Big Data, Machine Learning, Artificial Intelligence and Blockchain in Corporate Governance

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Abstract

The paper analyzes the dynamics of scientific research in, and the practical application of, key Industry 4.0 technologies in corporate governance, namely big data, artificial intelligence, machine learning, and blockchain. The contribution of specific authors, citations, and collaboration networks are assessed, along with that of individual countries and research organizations. A bibliometric network analysis of publications indexed in the Scopus and OpenAlex databases for 2011-2022 revealed a steady increase in the number of publications on the topic under consideration, and therefore growing interest in it. The use of the aforementioned technologies in corporate governance is expected to lead to increased performance and transparency as well as improved cybersecurity. The authors provide recommendations for various groups of users to maximize the potential of Industry 4.0 technologies for businesses and the economy as a whole.

Keywords: corporate governance; sustainable development; corporate social responsibility; technology; Industry 4.0

Citation: Meiryani M., Warganegara D.L., Andini V. (2023) Big Data, Machine Learning, Artificial Intelligence and Blockchain in Corporate Governance. *Foresight and STI Governance*, 17(4), pp. 69–78. DOI: 10.17323/2500-2597.2023.4.69.78

Introduction

Along with increased global competition, tighter regulations, and other factors, the technological breakthroughs of the Fourth Industrial Revolution (Industry 4.0) are transforming society and radically changing the business landscape. Computer systems based on big data, machine learning, blockchain, artificial intelligence (AI), and other advanced solutions allow one to establish cause-and-effect relationships and prepare (if necessary, substantiate) recommendations (Gomber et al., 2018).

The digital transformation significantly expands companies' opportunities to develop innovative business models and streamline operations (Kajikawa et al., 2022). Platform and internet-based companies tend to be among the most valuable ones in the world (Iansiti, Lakhani, 2017). Managing technological development and innovation is becoming a strategic corporate priority and commands significant attention of researchers (Adhariani, De Villiers, 2018). However, most of the existing publications are primarily focused on specific aspects of using particular technologies in corporate governance, while attempts to generalize and structure relevant practices remain rare. The objective of our study is to bridge this gap through a comprehensive analysis of the use of key Industry 4.0 technologies (big data, machine learning, AI, and blockchain) in corporate governance and assess the practical effects for companies. The presented picture improves the information basis for making better decisions.

Literature Review

Corporate Governance: Objectives and Challenges

The principles and structures of modern corporate governance stem from the agency theory, which describes a contractual relationship between company owners (principals) and top managers (agents) (Jensen, Meckling, 1976). Principals (shareholders, investors, etc.) authorize agents to manage the company with the obligation to account for actions taken and provide complete and up-to-date information in a timely manner. The principal expects the agent to act in the former's best interests, and contribute to the creation of shareholder value.

According to the agency theory, corporate governance is a set of monitoring mechanisms required to protect investments and generate profits when ownership and control are separated, to eliminate uncertainty and information asymmetry in parties' relations (Shleifer, Vishny, 1997). The corporate governance system includes principles, methods, and values according to which the organization is controlled and managed with the objective of increasing its value (Velnampy, 2013). An adequate quality of the corporate governance system is critical for earning the trust of shareholders, investors, and other stakeholders, achieving long-term company viability, and sustaining sufficiently high performance. Failures in this system, including information asymmetry, can result in instability, financial losses, and serious reputational damage. Applying advanced technologies increases the transparency of asset management and thus the overall corporate governance quality (Agarwal et al., 2013).

The Scope for, and Practices of, Applying Industry 4.0 Technologies in Corporate Governance

Issues with preparing and auditing corporate reports are widely discussed in the literature. For example, manually entering data increases labor costs as well as the risks of unintentional (or deliberate) distortions (Du et al., 2019; Tan, Low, 2019). Many organizations maintain records in multiple formats, which requires careful document reconciliation (Brown et al., 2016).

Big data technologies allow one to analyze information (such as, e.g., company survey results) more rapidly and more thoroughly, to identify corporate governance practices' trends, variations, and patterns in different countries. It becomes possible to generate extensive data arrays covering a certain period of time, which allows auditors to track the dynamics of management standards.

Machine learning helps create predictive corporate governance rating models based on a number of important variables including financial data, company size, and industry-specific features. This becomes possible through the automatic analysis of various types of corporate reports (Rantanen et al., 2019; Agarwal et al., 2013).

Blockchain technology improves management processes through the efficient and transparent distribution of information (participants in the chain can exchange information in real time) (Fahlevi et al., 2022). All stakeholders have access to corporate governance data, which is adequately safeguarded to ensure its integrity and reduce alteration risks (Benlian et al., 2018; Velnampy, 2013; Dai, Vasarhelyi, 2017).

AI technologies are applied to analyze complex data arrays, which helps to identify non-obvious connections between factors affecting governance

quality indicators and allows for making international comparisons. It becomes possible to predict audit results and improve management practices. Used in combination with big data technology, AI allows one to monitor financial flows in real time (Cong et al., 2018; Ivaninskiy, Ivashkovskaya, 2020). Thanks to the improved quality of data analysis, a more accurate assessment of risks and opportunities, and the automation of repetitive processes, companies can make better-informed decisions and do so more efficiently.

Research Methodology

Research Questions and Variables

We explore the trends in the application of key Industry 4.0 technologies in corporate governance. The role of specific authors and co-authorship networks are assessed, along with the contribution of particular countries and research organizations to the studying of the aforementioned topic. The sample covered the period 2011–2022.[1] The Industry 4.0 concept comprises digital technologies designed to optimize production processes, including big data, AI, machine learning, and the Internet of Things.

These four key Industry 4.0 technologies served as independent variables for the analysis, since they allow one to successfully deal with complexity in corporate governance (which was used as the dependent variable) and improve its quality.

Data Types and Sources

Bibliometric network analysis combines expert-based techniques and quantitative tools to improve the quality of interpretations and conclusions (Chichorro et al., 2022). Elements such as semantics, citation statistics, and authorship are taken into account. The obtained results are presented in the form of network maps, to facilitate the perception of information by both the scientific community and the general public (Gibson et al., 2018). Visualization of the use of particular keywords identifies research topics (clusters) in specific areas, which allows one to establish authors' affiliation with specific journals to determine the former's geographical coverage and assess institutional and international collaboration in researching emerging technologies (Tanudjaja, Kow, 2018; Erthal, Marques, 2018).

In the course of our literature review relevant research papers were identified to build the study sample. The process comprised several stages: identifying appropriate publications, structuring them by topic and year of publication, designing an analytical structure, and comparing data. A keyword search was performed in the titles, abstracts, and keywords of papers indexed in the Scopus and OpenAlex databases, based on the following criteria: "time range or year of publication," "source type," and "document type." The time range was set between 2011 and 2022, the source type set as journal, and the document type as paper (article).

Figure 1. **Dynamics of Scopus-indexed Publications**

Source (here and below): authors, based on data from relevant databases as of 5 November, 2023.

[1] 2011 was chosen as the starting point of the study period because it was the year when the Industry 4.0 concept was first presented, at the Hannover Messe trade fair in Germany (https://www.hannovermesse.de/de/news/news-fachartikel /technologiekarten-machen-industrie-4-0-verstaendlich, accessed on 15.10.2023).

Box 1. Stages of Bibliometric Analysis

Step 1. Formulate keyword search queries:
- „big data" OR „artificial intelligence" OR „machine learning" OR „blockchain" AND „Corporate Governance"
- "big data" AND "corporate governance"
- "artificial intelligence" AND "corporate governance"
- "machine learning" AND "corporate governance"
- "blockchain" AND "corporate governance".

Step 2. Set sample building criteria (Scopus and OpenAlex databases):
- time range or year of publication: 2011-2022
- source type: journal
- document type: paper (article).

Step 3. Extract data from Scopus and OpenAlex.

Step 4. Identify relevant research papers:
- generate annual statistics for relevant publications
- conduct quantitative analysis, visualise bibliographic data network.

Source: authors.

Table 1 presents the identified publications' statistics before filtering.

Data Analysis Methods

A quantitative (statistical) method was applied in the bibliometric analysis to identify patterns in the dynamics of different types of publications on a particular topic. Two main techniques are commonly used to conduct such an analysis: performance analysis and science mapping (Cobo et al., 2011). The first uses indicators such as institution, country, and author, and assesses their impact on the basis of bibliographic data (Henderson et al., 2009). The second describes the structural and dynamic aspects of scientific publications (Borner et al., 2003). The stages of our bibliometric analysis are described in Box 1.

Results and Discussion

Annual Publication Trends

Figure 1 shows the number of papers published between 2011 and 2022 found in Scopus on the basis of the adopted research criteria. Until 2018 the number of such publications grew slowly; in 2011, 2012, 2014, 2015, and 2017 there was no growth at all (not a single new publication appeared). After 2018 their number grew steadily. In terms of the use of keywords relevant to the technologies under consideration in combination with the term "corporate governance", the largest number of Scopus-indexed papers turned out to be focused on AI (38 documents). Blockchain came second (30 papers), machine learning third (28), and big data fourth (26).

Figure 2 shows the growth in the number of papers published between 2011 and 2022, found on the basis of the same criteria in the OpenAlex database. In 2013, the number of publications on the use of big data technology decreased; in 2015 so did the number of papers on AI, machine learning, and blockchain. After 2015, research on all technologies under consideration sharply increased. As with Scopus-indexed publications, the most common keyword used in combination with "corporate governance" was "AI" (1,118 documents). "Big data" came second (1,004), "machine learning" third (696), and "blockchain" fourth (635).

An analysis of the dynamics of relevant publications indexed in the both databases revealed that the largest number of documents contain the keyword combination "AI" + "corporate governance". Therefore interest in this area is growing and the volume of knowledge about the use of AI in corporate governance generated in the course of scientific research and applied by government agencies and business organizations is constantly increasing. The same goes for big data, machine learning, and blockchain.

Table 1. Publication Statistics before Filtering

Search query	Number of documents found in the databases	
	Scopus	OpenAlex
1. "big data" OR "artificial intelligence" OR "machine learning" OR "blockchain" AND "corporate governance"	324	1432
2. "big data" AND "corporate governance"	85	2018
3. "artificial intelligence" AND "corporate governance"	120	2322
4. "machine learning" AND "corporate governance"	83	1458
5. "blockchain" AND "corporate governance"	83	1432

Source: authors.

Figure 2. **Dynamics of OpenAlex-indexed Publications**

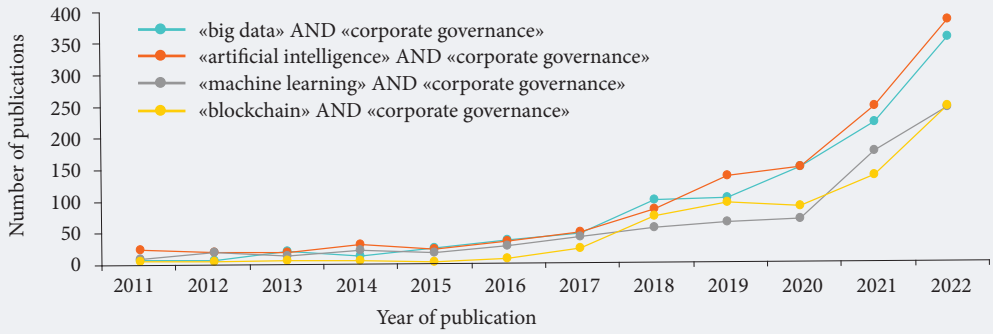
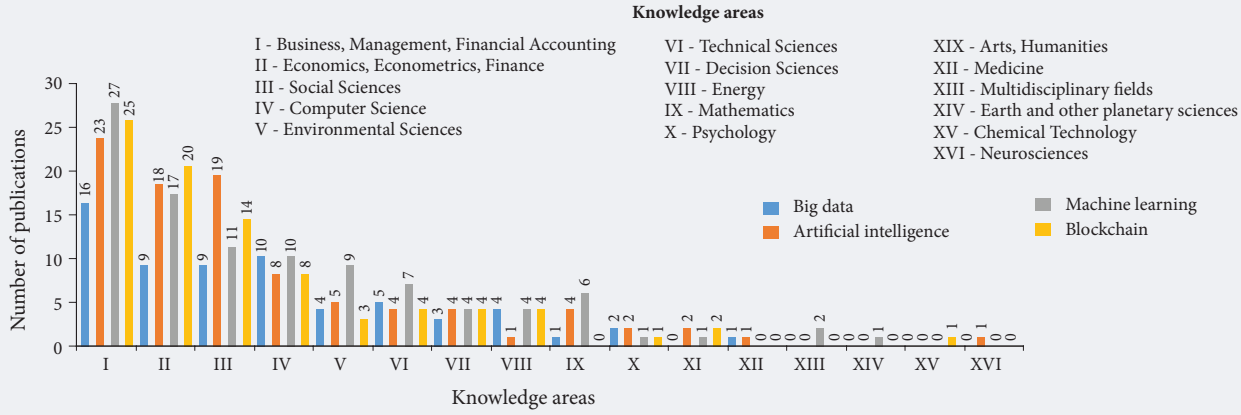


Figure 3. **Number of Scopus-indexed Publications on 16 Knowledge Areas**



Distribution of Publications

Figure 3 presents the results of an analysis of Scopus-indexed publications which meet the research criteria and contain the keywords "big data", "AI", "machine learning", "blockchain" and "corporate governance". A total of 3,453 documents were found and then broken down into 16 categories (business, management, accounting, economics, finance, social sciences, etc.).

As one can see in Figure 4, the largest categories are business, management, and accounting (27% of all papers), economics, econometrics, and finance (19%), and social sciences (15%). The smallest number of papers containing the keywords in question were found in the following categories: "medicine" ("big data", "AI"), "Earth and other planetary sciences" ("machine learning"), "chemical engineering" ("blockchain"), and neuroscience ("AI"). Their share ranges from 0.3% to 0.6%.

Figure 5 presents the results of the analysis of publications found using the same criteria and keywords in OpenAlex (17,752 in total). They were also divided into 16 categories. The largest turned out to be "Business" (27% of all papers), "Informatics" (13%), "Political Science" (10%), "Finance" (10%), and "Economics" (9%). Researchers were least interested in "Computer security" (3.2%), "Mathematics" (2.9%), "Management", and "Politics" (2.1% each). The results indicate that studies and analysis of Industry 4.0 technologies' application cover many different areas, but the scale of research significantly varies.

Figure 4. **Distribution of Scopus-indexed Publications across 16 Knowledge Areas (%)**

Researcher Co-Authorship Networks

Figure 7 shows a visualization of the co-authorship network based on the analysis of Scopus-indexed publications identified using the generalized search query formula 1 (Table 1). To be counted, each author must have co-authored at least two papers in partnership with others. Of the 449 authors in total (who have used the specified keywords), 27 participated in co-authorship.

Figure 8 shows a visualization of the co-authorship network based on the analysis of OpenAlex publications identified using the same criteria. Of the total of 1,445 authors whose papers contained the abovementioned keywords, 59 took part in co-authorship. In this visualization, author networks are not connected to each other, except for a few groups.

Distribution of Publications by Country

Figure 9 shows the top 30 countries by the number of OpenAlex-indexed publications on the use of the technologies in question in corporate governance. These include China, the UK, the US, Italy, Australia, and Indonesia, indicating a significant interest on their part in applying the relevant tools.

Organization Co-Authorship Networks

Figure 10 presents a visualization of the organizations' co-authorship network for the papers found in OpenAlex using the general search query 1 (see Table 1). Co-authorship networks show the links between organizations or countries (Zhao et al., 2017). To be included, each organization had to have at least two papers published jointly with other ones. Out of the total of 1,050 organizations, 134 took part in co-authorship according to this criterion. The largest group of interconnected units comprises 65. The largest number of papers co-authored with researchers from other organizations were published by staff members of the University of Oxford, University of Sussex, University of Glasgow, Shanghai University of Finance and Economics, University of Technology Sydney, and University of Indonesia.

Figure 5. **Number of OpenAlex-indexed Publications on 16 Knowledge Areas (%)**

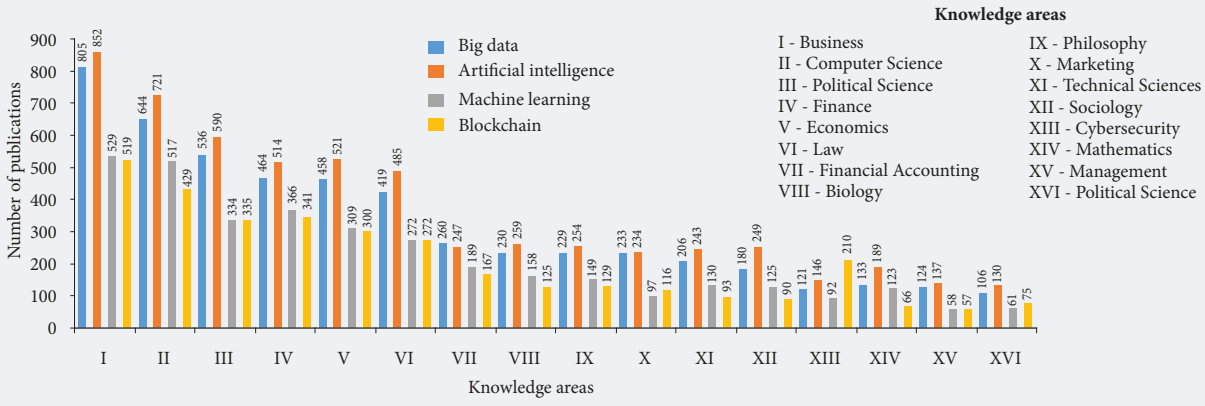


Figure 6. **Distribution of OpenAlex-indexed Publications across 16 Knowledge Areas (%)**

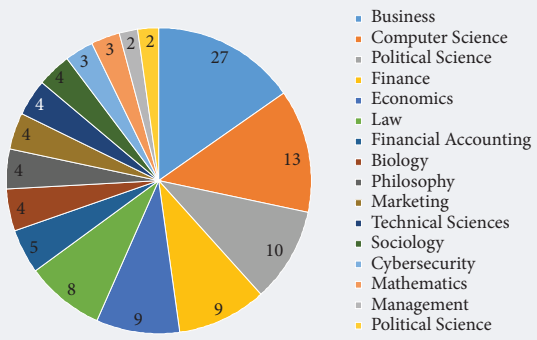
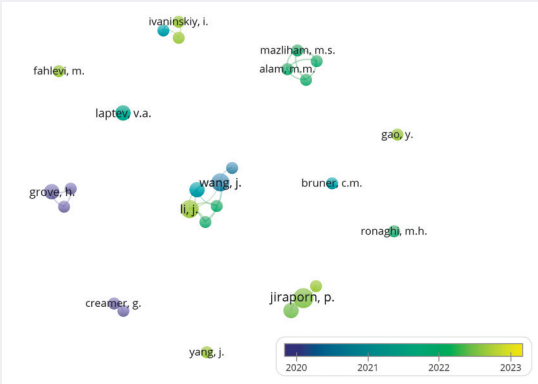
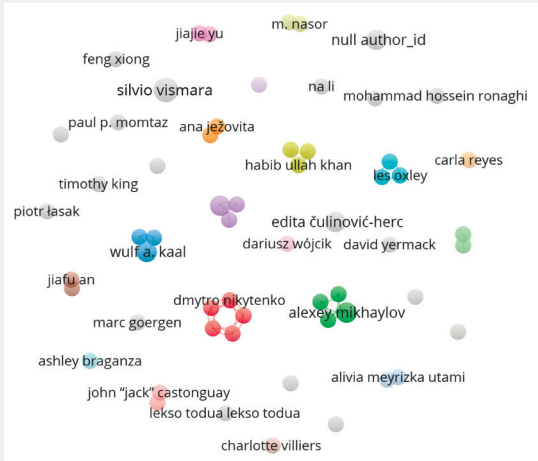


Figure 7. **Visualisation of Co-authorship Networks for Scopus-indexed Publications**



Note: the author's colour in the figure indicates the average year of their papers' publication. E.g. Grove, H. is displayed in purple (publication year 2019), Wang J. in blue (2020), Li J. and Jiraporn P. in green (2022).).

Figure 8. **Visualisation of Co-authorship Networks for OpenAlex-indexed Publications**



Discussion

Big data analytics has significant potential for application in various Indonesian sectors, organizations, and companies, especially to improve cybersecurity and infrastructure (Prasetyo, 2019). This technology opens realistic prospects to improve business performance, because valuable information extracted from large volumes of data can help entrepreneurs increase profits and productivity and create innovations (Erevelles et al., 2016). The first detailed analysis of using machine learning technology to automatically assess companies' online reputation was presented in (Rantanen et al., 2019). Reputation is critical to establishing and maintaining long-term relationships with partners. Despite the different interpretations of this concept, it generally refers to stakeholders' (customers, etc.) perception of the company in a particular context at a specific point in time. For example, machine learning was applied to predict the performance of directors of large US companies publicly traded in 2000-2011 by analyzing a large data array (Erel et al., 2019). Such algorithms can determine which directors may not be popular with shareholders.

AI can be applied to cut costs and manage risks to increase profit margins.[2] A number of studies noted that AI can help improve management and reduce costs through automation based on real-time big data analysis. Robotization can improve the quality of data provided to shareholders for making informed decisions (Ivaninskiy, Ivashkovskaya, 2020; Shu-Hsien, 2005).

More important benefits of blockchain include cutting transaction times, minimizing fraud risks, and streamlining complex procedures which hinder traditional trading (Fahlevi et al., 2022). Blockchain is usually associated with the popular cryptocurrency Bitcoin, since the latter is based on the former (Yermack, 2015; Crosby et al., 2016). However, this technology is applied not only in finance and securities, but also to improve food security, environmental management, and urban planning (Anascavage, Davis, 2018). It has the potential to become the basis of crowdfunding platforms in the future (Harahap et al., 2019). Currently, most such sites' security systems cannot yet adequately protect the funds of project participants. The Ethereum blockchain platform, designed to store a wide range of different data types, is positioned as a possible solution to this problem.[3]

[2] https://cse.engin.umich.edu/stories/computer-scientists-employ-ai-to-help-address-covid-19-challenges, accessed on 15.10.2023.

[3] https://medium.com/@feryycah/mybillcash-is-a-decentralised-microtask-platform-on-the-blockchain-2b39d69a567f, accessed on 15.10.2023.

Figure 9. **Number of Publications by Country (OpenAlex data)**

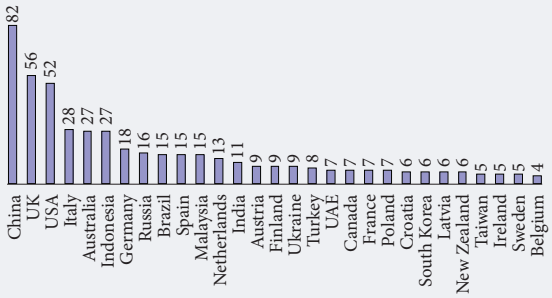
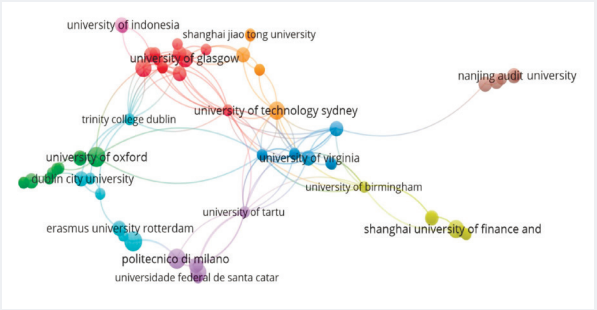


Figure 10. **Visualisation of Organisations' Co-authorship (OpenAlex data)**



Conclusion

This study highlights the importance of stepping up innovation and international cooperation to more fully realize the potential of Industry 4.0 technologies in corporate governance. Our results indicate that the use of these technologies has significantly increased in various areas. However, an analysis of co-authorship networks revealed that the collaboration between different groups of researchers specializing in the area under consideration remains insufficient. More comprehensive research is needed to expand the knowledge network. Comparing the situation across countries and research organizations allowed for identifying leaders in the building of the knowledge base and competencies in the application of big data, AI, machine learning, and blockchain. Coordinated implementation of these technologies in the course of digitalization helps to optimize risks and improve the quality of corporate governance. It also increases one's ability to analyze data and make more accurate predictions and better-informed decisions. Recommendations for various user groups are summarized in Table. 2.

To conclude, we would like to note that the use of advanced technologies is largely determined by organizations' size and the context of their activities. The existing studies in this area are based primarily on secondary data, which may be incomplete. As a result, it is difficult to identify and correctly compare trends, while differences in company sizes and industry specifics are not sufficiently taken into account. It is recommended that primary data is more actively used in future research (such as case studies, surveys, and experiments of specific enterprises) in order to obtain more complete and contextualized information.

Table 2. **Recommendations For Applying Industry 4.0 Technologies To Improve Corporate Governance**

User group	Recommendations
Businesses	• Use machine learning to automate routine and repetitive tasks (such as inventory management or customer service, identifying customer behavior patterns, forecasting sales, etc.); • Use AI to better serve customers and workers (AI-powered chatbots and virtual assistants), analyze risks, manage finances, improve performance in manufacturing, logistics, and human resources.
Future researchers	• Focus on in-depth analysis of applying blockchain in supply chain management, the use of big data to support strategic decision making, and the importance of machine learning for managing risks; • Summarize the findings presented in the literature, identify trends, patterns, and context-specific features in the use of these technologies. The information can be presented in graphic visual formats.
Public authorities	• Increase the funding for research and development of the technologies under consideration, to encourage businesses to actively adopt them; • Establish an institution responsible for assessing the impact of Industry 4.0 technologies on businesses and the economy as a whole in terms of data privacy and security, and maintain a balance with the interests of society.
General public	• The general public can obtain a better understanding of Industry 4.0 technologies by taking part in face-to-face and online training courses, seminars, etc.; • The general public should be aware of the potential risks of using digital systems and procedures; • The general public should develop cybersecurity skills.

Source: authors.

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