of promoting the idea of implementing lean outside Japan. The second wave was the case-study approach of applying lean in specific industries and specific countries promoting a contingent way of managing lean (Schulze and Dallasega, 2021). Lean managers explained both the success and failure of implementing lean in specific organizational settings. After a while, a more systemic approach evolved toward literature review, common key success factors and obstacles for success regardless of the industry or country specifics (Puram, 2022). At the moment, literature is, predominately, about the combination of both case-study specifics and systemic approach to literature review. Based on the widespread use of systemic review of literature published in the last couple of years ,one might conclude several developmental topics (Stone, 2012, Danese et al., 2018, Antony et al., 2021, Kassem et al., 2024). The first one being the breath of lean. Lean was created for manufacturing, more specifically the auto industry, but spread to almost all sorts of manufacturing and service industries (Hopp, 2018), both public and private (Samuel et al., 2015), regardless of size (Hu et al. 2015). The second one is the spread of lean. Lean was created to enhance the business process of manufacturing only, but is now used in the concepts as lean startup, lean agile, lean supply chain or lean green. The revival of lean was received after being rediscovered and rebranded within the concept of Industry 4.0. as the tool for achieving smart manufacturing (Kasem, 2024). An additional trend in lean research are the barriers or inhibitors of successful lean implementation. The research shows that the success rate of lean implementation is considered to be small, ranging from 70-90% of failure (Mamoojee-Khatib, et al. 2023). The rate is continuously steady during a long period of time.

Contingency approach in addressing successful lean implementation is and will be present in the literature while it all depends on the context, culture, organizations priorities and supporting infrastructure among other variables in and across the companies (Leite et al., 2022). Each company is unique with its specifics but shares a common sense in the context of taking business decisions and implementing them. There is no magic bullet (Dixon et al., 2016) in expressing what makes a company successful.

The literature was overwhelmed by the listing of barriers in successful lean implementation. Both researchers and practitioners did not find any meaningful value in listing them in an extensive list of several hundred barriers informed by numerous case-studies and surveys. Classification of barriers with lean implementation have evolved in several steps. First of all, it was a numerous list of barriers that authors reported from their case-studies. The list got intensive (Jadhav et al., 2014) and reached the point of being useless. The systemic literature review currently suggests two advanced approaches toward the classification of barriers in the most functional way. The first one is suggested by Puram et al. (2022) offering a theoretical underpinning behind the classification of barriers inspired by Liker's work (2004) on 4P (Philosophy, Process, People and partners and Problem-solving). They found that the most common relation between barriers presented in the literature, before their study, is either a non-existing relation (just creating listings) or a tendency to be hierarchical (created by interpretative structural modelling (ISM) or decision-making trial and evaluation laboratory (DEMATEL). Their goal was to reach a common and persistent lean barrier list that exists irrespective of the context or geographies where the studies took place (Puram et al. 2022) and make causal linkages among them. Their results show that the barriers are interrelated, pointing to the systemic nature of lean barriers. Their conclusion was that Philosophy and Problem-solving are categories of barriers with the highest causal strength. For example, if an organization invests in the strategic planning of financial and human resources, and if done effectively, it would lead to sustainable improvements in the organization. When looking at the causal effect of specific barriers, authors mention lack of resources; lack of lean knowledge, expertise and training; lack of systemic understanding of lean and the need for lean implementation; lack of leadership and top management commitment for lean transformation; shortage of lean consultant and trainers and lack of information transparency, feedback loops and coordination with different departments. The relationship among barrier groups of 4Ps is given Figure 1 where values represent causal strength.

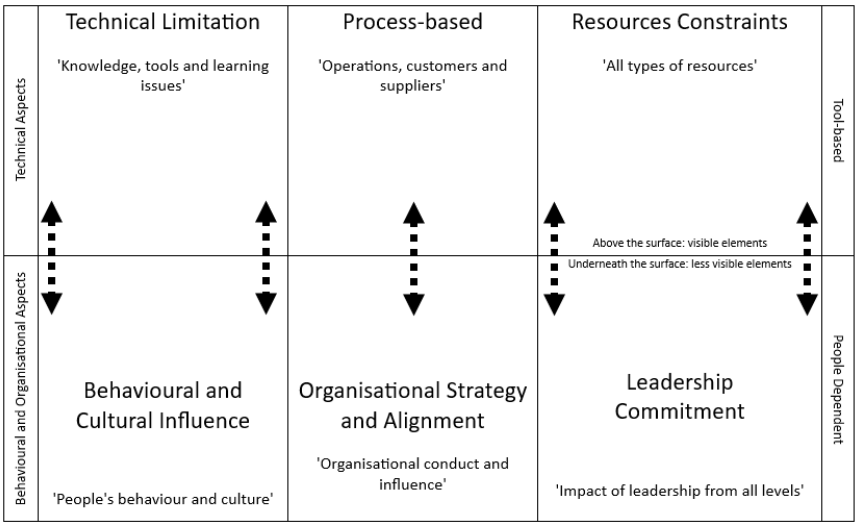
Figure 1 Groups of barriers and their causal relation



Source: Puram et al. (2022)

This knowledge will certainly help in focusing attention and resources on specific high causal strength barriers that will result in increasing the probability of successful lean implementation. The second contribution in advanced approaches toward classification of barriers, more specifically inhibitors, is suggested by Leite et al. (2022). Their main assumption was that lean is context-depended (Radnor et al., 2012), embedded in context and culture. No direct replication of lean success factors from one company to another is possible. Their approach was not to pinpoint specific barriers but to explain the interplay and impact of these barriers within the organization in two levels; the people-dependent or the tool-based level. Barriers (in Figure 2) are derived by thematic analysis of coders derived from systemic literature review of 204 papers, offering behavioral and cultural influence, organizational strategy and alignment, leadership commitment, technical limitation, process-based and resource constraints.

Figure 2 Organizational approach to group lean barriers



Source: Leite et al. (2022)

The degree of interplay between barriers is suggested by bidirectional arrows. The conclusion was that people-dependent barriers are more difficult to identify and have a great impact on lean. On the other hand, tool-based barriers are easier to identify and tackle, yet they create a fragmented implementation that cannot be sustained in the long-term. Behavior and cultural influence refers to behavior like resistance to change (Bateman and Rich, 2003) or lack of interest and commitment (Randor et al. 2006) serving as strong inhibitor or, if directed correctly, as empowering to employees. Organizational strategy and alignment implies the process of leading change, a supporting system creating a lean environment in the attempt to become a lean-thinking, rather than a problem-solving based organization (Bhasin and Burcher, 2006; Jain and Ajmera, 2019). Leadership commitment is crucial in the demonstration of direct commitment and enthusiasm toward the change process (Da Costa Nogueira et al., 2018). The technical aspects of lean barriers includes technical limitation, mainly knowledge, tools and learning issues (Knapić et al., 2024). Selecting only a couple tools or aspects of implementation contribute to a higher rate of failure in lean implementation. The second is Process-based which concerns operations, customers and suppliers' interplay. The main argument is to have clear customer and value identification, as well as supplier integration. The last one is Resource constraints concerning investment in time, human resources and financial resources to support the change needed. All the technical aspects are based on tools and techniques, which are very easy to depict when needed. They conclude that focusing only on the technical aspects helps the implementation in the short-term, but it has a negative impact in the long-run. Generally,

enhancing lean sustainability could be achieved through both levels - holistic, and long-term approach rather than the traditional tool-based and fragmented implementation heading towards failure.

Based on the systemic literature review one could propose the following research questions:
RQ1 *How to address barriers in lean implementation process in the context of business process and change management in order to have practical value in lean training and business improvement interventions.*

3 Methodology/Method/Model/Conception of analysis

In order to answer the proposed research question, a qualitative analysis of a semi-structured interview study was conducted. Targeted at lean managers in Croatian companies, we used purposeful sampling. This paper shows the results focused on the questions regrading lean implementation only. Large scale research included other aspects of lean implementation, future of lean development and specific topics of lean transformation. The study included 17 lean managers from 11 Croatian lean companies (Table 1). There is no complete list or precise number of lean companies in Croatia but the study by Leksic et al. (2020) assumed there are around 63 lean companies in Croatia. Based on this, our sample included around 17% of the total number of Croatian lean companies. We consider the sample size adequate since we reached data saturation. Interviews lasted approximately 50 minutes and they were performed face-to-face or by phone. Participants signed a consent and authorized the transcripts written upon the interview. The sample included various industries, company sizes and geographical regions in order to offer a more complete picture of lean in Croatia.

Table 1 Descriptive information from interview data on Croatian lean companies

ID	Type of industry and NACE code	Year of lean impl.	Lean mat. stage	Company size	Inter -view type	Role in company	G	Inter-viewee years in lean
1	Production of corrugated paper and cardboard and paper and cardboard packaging (17.21)	1990	mature	middle	face to face	CEO	M	14
2	Production of boilers, stoves and fireplaces (28.21)	2015	mature	middle	face to face	CEO	M	4
3	Production of other furniture (31.09)	2019	intro.	micro	face to face	CEO	M	1
4	Production of wire, chain and spring products (25.93)	2005	mature	middle	phone phone	quality manager assistant quality manager	M M	17 10
5	Iron casting (24.51)	2016	mature	middle	face to face	CEO lean coordinator	M M	6 6

					face to face			
6	Production of metal structures and their parts (25.11)	2014	mature	middle	phone	R&D manager	M	5
ID	**Type of industry and NACE code**	**Year of lean impl.**	**Lean maturity stage**	**Company size**	**Interview type**	**Role in company**	**Gender**	**Interviewee years in lean**
7	Production of refrigeration and ventilation equipment, except for household use (28.25)	2012	mature	middle	face to facefa ce to face	head of production technology production manager	M M	10 6
8	Production of refrigeration and ventilation equipment, except for household use (28.25)	2011	intro.	middle	face to face	quality manager	F	5
					face to face	production manager	M	2
					face to face	junior lean project manager	M	8
9	Data processing, server services and related activities (63.11)	N/A	N/A	large	phone	vicepresident of products	M	5
10	Production of pharmaceutical preparations (21.20)	2017	mature	large	face to face	LSS transformation program manager	M	6
					face to face	LSS transformation program manager	F	2
11	Production of pharmaceutical preparations (21.20)	2014	mature	large	phone	OPEX site leader	M	14

Note: LSS – Lean Six Sigma, CEO – chief executive officer, R&D – research and development, OPEX – Operation Excellence
Source: Author

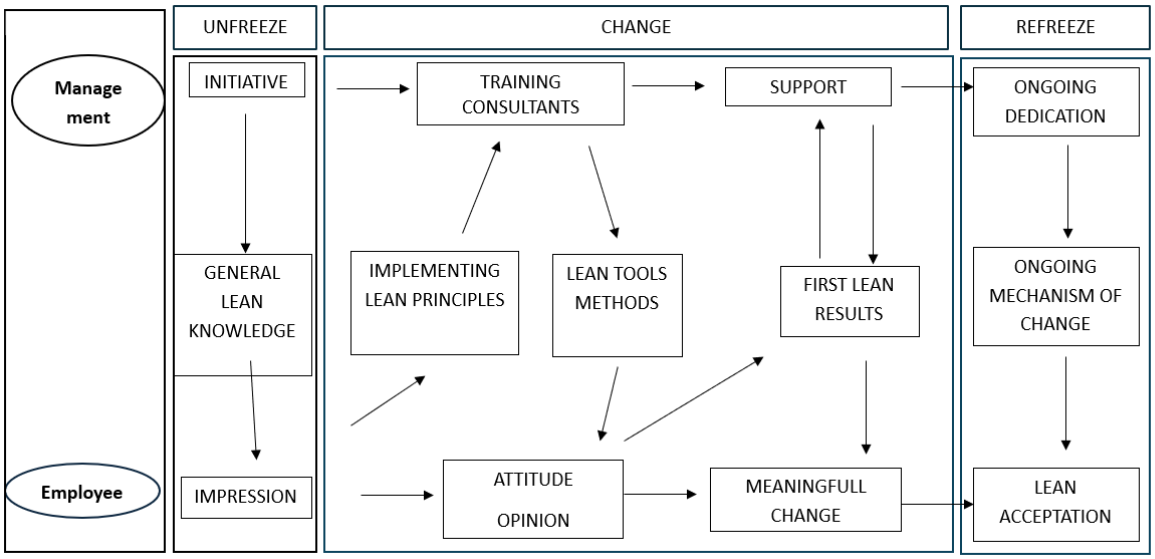
Out of the 11 companies, three are considered large, seven medium-sized enterprises, and one micro-enterprise. In some companies, there was more than one participant with the aim to provide a full picture of lean in the company since multiple people were overseeing the implementation. They validated the information on the implementation, but from different viewpoints (e.g., as a CEO or lean coordinator). Out of the 17 participants, only 2 were female (11.7%). There are some specifics among interviewed companies. While the majority of them have lean implemented in the traditional sense, one company is just starting to implement some tools (ID 3), one has agile methodology with lean components (ID 9), one 20 keys methodology and the IATF system (ID 4), and one has lean six sigma instead of just lean (ID 10).

The interviews were held in Croatian. Quotes used for presenting results were translated from Croatian to English. The transcripts were coded in the MaxQDA 2020 software. Coding was inductive-deductive. We started with selected codes connected to barriers but left space for emergent codes and bottom-up thematic analysis. Firstly, we extracted keywords and phrases which occur throughout interviews and made preliminary codes (Knapić and Jelenc, 2023). They were further developed and refined by re-reading the transcripts.

4 Empirical data (documentation background) and analysis

The research question was approached from several points of view and perspectives; hierarchy levels, iterations and four steps in lean implementation. The summary of the key research results are presented in Figure 3; management-employee dialogue, three cycles change management and iterations and steps in lean implementation process. Iterations presented are shown by arrows pointing the stream of business process, steps of lean implementation and the logic of flow interaction.

Figure 3 Connecting the Dots of Lean Implementation



Source: Author's research

4.1 The importance of management- employee dialogue

In the process of lean implementation there are two distinctive subjects that are important for the process. It is the level of management and employee. The level of management could be further divided into top management, manager production, plan manager, head of production and technology or equivalent and so called- middle man- the quality manager, lean coordinator, junior lean project manager or equivalent. The employee actually represents front-line employees on the production floor engaged in the lean. This paper focuses only on the relation between management and employee with no further distinctions on levels of management which is actually common in practice. The reason for that is that interviews were conducted with management only and therefore the material received by them is the perspective of management versus employees. The perspective of the employees is not included in the research question, interview protocol and therefore could not be presented in this study.

The lean implementation is and should be about the dialogue between management and employees. Therefore, it is important to offer a model with the division of authorities, responsibilities and communication channels needed for lean implementation to be successful. Lean implementation initiative starts with management and is directed towards employees. The following dialogue steps are about how to communicate the steps in lean implementation, actually introducing change management steps and iterations of communication. Out of the group barriers mentioned before, one aspect of the human part of the equation of successful lean implementation is mentioned here - organization and strategy based on communication. This relation is distinctive from two other perspectives as it points to the organizational nature of the relation. It is about organizations with the task of implementing lean. The division of authorities should be clear and, at the same time, there should be a bottom-up approach which makes the lean implementation more successful. The classic approach of management division created a line, actually separation, between the ones that create and the ones that implement. It is important to see lean implementation as an organizational challenge that is set up the other way round- management is about giving initiative and providing constant support in the most practical term of the word; while employees are about being motivated and constantly "strategically" supporting the process by giving feedback, initiative and suggestions. The lean implementation resembles contemporary management trends on servant leadership. Without strategic support of employees, the lean implementation is doomed to fail.

> *…Whenever we start with lean implementation in some department, employees always ask what will they get from lean implementation …(ID3)*
>
> *We (managers) ask them how we can help them (employees) and they tell us to intervene, to provide more resource, to change work procedures or something else… around 60% of their suggestions we do implement. (ID 5)*
>
> *If we do not get employees on our side and they do not start to improve themselves and we (managers) do not develop metrics and support system… everything is doomed to fail. (ID 7)*

4.2 Change management three cycles change

The literature on implementing lean in healthcare has made the greatest reported progress in implementing lean. They (Harrison et al., 2021) promote the introduction of change management models in the lean implementation process. The underlying idea is that in complex systems like healthcare, it is crucial to follow the nature of human behavior in the process of change. When you understand the stages, obstacles, the nature of resistance and employees' or any other stakeholder's point of reference, it is easier to lead the change through the specific steps or stages of implementing change. The implementation of such change management tools is expected to be flexible and contingent in nature in order to adjust to the specific environment, circumstance and nature of the business process. Systemic literature papers and reviews (Harrison et al., 2021) inform about the use of Kotter's 8-Step Model and Lewin's 3-Stage Model of Change as the most common models of change management. Additionally, they report that the main benefit was providing for a broad guiding framework for creating change, and not so much in helping them with the resistance to change or the creation of specific change related activities.

When applied to the general setting of the lean implementation process, one might conclude that following on change management literature some specific lean implementation steps can be depicted: unfreeze, change, refreeze. Within the three stage process framework there are four iteration processes from both the management and the employee perspective and five distinctive steps in lean implementation process recognized in the surveyed Croatian companies. The three cycle change management will be discussed within the general framework, whereas the steps and iterations will be described in the following section. The process is described by the feeds from Croatian companies about the mistakes and pitfalls they do in the light of the barriers mentioned by two theoretical models.

In the first, the unfreeze stage of change, the information on introducing lean was vaguely presented and was followed by a lot of theoretical knowledge on lean and less on what it is going to bring to the front- line employees and the specifics of such a change. The information was given either through a short written document or oral presentation by top management with no possibilities to ask questions regarding the vague explanation about the necessity of introducing lean. The most common approach was to use a pilot department, a pilot product line or business process. They firstly try to introduce lean tools and techniques on a small scale business process. The vital activity within this stage is to offer the perspective of the lean potential, to picture the future with and without lean, and to offer space for questions.

After the initial stage, the next stage – change - lean got introduced in additional departments, product lines or business processes. Small steps and victories are celebrated. The problem appears when front- line employees answer the management plea for giving feedback. They are ready to suggest improvement, yet waiting long for management approval. The management cannot provide needed resources, authorization of business processes and change take forever, the management realizes that the proposed improvement does not match customer value proposition and reject the employee's suggestion with no detail explanation just to name a few. The management introduced and imposed lean, but the change requires some form of dialogue and iterations that the management does not consider as urgent or priority. Management lacks responsibility to follow the change process and to answer the requests of front-line employees, to communicate, to continuously support and adjust. The vital activity within this stage is for the management to practice responsibility and agility in order to introduce change based on the management role model.

The refreezing stage starts as soon as management receives reports on the first lean implementation results. For them, it is a signal that the third stage, the refreezing stage needs to start. That is the moment when employees do not really understand the feedback and the supporting process, they start to lack intensive communication from management and start to feel abandoned; they do not understand and thus loose energy and eagerness to implement lean. Management thinks that they have put a new system of business process management in place and switch their attention to other business challenges in the company, but the employees are actually ready for a new round of small changes within the refreezing stage of implementing lean. They need small PDCA within the cycle of large PDCA. This is the moment where lean loses the possibility of being sustainable or at least constantly successful. The situation with Croatian lean companies is that they switched very fast to refreezing business processes. Once starting, lean is an on-going process with no value of being stopped. The vital activity within this stage is to put in place and practice a mechanism of change within the stage of refreezing.

> *…Employees started to give a lot of suggestions, always when something new comes, there is a ton of ideas and suggestions…If you do not reply with a*

reward system or any other system to keep them organized, if you do not delegate, and act upon their suggestions, there is high possibility that the number of suggestions will drop … (ID 10)

There is always something urgent to deliver. We are a production company, production comes first and it is very difficult to convince people that [lean] is just as important. One foreman, for example, is currently, among other things, repairing our main production line which is worth around 2 million euros. And now you need to explain to him that he should leave that job and that the line must stop, that lean is equally important and that he should go do the checklist [A/N lean tool]. And, I mean, there is simply no compromise, and that's very difficult." (ID 8)

Our internal team was overloaded and we needed someone to keep the pressure on the font-line employees so we hired consultsnats… out technology director did not have time to spend with employees and intoduce change … we needed that push. (ID 8)

We do not have a person in charge of lean. We gave that authority and responsibility to team lead employees and they run meetings and coordination on the level of production teams. (ID 8)

4.3 Iterations and steps in lean implementation

The results imply five step mechanisms on how the iteration steps follow in the lean implementation process and the behavioural characteristics that are expected by each of the hierarchy levels. The four step iteration has two sides: management level has the burden of giving the initiative, organizing trainings or engaging consultants, giving support and ongoing dedication. On the other side, employees form impressions, later on attitudes and opinions, they form the sense of meaningful change and finally accept lean.

First of all, management starts with the initiative to implement lean. The communication is about general lean knowledge, about why lean needs to be implemented in the company. Employee shape first impressions on the change process ahead of them. The second step is the first feedback by employee providing help in implementing lean principles in the current production process. Based on that, management gives more specific tools and methods through consultants and/or trainings and employees start to form attitudes about what and how they think about lean. It is a crucial step in which employees form an opinion. The second feedback that employees give is based on the first lean results of business process. This is the point in which we reach the crucial point for management - they need to provide support. Not just a declarative one, rather concrete action, change in the management style, change in business decisions on resources. Based on the management actions, employees can perceive the meaning of these changes and accept lean as a new normal way of performing business processes. The next fourth iteration, which is actually the last one, occurs when management is dedicated to lean implementation long after the initial lean implementation project ends. Although it is the last stage of lean implementation, it is not the last stage for lean being implemented in the company. If the mechanism of change is put in place, employees accept it and change is being accepted and implemented.

The five steps lean implementation is about introducing general lean knowledge, implementing lean principles, introducing lean tools methods, experiencing first lean results and creating an ongoing mechanism of change. The difference is that five steps of lean implementation address more the technical and process-based group of barriers while iterations explain more the people and human group of barriers of the lean implementation journey.

> *He [lean coordinator] has a lot of responsibility, but he doesn't have any authority. And that's the problem. So, the results of [his] work do not depend on [him]. At the moment, I have five finished projects just waiting for the implementation phase – and the implementation phase also depends on the production manager, control manager, who have to do a part of their job. (ID 2, CEO)*

> *…I think that the most crucial thing is that management was insisting on lean and pushed it through until the employees could see the first results, improvement, clean working space and much better organization of supplies and workflow. At some point management wanted to resign, but the good results were the motivation to stay in the lean... (ID11)*

5 Results and discussion

The literature review offers ways to capture lean implementation barriers allowing for theoretically founded conclusions based on systemic literature review on how to categorize, and group barriers and the interaction among selected categories of barriers. They do not offer a business process-based approach when it comes to the process of lean implementation. Therefore, this research focuses on how barriers interact between two levels of managerial hierarchy, with iterations and within steps in the business change process of lean implementation.

What is important in their relation is the dialogue between the two hierarchy levels. Previous models offered only the perspective of top management without intruding the interaction between the two levels. The direction was dominantly one way, from the top management down and very rarely the other way up. This could also be the reason why a lot of lean implementation processes were not successful. The feedback bringing the information back to the source for correction, reevaluation and control was not pointed as important but rather as self-understood. The suggested approach is in line with servant leadership stream of literature.

The proposed model is quite different when compared to other models currently dominating in the lean literature. The fact is that others gained their insights from systemic literature review and we from qualitative interviews with Croatian lean companies. Like the model developed by Puram et al. (2022), our model includes all barrier groups. However, the relations in our model are more realistic and concrete, ready to be used in lean implementation and business process interventions. When compared to the model of Leite et al. (2022), our model brings more emphasis on the actual relations and concrete steps when introducing lean in the company and presents the organizational framework and broad categories. It offers the perspective from the change management literature that can contribute to the success of lean implementation process, by understanding the nature of change and by proposing the fourth stage – the embedded change within the refreezing stage of change management.

The implications for research and managers is like a two-way bridge. Research should inform lean managers about the benefits of comprehensive reviews of systemic literature reviews and their potential benefit for everyday use. Additionally, the relation between barriers and actual activities is important to show case. The body of knowledge from change management is an important source of information managers should be knowledgeable about within lean trainings. On the other side of the bridge is the body of knowledge about iterations and communication that managers witness every day bur which is still not present in the lean research literature. The benefit of this paper is to build this kind of bridge between managers and lean research. The model is the extension of managers' experience and it is empowered by change management notions.

Concerning the limitation, this paper focuses only on the relation between management and employees with no further distinctions as to the levels of management, which is actually common in practice. Usually, it is not the top management that is greatly involved in the lean implementation process but the middle management, which is in most cases the leader in lean implementation. Additionally, the model itself is too simple at first-hand as it tries to be lean in presenting a realistic and value-added setting. On the other hand, it is too complex as there are too many elements to act as search variables, too many to operationalize and make suitable for quantitative testing.

Future research suggestions could be directed in several directions. The first one is to test for validity and reliability of the proposed model within different industries and across different countries. The second one is to go further with the interviews, but this time from the perspective of front-line employees in order to test whether there is a different perspective of lean implementation between employees and management.

6 Conclusions

This research was designed to help understand how lean gets implemented in Croatian companies. Apart from the systemic literature review that represented the source of information for others in the literature, the author tried to derive information using the qualitative method of interviewing Croatian lean managers. The insights derived based on the thematic method of analysing interviews and by combining the inductive-deductive approach in coding and explaining empirical data. The underlying assumption was that it was based on the subjectivity of the lean manager experiencing lean implementation in their companies. The perspective of their experience, the success and failure stories are being dismantled and then put together to create a model of lean implementation in Croatian companies with a specific perspective of change management, two hierarches' relations and the way their iteration works in addressing steps in the lean implementation process. It offered another perspective to the formal grouping of barriers present in the existing literature and enriched it with a number of perspectives, specific streams of activities, steps, interactions and nature of change in the lean implementation process.

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Investing in Customer Loyalty Programs: Simulating Costs in Defensive Strategies

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ABSTRACT

The aim of this research is to introduce a novel approach to address the challenge of allocating investment between offensive and defensive marketing strategies. By utilizing a modified Lanchester model of combat, the study seeks to offer insights into optimizing marketing decisions in competitive markets. Through the derivation of Nash feedback equilibrium, the research provides a robust framework for finding solutions to the resulting nonlinear system of equations, efficiently solved using the Newton method. Focusing on a duopoly scenario with varying market shares, the study aims to shed light on the intricate dynamics between offensive and defensive marketing efforts. Through computational methods like the Newton method, the research highlights the significance of comprehensively understanding these dynamics in order to develop and refine defensive marketing strategies. Ultimately, the aim is to elucidate how these strategies play a crucial role in enhancing a company's competitive edge in the marketplace. By bridging theoretical insights with practical applications, the study contributes to advancing the understanding of marketing strategies in competitive environments, while underscoring the importance of leveraging computational tools to inform strategic decision-making processes. Further exploration in this area holds promise for refining marketing strategies and improving competitiveness in dynamic market landscapes.

Key words: *Lanchester model, marketing strategies, differential games, competitive dynamics*

JEL classification: *C0, M0, M3*

1 Introduction

In today's highly competitive business environment, companies are constantly striving to retain their customer base and increase customer loyalty. One of the most popular strategies for achieving this goal is the implementation of customer loyalty programs. These programs are designed to reward customers for their continued patronage, encouraging them to make repeat purchases and remain loyal to the brand (Rossi and Chintagunt, 2023). However, while customer loyalty programs have been proven to be effective in retaining customers and increasing revenue, they also come with a cost. The implementation and maintenance of these programs can be expensive, with costs associated with rewards, promotions, and administrative expenses (Tsabita and Djamaludin, 2023). In addition, there is always the risk that competitors will launch similar programs, eroding the competitive advantage that the loyalty program provides. As such, companies must carefully consider the costs and benefits of investing in customer loyalty programs. This paper aims to provide insights into the costs associated with

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such programs, particularly from a defensive perspective. By simulating different scenarios and strategies, companies can better understand the potential costs of loyalty programs and develop effective defensive strategies to mitigate these costs. Navigating the complexities of a swiftly evolving market landscape necessitates the cultivation of precise analytical models to guide strategic marketing endeavours. The intricate web of interactions among market participants accentuates the practical importance of such undertakings, with implications extending to both academic inquiry and real-world business applications. Kimball's pioneering exploration of the Lanchester model's adaptability to marketing contexts in 1957, marked a seminal moment in the field's evolution (Kimball, 1957). The Lanchester model, originally developed to describe military combat, has since been adapted to analyze competitive marketing strategies. It provides a framework for understanding how the market share battles between firms can be viewed through the lens of strategic resource allocation. This model's application in marketing has opened new avenues for analyzing competitive interactions, particularly in understanding how companies can defend their market positions against aggressive competitors. At the heart of many strategic deliberations lies the pivotal question of resource allocation, particularly concerning defensive marketing initiatives. Scholarly investigations have underscored the efficacy of optimizing resource allocation strategies, especially in response to customer feedback and complaints, as a means to streamline overall marketing expenditures (Liu and Li, 2023; Long and Zhao, 2022). This focus on optimizing resource allocation is critical in the context of customer loyalty programs, where the goal is to maximize the return on investment by carefully balancing the costs and benefits of various program components. In recent years, there has been a notable uptick in research endeavours aimed at elucidating the competitive advantages wielded by various market players. The relentless pursuit of expanded market share by individual firms often precipitates a corresponding erosion of competitors' market presence. Consequently, the application of differential game theory has emerged as a potent analytical tool for delineating and understanding the dynamics of competition within diverse market structures (Cui et al., 2021). Differential game theory allows for the modeling of strategic interactions in a dynamic setting, where firms continuously adjust their strategies in response to the actions of competitors (Long and Zhao, 2022). This paper is squarely situated within this scholarly milieu, with a particular focus on leveraging a modified Lanchester model to address the nuanced interplay between offensive and defensive marketing strategies which is an indispensable consideration in the formulation of effective marketing strategies.

Through the utilization of Nash feedback equilibrium, the model yields a robust framework comprising a set of nonlinear equations that can be effectively solved using the Newton method. This approach enables the precise modeling of strategic interactions, providing valuable insights into the optimal allocation of resources for customer loyalty programs. The subsequent sections of this paper meticulously dissect the model's foundational components, elucidate the methodological intricacies of its application, and expound upon the resultant findings and their broader implications. By systematically unpacking these facets, this study aims to furnish scholars and practitioners alike with a deeper and more nuanced understanding of the intricate calculus underpinning competitive marketing strategies within the dynamic crucible of modern market environments. In the process of this analysis, several key themes emerge. First, the importance of understanding the cost structures associated with customer loyalty programs is paramount. These costs can be categorized into direct costs, such as rewards and promotional expenses, and indirect costs, such as administrative overhead and program management. Each category of costs requires careful consideration to ensure that the overall program remains financially viable. Second, the competitive dynamics of the market play a crucial role in determining the effectiveness of customer loyalty programs. The presence of similar programs offered by competitors can dilute the impact of a company's loyalty initiatives, necessitating a

more sophisticated approach to program design and implementation. This includes the need for continuous innovation and differentiation to maintain a competitive edge. Third, the role of defensive strategies in maintaining market position is highlighted. Defensive strategies are designed to protect a company's existing customer base from being poached by competitors. This involves not only the implementation of robust loyalty programs but also the strategic use of marketing resources to address potential threats and reinforce customer relationships. Finally, the integration of advanced analytical tools and models, such as the modified Lanchester model and Nash feedback equilibrium, provides a powerful framework for understanding and optimizing the interactions between offensive and defensive marketing strategies. These tools enable companies to simulate various scenarios and develop strategies that are both responsive to competitive pressures and aligned with long-term business objectives. In conclusion, this paper provides a comprehensive analysis of the costs and benefits associated with customer loyalty programs from a defensive perspective. By leveraging advanced analytical models and strategic insights, businesses can better navigate the complexities of implementing effective loyalty programs. The findings underscore the importance of continuous innovation, strategic resource allocation, and a dynamic approach to competitive interactions in maintaining a competitive edge in today's fast-paced market environment.

2 Literature review

Customer loyalty programs have gained significant attention in the marketing literature as a crucial tool for businesses to build and maintain strong relationships with their customers (Bolton et al., 2000). These programs offer various incentives, rewards, and exclusive benefits to encourage repeat purchases and foster customer loyalty (Reinartz and Kumar, 2002). Researchers have highlighted the positive impact of customer loyalty programs on customer retention, satisfaction, and overall profitability (Lemon and Verhoef, 2016). Customer loyalty is a pivotal aspect of consumer behavior, reflecting a customer's preference for a particular brand over its competitors, often driven by satisfaction with the product or service (Verma et al., 2022). It encompasses the willingness of customers to repeatedly choose a company's offerings, stemming from positive past experiences and a sense of trust and familiarity (Rossi and Chintagunt, 2023). While satisfaction is a central element, loyalty extends beyond mere repetition of behavior, encompassing emotional bonding, trust, and habitual choice (Verma et al., 2022). Consequently, customer satisfaction emerges as a critical determinant of long-term competitiveness, shaping the likelihood of repeat purchases and fostering brand loyalty (Liu et al., Ansari, 2021). In the realm of marketing strategies, loyalty programs have emerged as structured initiatives designed to incentivize and reward loyal buying behavior, thereby fostering customer retention and brand allegiance (Rossi and Chintagunt, 2023). By encouraging repeat purchases and shifting consumers towards dynamic decision-making, loyalty programs enhance retention rates and foster brand loyalty (Verma et al., 2022). However, it's crucial to distinguish between loyalty and rewards, as loyalty entails genuine support and commitment to a brand rather than mere accumulation of points or rewards (Ilyas et al., 2020; Verma et al., 2022). Moreover, loyalty programs serve as valuable tools for gathering insights into customer shopping habits and preferences, enabling organizations to tailor their services and offerings accordingly (Tsabita and Djamaludin, 2023). By segmenting customers based on their loyalty potential, organizations can effectively target and incentivize their most valuable customers while customizing their approach to different customer groups (Tsabita and Djamaludin, 2023). Thus, loyalty programs not only serve to retain existing customers but also facilitate the acquisition of valuable customer data, aiding in strategic

decision-making and enhancing overall customer experience. Investing in customer loyalty programs is considered a proactive strategy for businesses to safeguard against customer churn and competitive pressures (Homburg and Giering, 2001). By offering personalized incentives and rewards, businesses can create a sense of belonging and exclusivity among their customers, leading to increased customer engagement and loyalty (Wirtz and Lovelock, 2017). However, the implementation and maintenance of customer loyalty programs come with associated costs, including program design, rewards, technology infrastructure, and operational expenses (Nunes and Dreze, 2006).

Simulation techniques have been widely used in the literature to analyse the costs and benefits of customer loyalty programs and evaluate their effectiveness in different business contexts (Rust et al., 2000). By simulating various scenarios and parameters, researchers can estimate the return on investment of loyalty programs, optimize program design, and identify potential risks and challenges (Pfeifer et al., 2019). These simulations provide valuable insights for businesses to make informed decisions about their investment in customer loyalty programs and develop effective defensive strategies against customer churn. In the context of defensive strategies, investing in customer loyalty programs can be seen as a proactive measure to retain customers and protect market share from competitors (Fornell et al., 2006). By simulating the costs associated with loyalty programs, businesses can assess the feasibility and sustainability of such investments in the long run. Understanding the trade-offs between costs and benefits is essential for businesses to optimize their loyalty programs and maximize their impact on customer retention and profitability.

The decisions firms make regarding their marketing strategies, spanning various organizational levels, are shaped by insights from both the demand and supply sides of the market. Demand side insights encompass the firm's understanding of its customers, including their demographic, socio-economic, and psychographic characteristics, as well as their needs, wants, and behaviors (Liu and Ansari, 2021). Zhao et al. (2022) emphasize the importance of comprehending consumer behavior to drive strategic decisions, whereas Verma et al. (2022) promote a strategy grounded in consumer insights, termed consumer-based strategy. However et al. (2021) observe that a considerable portion of consumer behavior research lacks direct implications for marketing strategies.

On the supply side, insights encompass factors such as industry structure, firm resources and capabilities, and competitor analysis (Al-Hakimi et al., 2023). Market orientation, a cornerstone concept in marketing research, focuses on generating customer insights to inform business decisions ((Nnindini and Dankwah, 2022). Market-oriented organizations excel in understanding and satisfying customer needs, possessing superior information gathering and dissemination capabilities, and coordinating resources to deliver customer value (Long and Zhao, 2022). Mansouri et al. (2022) emphasize the role of market orientation in delivering superior customer value based on comprehensive knowledge about customers and competitors, leading to the development of distinctive marketing capabilities for a sustainable competitive advantage. They highlight the importance of ongoing information acquisition and sharing within the organization, facilitating the development of an organizational memory and fostering a culture of continuous learning. In order to maximize profit on rapidly changing market there have been many efforts to develop accurate models as the tools to support marketing strategy decisions. Development of such tools is a demanding task due to the complexity of interactions between companies on the market, and therefore is of practical interest both for research and industry implementations. The fundamental problem is often how to determine the share of budget to be allocated for defensive marketing strategies (Amir et al., 2021). It has been shown

that a maximization of cost restrictions due to customer complaints can reduce total marketing costs (Kim and Lim, 2021). Accordingly, in recent years there have been many studies in this field (Alarifi et al., 2023; Kunathikornkit et al., 2023; Morgeson et al., 2020). Determining the competitor relative advantages on the market is important in constructing efficient marketing strategies. Increase of market share of one company commonly leads to the reduction of a competitor's share on the market. Therefore, a differential game theory can be employed in modelling the market (Ma and Hu, 2020; Sayadi and Makui, 2014; Vatankhah and Samizadeh, 2022). Game theory, initially developed as a branch of microeconomics, has expanded its reach into diverse fields such as evolutionary biology, sociology, psychology, political science, project management, financial management, and computer science. This expansion is due to the ubiquity of strategic decision-making scenarios across different disciplines. Game theory provides valuable insights into various behavioral interactions, such as cooperative interactions within groups of animals, bargaining and exchange in marriage, and the incentivization of Scottish salmon farmers. A game typically involves two or more players, each with a set of strategies and corresponding payoff values (or utility values), often presented in a payoff matrix for two-player games. Differential games extend the concept of game theory to continuous time frames, modeling scenarios where each state variable evolves continuously according to a differential equation. These games are particularly useful for rapidly evolving defense scenarios, such as missile tracking problems where the pursuer and the target continuously adjust their strategies. Unlike iterative decision-making rounds, differential games capture the continuous movements and computations of each player, providing a more accurate representation of such scenarios. A fundamental concept in game theory is the Nash equilibrium. It describes a situation where no player can improve their payoff by unilaterally changing their strategy. Both pure strategy and mixed strategy Nash equilibria exist, and a game can have multiple Nash equilibria. Every game with a finite number of players and a finite set of pure strategies has at least one Nash equilibrium in mixed strategies.

Formally, let (S, f) be a game with n players, where SiSi is the strategy set for player i. The strategy profile S, consisting of all players' strategy sets, is $S=S1\times S2\times S3\times\cdots\times Sn$S=S1×S2×S3×⋯×Sn. The payoff function $f(x)=(f1(x),\ldots,fn(x))$f(x)=(f1(x),…,fn(x)) assigns a payoff to each strategy set $x\in S$x∈S. For a strategy xixi of player i and the strategy set $x-i$x−i of all other players, the resulting strategy set $x=(x1,\ldots,xn)$x=(x1,…,xn) yields a payoff $fi(x)$fi(x) for player i. A strategy set $x*\in S$x∗∈S is a Nash equilibrium if no unilateral deviation by any player increases their utility. Formally, $x*$x∗ is in Nash equilibrium if and only if: $fi(xi*,x-i*)\geq fi(xi,x-i*)$fi(xi∗,x−i∗)≥fi(xi,x−i∗) for all $xi\in Si$xi∈Si and all players $i\in\{1,\ldots,n\}$i∈{1,…,n}. Game theory has evolved from its microeconomic origins to become a powerful tool for analyzing strategic decision-making across numerous disciplines. Its concepts, particularly the Nash equilibrium, provide critical insights into the behavior of individuals and groups in competitive and cooperative scenarios.
Differential game theory can be employed for different market structures. Allocation of the budget for different brands of a single company can be observed. A hierarchical model of the oligopolistic market is explored through the application of the Lanchester model, as presented by Amir et al. (2021). There are efforts different than the common Lanchester model. A modified Vidale-Wolfe model is presented and compared with the Lanchester model (Wang and Wu, 2001; Yang et al., 2022). Besides the mentioned models, the diffusion model is often analyzed (Jiang and Jain, 2012; Ma and Hu, 2020; Najafi-Ghobadi, Bagherinejad et al., 2021). The basic assumption of the diffusion model is that consumers learn about the product present on the market for a period from the communication with other consumers rather than from advertising. Dynamic advertising-competition models incorporating additional attributes, such as sticky pricing and reservation pricing among multiple firms in the market, have been expounded upon in recent literature (Liu and Li, 2023; Long and Zhao, 2022). Differential

games frequently utilize Nash equilibrium strategies for resolution. Recent research has delved into the development of response models, considering factors like inflation to evaluate various strategies aimed at profit maximization (Cui et al., 2021; Long and Zhao, 2022). In this paper, a modified Lanchester model of combat is employed to solve the problem of offensive versus defensive budget allocation, important for the development of marketing strategies. Nash feedback equilibrium is used to solve such a model, resulting in a set of four nonlinear equations efficiently solved by the Newton method (Amir et al., 2021). The Lanchester model has been instrumental in providing insights into competitive interactions and market dynamics (Amir et al., 2021). By modeling advertising efforts as a form of combat, companies can determine optimal budget allocations for both offensive and defensive strategies. This approach helps firms understand how to best allocate resources to maximize market share while minimizing costs. The application of differential game theory allows for the continuous adjustment of strategies, reflecting real-time market changes and competitive actions. Moreover, the modified Vidale-Wolfe model incorporates aspects of advertising effectiveness and diminishing returns, offering a nuanced view of marketing dynamics. This model emphasizes the importance of strategic advertising investments, considering factors such as brand awareness decay and consumer response saturation (Yang et al., 2022). By comparing the Vidale-Wolfe and Lanchester models, businesses can identify which approach better suits their market environment and competitive landscape. In addition to these models, the diffusion model provides valuable insights into how products spread through markets via word-of-mouth communication. This model highlights the critical role of consumer networks in product adoption and the impact of social influence on purchasing decisions. Understanding these dynamics enables companies to leverage social interactions to enhance brand visibility and customer loyalty. Dynamic advertising-competition models further enrich the analysis by incorporating additional market complexities. Attributes such as sticky pricing, where prices remain rigid despite market changes, and reservation pricing, where consumers have a maximum price they are willing to pay, add layers of realism to the models. These factors are crucial for developing robust marketing strategies that can adapt to various economic conditions and consumer behaviors. The use of Nash equilibrium strategies in differential games provides a stable solution framework for competitive interactions (Long and Zhao, 2022).

By identifying equilibrium points in which no player can unilaterally improve their payoff, firms can develop strategies that are resilient to competitor actions (Wang and Wu, 2001). This stability is essential for long-term planning and investment in customer loyalty programs. Recent advancements in response models consider macroeconomic factors like inflation, which impact consumer purchasing power and market conditions. Incorporating these elements into marketing strategy models ensures that firms remain responsive to broader economic trends (Amir et al., 2021). This holistic approach enables companies to anticipate market shifts and adjust their strategies accordingly, ensuring sustained profitability and competitive advantage. In this paper, the focus is on applying a modified Lanchester model to address the critical issue of budget allocation between offensive and defensive marketing efforts. The model's equations capture the dynamic interplay between competing firms, allowing for the optimization of resource allocation. The use of Nash feedback equilibrium ensures that the solutions are practical and implementable, providing actionable insights for marketing strategists. The Newton method is employed to solve the resulting set of nonlinear equations efficiently. This mathematical approach ensures precise solutions, enabling firms to fine-tune their strategies for maximum effectiveness. By leveraging these advanced mathematical techniques, businesses can gain a competitive edge in the market. Overall, the integration of differential game theory, modified Lanchester models, and advanced mathematical methods offer a powerful toolkit for optimizing marketing strategies (Liu and Li, 2023). This approach not only enhances customer

retention and loyalty but also drives overall market performance. By continually refining these models and incorporating new market insights, companies can stay ahead of the competition and achieve long-term success. The strategic investment in customer loyalty programs, supported by these sophisticated models, ensures that firms can build and maintain strong customer relationships. By understanding the intricacies of market dynamics and consumer behavior, businesses can create targeted marketing campaigns that resonate with their audience. This personalized approach fosters deeper connections with customers, leading to increased brand loyalty and repeat purchases. In conclusion, the application of the differential game theory and related models provides valuable insights into the complex world of marketing strategy. By employing these advanced techniques, firms can optimize their budget allocations, enhance customer loyalty, and achieve sustainable competitive advantages in the market.

3 Modified Lanchester model and Nash feedback equilibrium

The Modified Lanchester model and Nash feedback equilibrium are pivotal concepts in strategic marketing and competitive analysis (Martín-Herrán et al., 2012). The Modified Lanchester model extends traditional combat models to capture the dynamics of market competition, focusing on both offensive and defensive marketing efforts. This model quantifies how companies allocate resources to gain market share and defend existing customer bases (Kim and Hahn, 2004). Nash feedback equilibrium, on the other hand, provides a framework for determining optimal strategies when multiple firms interact competitively. In this context, each firm's strategy is continuously adjusted based on the actions of its competitors, leading to a dynamic equilibrium state (Amir et al., 2021). These mathematical models are particularly useful for analyzing duopolies, where two firms dominate the market and their strategic decisions are highly interdependent (Cui et al., 2021). By incorporating elements of game theory, such as the Nash equilibrium, these models help predict the outcomes of strategic interactions over time. The Modified Lanchester model specifically accounts for the effectiveness of different marketing strategies, making it a valuable tool for resource allocation decisions. Nash feedback equilibrium ensures that the strategies are optimal in a dynamic setting, where competitors' actions are constantly influencing each other. Together, these models provide a robust analytical framework for enhancing competitive strategies in complex market environments.

The utilization of the Modified Lanchester model and Nash feedback equilibrium, as employed in this paper, is detailed in Martín-Herrán et al. (2012). The problem under consideration consists of a duopoly on the market. It is assumed that each company will try to gain new customers and thus strengthen its position on the market and at the same time retain existing customers. Change in Company 1 market share vary in time with:

$$\begin{aligned} \dot{M}(t) &= \left[f_1(a_1(t), b_1(t)) - f_4(b_2(t)) \right](1 - M(t)) \\ &\quad + \left[f_2(b_1(t)) - f_3(a_2(t), b_2(t)) \right] M(t) \\ M(0) &= M_0 \end{aligned} \tag{1}$$

where a_i and b_i are company, i-s offensive and defensive marketing efforts in time t, M_0 is initial market share, and f_i are functions as follows in equation (2):

$$
\begin{aligned}
f_1 &= \alpha_1 a_1 + \beta_1 a_1 b_1, \\
f_2 &= \gamma_1 b_1, \\
f_3 &= \alpha_2 a_2 + \beta_2 a_2 b_2, \\
f_4 &= \gamma_2 b_2.
\end{aligned} \tag{2}
$$

Coefficient α_i describes the effectiveness of the offensive marketing strategy, β_i interaction between offensive and defensive strategy and γ_i describes the effectiveness of the defensive strategy. Offensive and defensive marketing costs $C_{ij,}, j$=1,2 are assumed quadratic:

$$
\begin{aligned}
C_{i1} &= \frac{c_{i1}}{2} a_i^2, \\
C_{i2} &= \frac{c_{i2}}{2} b_i^2.
\end{aligned} \tag{3}
$$

Positive cost parameters are denoted $c_{ij.}$ Objective functions of companies 1 and 2 are:

$$
\begin{aligned}
&\max_{a1,b1} \int_0^\infty e^{-rt} h_1(t) dt, \\
&\max_{a2,b2} \int_0^\infty e^{-rt} h_2(t) dt,
\end{aligned} \tag{4}
$$

where:

$$
\begin{aligned}
h_1(t) &= g_1 M(t) - \frac{c_{11}}{2} a_1(t)^2 - \frac{c_{12}}{2} b_1(t)^2 \\
h_2(t) &= g_2 (1 - M(t)) - \frac{c_{21}}{2} a_2(t)^2 - \frac{c_{22}}{2} b_2(t)^2
\end{aligned} \tag{5}
$$

In order to solve the problem using Nash equilibrium, Hamilton- Jacobi-Bellman equations are introduced for companies 1 and 2:

$$
\begin{aligned}
&rV_i(M) = \max_{a_i, b_i} (k_i), \qquad i = 1,2 \\
&k_1 = g_1(M) - \frac{c_{11}}{2} a_1^2 - \frac{c_{12}}{2} b_1^2 + V_1'(M)\dot{M} \\
&k_2 = g_2(1 - M) - \frac{c_{21}}{2} a_2^2 - \frac{c_{22}}{2} b_2^2 + V_2'(M)\dot{M}
\end{aligned} \tag{6}
$$

Parameters $V_{i,}$, and V_i' are value function and value function derivative of company i. Maximization of RHS of Hamilton- Jacobi-Bellman equations determines the derivatives V_i':

$$
\begin{aligned}
V_1' &= \frac{c_{11} a_1}{\alpha_1 + b_1 \beta_1} \frac{1}{1 - M}, \\
V_1' &= \frac{c_{12} b_1}{\beta_1 a_1 (1 - M) + \gamma_1 M}, \\
V_2' &= \frac{c_{21} a_2}{\alpha_2 + b_2 \beta_2} \frac{1}{M}, \\
V_2' &= \frac{c_{22} b_2}{\beta_2 \alpha_2 M + \gamma_2 (1 - M)}.
\end{aligned} \tag{7}
$$

Directly from (7):

$$\frac{c_{11}a_1}{\alpha_1+b_1\beta_1}\frac{1}{1-M}=\frac{c_{12}b_1}{\beta_1 a_1(1-M)+\gamma_1 M},$$
$$\frac{c_{21}a_2}{\alpha_2+b_2\beta_2}\frac{1}{M}=\frac{c_{22}b_2}{\beta_2 a_2 M+\gamma_2(1-M)}. \quad (8)$$

The system of two equations in (8) is rearranged to find separate coefficients a_i:

$$a_1=-\frac{M\gamma_1}{2(1-M)\beta_1}+\frac{1}{2}\sqrt{\frac{1}{\beta_1^2}\left(\frac{4b_1c_{12}\beta_1(\alpha_1+b_1\beta_1)}{c_{11}}+\left(\frac{M\gamma_1}{M-1}\right)^2\right)} \quad (9)$$

$$a_2=\frac{(M-1)\gamma_2}{2M\beta_2}+\frac{1}{2}\sqrt{\frac{1}{\beta_2^2}\left(\frac{4b_2c_{22}\beta_2(\alpha_2+b_2\beta_2)}{c_{21}}+\left(\frac{(M-1)\gamma_2}{M}\right)^2\right)} \quad (10)$$

Setting $r = 0$ in (6), results in four nonlinear equations:

$$g_1M+\frac{c_{11}a_1^2}{2}-\frac{c_{12}b_1^2}{2}-\frac{c_{11}a_1}{\alpha_1+\beta_1b_1(1-M)}(\gamma_2b_2(1-M)-(\gamma_1b_1-a_2(\alpha_2+\beta_2b_2))M)=0 \quad (11)$$

$$g_1M-\frac{c_{11}a_1^2}{2}-\frac{c_{12}b_1^2}{2}+\frac{c_{12}b_1}{a_1\beta_1(1-M)+\gamma_1M}((1-M)(a_1\alpha_1-\gamma_2b_2)-a_2(\alpha_2+\beta_2b_2)M))=0 \quad (12)$$

$$g_2(1-M)+\frac{c_{21}a_2^2}{2}-\frac{c_{22}b_2^2}{2}-\frac{c_{21}a_2}{(\alpha_2+\beta_2b_2)M}(\gamma_1b_1M-(\gamma_2b_2-a_1(\alpha_1+\beta_1b_1))(1-M))=0 \quad (13)$$

$$g_2(1-M)-\frac{c_{21}a_2^2}{2}-\frac{c_{22}b_2^2}{2}- \frac{c_{22}b_2}{\alpha_2\beta_2 M+\gamma_2(1-M)}(-(a_2\alpha_2 -\gamma_1 b_1)M+a_1(\alpha_1+\beta_1 b_1)(1-M))=0 \quad (14)$$

One approach could be to put (9) and (10) to (11)-(14) in order to eliminate a_1 and a_2 from the system of equations (13). This results in a two-dimensional nonlinear problem, while coefficients a_i, are obtained from (9) and (19), after solving the system for b_i. In this paper nonlinear system of equations is formed directly from equations (9), (10), (11) and (13). To solve the system effectively, the Newton method is employed which assured fast convergence on test examples.

The Modified Lanchester model and Nash feedback equilibrium provide robust tools for analyzing and optimizing competitive strategies in a duopoly market. These models enable a detailed understanding of how companies can allocate resources between offensive and defensive marketing efforts to maximize market share and customer retention. By incorporating game theory elements and dynamic adjustments, the study offers valuable insights into the strategic interactions between competing firms. The application of these mathematical frameworks facilitates more precise and effective decision-making, highlighting the importance of adaptive strategies in a competitive environment.

4 Newton method for systems of nonlinear equations

The Newton method for systems of nonlinear equations is a powerful iterative technique used to find solutions to complex mathematical problems (Martínez, 2000). This method relies on linear approximations to iteratively converge to the solution of a system of nonlinear equations. At each iteration, the Newton method updates the current estimate by solving a linear system derived from the Jacobian matrix of partial derivatives. This process is repeated until the solution converges within a desired level of accuracy. One of the key strengths of the Newton method is its rapid convergence, especially when the initial guess is close to the true solution. The method is widely used in various scientific and engineering applications due to its robustness and efficiency. It can handle a broad range of problems, including those with multiple variables and highly nonlinear behavior. However, the Newton method requires the computation of the Jacobian matrix and its inverse at each iteration, which can be computationally intensive. Despite this, its quadratic convergence rate makes it a preferred choice for solving nonlinear systems in practice.

To describe a Newton method for a resolution of nonlinear system in four variables, a n-dimensional system is formulated as:

$$\begin{aligned} f_1(x_1,x_2,\cdots,x_n)&=0\\ f_2(x_1,x_2,\cdots,x_n)&=0\\ &\vdots\\ f_n(x_1,x_2,\cdots,x_n)&=0 \end{aligned} \quad (15)$$

In order to simplify the notation, the vector valued function is employed:

$$\mathbf{f}(x) = \begin{bmatrix} f_1(x_1, x_2, \cdots, x_n) = 0 \\ f_2(x_1, x_2, \cdots, x_n) = 0 \\ \vdots \\ f_n(x_1, x_2, \cdots, x_n) = 0 \end{bmatrix} \tag{16}$$

Assuming that a point:

$$\mathbf{r} = \left[r_1, r_2, \cdots r_n\right]$$

exists for which the equations (15) are satisfied, a variable **h** is introduced

$$\mathbf{h} = \mathbf{r} - \mathbf{x_m},$$

where $\mathbf{x_m}$ is the sequence of vectors representing iterative steps, hopefully converging to **r**.

Using a multivariate Taylor expansion in each of *n* original equations a vector form of (16) is:

$$\begin{bmatrix} f_1(x_m) + \sum_{j=1}^{n} h_j \frac{\partial f_1}{\partial x_j}(x_m) + O(h^2) \\ f_2(x_m) + \sum_{j=1}^{n} h_j \frac{\partial f_2}{\partial x_j}(x_m) + O(h^2) \\ \vdots \\ f_1(x_m) + \sum_{j=1}^{n} h_j \frac{\partial f_n}{\partial x_j}(x_m) + O(h^2) \end{bmatrix} = \mathbf{0} \tag{17}$$

Finally, to formulate theNewton method, a Jacobian of the *n* x *n* is necessary:

$$D\mathbf{f}(\mathbf{x}) = \begin{bmatrix} \frac{\partial f_1}{\partial x_1}(x) & \frac{\partial f_1}{\partial x_2}(x) & \cdots & \frac{\partial f_1}{\partial x_n}(x) \\ \frac{\partial f_2}{\partial x_1}(x) & \frac{\partial f_2}{\partial x_2}(x) & & \frac{\partial f_2}{\partial x_n}(x) \\ \vdots & & \ddots & \\ \frac{\partial f_n}{\partial x_1}(x) & \frac{\partial f_n}{\partial x_2}(x) & & \frac{\partial f_n}{\partial x_n}(x) \end{bmatrix}$$

Now, using vector notation, disregarding residual, and assuming that Jacobian is regular, (17) can be written as:

$$D\mathbf{f}(\mathbf{x}_m)\mathbf{h}_m = -\mathbf{f}(\mathbf{x}_m) \tag{18}$$

Next term in the sequence, *m* +1 is determined as:

$$\mathbf{x}_{m+1} = \mathbf{x}_m + \mathbf{h}_m. \tag{19}$$

Procedure to solve the problem is:

1) Set the initial vector $\mathbf{x}_1$
2) Calculate Jacobian
3) Solve the linear system in (18)
4) Proceed to the next iteration setting (19).

Results obtained by Newton method were fast convergent for the four-dimensional problem presented. For each problem tested, a precision of 5 decimal places was achieved in a maximum of 6 iterative steps. The Newton method for systems of nonlinear equations proves to be an exceptionally robust and efficient technique for solving complex mathematical problems. Its iterative approach, which utilizes linear approximations and the Jacobian matrix, ensures rapid convergence, particularly when the initial guess is in proximity to the true solution.

Despite the computational intensity of calculating the Jacobian matrix and its inverse at each iteration, the method's quadratic convergence rate significantly enhances its practicality for a wide array of scientific and engineering applications. The application of the Newton method to a four-dimensional problem demonstrates its effectiveness, achieving a precision of five decimal places within a maximum of six iterations. This level of accuracy and efficiency underscores the method’s utility in handling systems with multiple variables and highly nonlinear behavior. Overall, the Newton method remains a preferred choice for resolving nonlinear systems due to its convergence speed and robustness, making it a valuable tool in both theoretical and applied contexts.

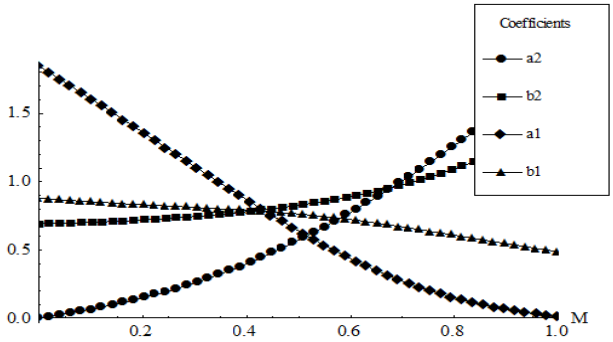
5 Results and discussion

This section presents a detailed analysis of the costs associated with implementing various marketing strategies within a duopoly market context, focusing on the effectiveness and financial implications of offensive versus defensive efforts. By leveraging the concepts and models discussed in previous sections, this study evaluates how different strategic approaches influence market share dynamics and resource allocation, providing insights into the optimal balance of marketing investments. The modified Lanchester model serves as the foundation for these simulations, enabling a quantitative comparison of marketing strategies.

5.1 Analysis of different effectiveness of defensive and offensive marketing strategies

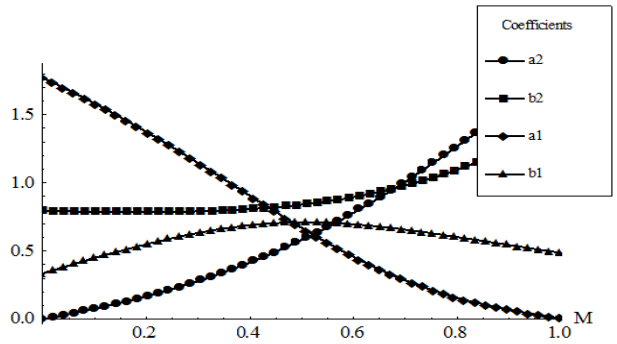
An analysis is performed for different offensive versus defensive efforts for company 1, in presence of company 2, in which efforts are balanced in offensive and defensive marketing strategies. Costs are for both companies normalized to 1. Coefficients for the modified Lanchester model employed are stated in each figure.

Figure1 Effects of different effectiveness of offensive and defensive marketing efforts (α_1=0.9, α_2=0.5, β_1=0.1, β_2=0.5, γ_1=1, γ_2=1, c_{11}=c_{12}=c_{21}=c_{22}=1)



Source: Author's treatment

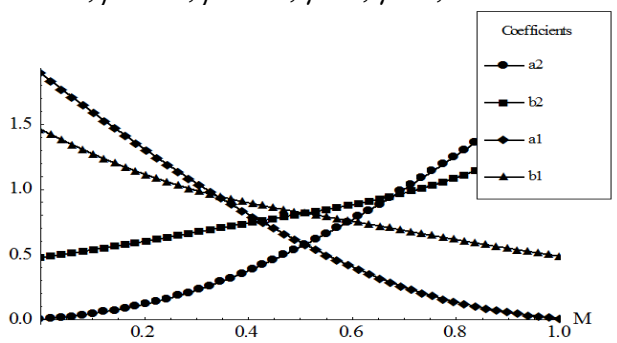
Figure 2 Effects of different effectiveness of offensive and defensive marketing efforts (α_1=0.75, α_2=0.5, β_1=0.25, β_2=0.5, γ_1=1, γ_2=1, c_{11}=c_{12}=c_{21}=c_{22}=1)



Source: Author's treatment

By analyzing coefficients presented in Figure 1, declaring significantly lower rate of effectiveness of a defensive marketing strategy, it is clear that in cases of penetrating the market by company 1, at the point with the market share M=0, most of the resources should be used for an offensive strategy. Although the number of existing customers is not significant for company 1, in case of the increase of the defensive effectiveness, according to data presented in Figure 2 and Figure 3, more resources should be allocated for a defensive strategy, for example for development of customer relationship programs.

Figure3 Effects of different effectiveness of offensive and defensive marketing efforts (α_1=0.5, α_2=0.5, β_1=0.5, β_2=0.5, γ_1=1, γ_2=1, c_{11}=c_{12}=c_{21}=c_{22}=1)



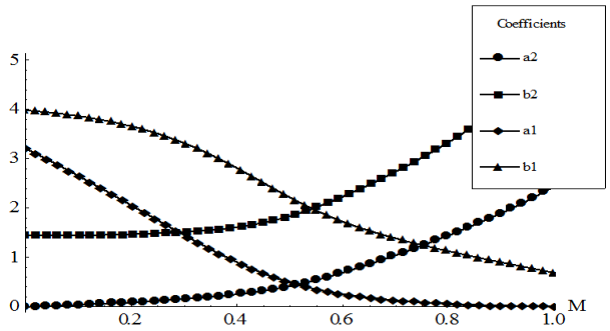
Source: Author's treatment

The analysis of the results for defensive marketing effectiveness in Figure 2 clearly shows that although offensive effectiveness is assumed 0.75, compared to defensive 0.25 at M=0, marketing efforts are only $a_1(M=0) \approx 2b_1(M=0)$. Results in figure 3 present a coherent conclusion that although effectiveness is equal for company 1 at M=0, more efforts are necessary for offensive marketing activities since the market share is not significant.

5.2 Analysis of costs on defensive marketing strategies

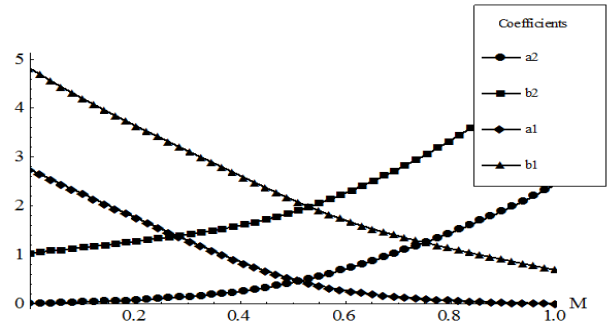
In this part analysis is performed taking into account different costs of defensive and offensive marketing strategies.

Figure 4 Effects of different costs of offensive and defensive marketing efforts (α_1=0.9, α_2=0.5, β_1=0.1, β_2=0.5, γ_1=1, γ_2=1, c_{11}==c_{21}=1, c_{12}=c_{22}=0,2)



Source: Author's treatment

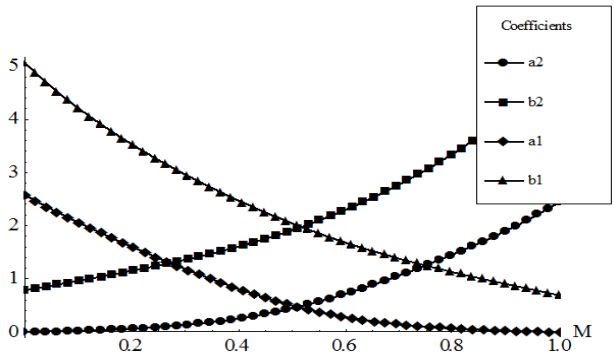
Figure 5 Effects of different costs of offensive and defensive marketing efforts (α_1=0.75, α_2=0.5, β_1=0.25, β_2=0.5, γ_1=1, γ_2=1, c_{11}==c_{21}=1, c_{12}=c_{22}=0,2)



Source: Author's treatment

Comparing the results in figures 4-6 at M=0, it is obvious that the coefficients a_1 and b_1, representing offensive and defensive marketing efforts of company 1 increased due to a significantly decreased cost of defensive marketing. Due to the assumed quadratic dependence of costs and efforts as in equation (3), it is clear that decreased cost of a defensive marketing strategy leads to evident increase of defensive efforts even in a low market share. Surprisingly, the difference between defensive and offensive efforts decrease significantly in a monopoly situation for company 1, M=1.

Figure 6 Effects of different costs of offensive and defensive marketing efforts (α_1=0.6, α_2=0.5, β_1=0.4, β_2=0.5, γ_1=1, γ_2=1, c_{11}=c_{21}=1, c_{12}=c_{22}=0.2)



Source: Author's treatment

In summary, the analysis demonstrates that the effectiveness and cost-efficiency of marketing strategies significantly impact a company's decision on resource allocation. Offensive strategies prove more beneficial when entering a new market, particularly when defensive effectiveness is low. However, as defensive effectiveness increases, investing in customer loyalty programs becomes more advantageous, highlighting the importance of adapting strategies based on market conditions. The study's limitations, including the assumption of a mature duopoly market and the strict division between customer retention and acquisition activities, suggest areas for further research to enhance the model's applicability to more complex market scenarios.

6 Conclusions

This paper offers a comprehensive method for analyzing and modeling both offensive and defensive marketing activities within the context of the relationship between two companies operating in a mature market. By leveraging the modified Lanchester model of combat and employing Nash feedback equilibrium, the study provides valuable insights into the dynamics of competitive marketing strategies. The findings indicate that the effectiveness and cost-efficiency of marketing strategies significantly impact a company's decision on resource allocation. Offensive strategies are more beneficial when entering a new market, particularly when defensive effectiveness is low. However, as defensive effectiveness increases, investing in customer loyalty programs becomes more advantageous, highlighting the importance of adapting strategies based on market conditions. The study reveals that companies entering the market can benefit from prioritizing defensive marketing efforts, especially when faced with lower defensive costs relative to offensive costs. A key deviation from existing studies is the observation that even in low market share scenarios, significant investments in defensive marketing can yield substantial benefits (Amir et al., 2021; Cui et al., 2021). This contrasts with traditional views that emphasize offensive strategies for market penetration. From an economic perspective, the study underscores the importance of cost considerations in shaping marketing decisions. The development of a computer code based on these methods facilitates a deeper exploration of how the effectiveness of defensive marketing activities influences overall marketing efforts, enabling businesses to simulate various scenarios and to optimize their strategies accordingly. The results suggest several policy implications for businesses operating in competitive markets. Companies should consider the cost-effectiveness of defensive marketing strategies, particularly customer relationship programs, as a means of building and maintaining market share. Policymakers and market regulators could also encourage

transparency in marketing costs and effectiveness to help companies make more informed decisions.

While this study provides valuable insights into the dynamics of offensive and defensive marketing strategies, several limitations need to be acknowledged. First, the model assumes a mature duopoly market, which may not capture the complexities and variations present in more dynamic or multi-faceted markets. Additionally, the strict division between customer retention (defensive) and new customer acquisition (offensive) activities does not account for the overlap and interplay between these strategies in real-world scenarios. Furthermore, the study relies on a set of fixed coefficients for the modified Lanchester model, which may not fully reflect the variability in marketing effectiveness across different industries and market conditions. The quadratic dependence of costs and efforts, while useful for modeling purposes, might oversimplify the cost structures encountered by businesses in practice. Future research should explore the applicability of the model to more complex market structures, including oligopolies and monopolistic competition. Investigating the impact of fluctuating market conditions and integrating more nuanced cost functions could provide a deeper understanding of marketing strategy effectiveness. Additionally, empirical validation using real-world data would strengthen the practical relevance of the findings. Further studies could also examine the role of digital marketing and technological advancements in shaping offensive and defensive strategies. As the marketing landscape continues to evolve, incorporating these elements into the model would provide more comprehensive insights and guide businesses in developing more adaptive and effective marketing strategies.

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