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Contact to corresponding author: Barbara Ocicka, barbara.ocicka@sgh.waw.pl

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Jolanta Turek

SGH Warsaw School of Economics, Poland

 orcid.org/0000-0002-4553-2815

Barbara Ocicka

SGH Warsaw School of Economics, Poland

 orcid.org/0000-0003-4898-9594


Waldemar Rogowski

SGH Warsaw School of Economics, Poland

 orcid.org/0000-0003-0214-3446

Bartłomiej Jefmański

Wroclaw University of Economics and Business, Poland

 orcid.org/0000-0002-0335-0036

The role of Industry 4.0 technologies in driving the financial importance of sustainability risk management

JEL Classification: G320; M140; M150; M160; F230

Keywords: *sustainability risk; financial risk; financial performance; Industry 4.0 technologies; Blockchain, Big Data analytics, the Internet of Things, cloud computing, artificial intelligence, 3D additive manufacturing; digital transformation*

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Abstract

Research background: The climate crisis is one of the greatest challenges the world is facing in the 21st century. The global response to this problem must comprise transitions in land and ecosystems, energy, urban, infrastructure, and industrial systems and a transformation in enterprise and risk management. With the global pressure to fight climate change and achieve the Sustainable Development Goals, the innovative potential of Industry 4.0 technologies (blockchain, Big Data analytics, the Internet of Things, cloud computing, artificial intelligence, 3D additive manufacturing and technology platforms) has been subject to enormous interest among researchers and practitioners. Additionally, the COVID-19 pandemic has accelerated technology investment and digital transformation in many business areas, potentially including sustainability risk management.

Purpose of the article: The purpose of this paper is to explore the scope of Industry 4.0 technology implementation in sustainability risk management and its financial impact.

Methods: Based on the survey research, the authors verified if enterprises implementing Industry 4.0 technologies during the last five years are benefiting from their investment depending on the number of technologies. Due to the ordinal measurement scale of the analyzed variables, the verification of hypotheses was carried out using the Mann-Whitney U test.

Findings & value added: In the opinion of the managers surveyed, the number of Industry 4.0 technologies implemented in the sustainability risk management process does not affect the enterprise's aggregate Financial Performance Indicator, individual financial indicators (ROA, ROE, OPM, NPM and FLR) and the enterprise's ability to manage financial risk. This study contributes to the literature on the technological transformation of the sustainability risk management process and its financial importance. The design and implementation of sustainable development strategies imply a long-term perspective, including the achievement of risk management effects in this area. The implementation of one technology, let alone two or more, is a difficult and time-consuming management challenge before synergy effects are achieved in an integrated technological eco-system.

Introduction

The climate crisis is one of the greatest challenges the world is facing in the 21st century. The UN Intergovernmental Panel on Climate Change (2019) asserts that the global response to this problem must comprise transitions both in land and ecosystems, energy, urban, infrastructure, and industrial systems and a transformation in enterprise and risk management. On the one hand, climate change increases uncertainty in business and financial circles (Ozili, 2020). On the other hand, there is an expectation of a revision of the role of business and financial systems in helping to accelerate responses to climate change (Newell, 2020). There is comprehensive literature dealing with responses to climate change from various perspectives and disciplines, covering issues such as business strategies, models, processes, relationships and management concepts, methods and tools (George *et al.*,

2021; Gohar & Indulska, 2021; Kara *et al.*, 2021; Chen *et al.*, 2022; Hösli & Weber, 2022). Sustainable development (SD), defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (The World Commission on Environment and Development, 1987), is an increasingly important concept in the multidimensional assessment of contemporary enterprises by stakeholders. It is sufficient to mention green financing by banks (sustainable banking) or other financial institutions and Socially Responsible Investment (SRI) by private and public investors (Aracil *et al.*, 2021; Losse & Geissdoerfer, 2021; Kumar *et al.*, 2022a). As a result, the importance of SD increases in relation to financial risk, financial results and the market value of enterprises. With the global pressure to fight climate change and achieve the Sustainable Development Goals (United Nations, 2015), the innovative potential of Industry 4.0 technologies (T4.0) has been subject to enormous interest among researchers and practitioners. In fact, the COVID-19 pandemic has accelerated technology investment and digital transformation in many business areas, including sustainability risk management (SRM). It is clear that T4.0, such as additive manufacturing, artificial intelligence, Big Data analytics, blockchain, cloud computing, digital platforms, and the Internet of Things, have the potential to successfully support SRM (Ocicka & Turek, 2021). Digital transformation offers previously unexploited opportunities in risk management and impacts that are still not well recognized, especially in the early stage of T4.0 adoption.

The purpose of this paper is to explore the scope of T4.0 implementation in the sustainability risk management process and its financial impact. We investigate this topic for two reasons. First, despite the growing volume of literature¹ on the application of T4.0 in many business areas for sustainability, previous publications rarely referred to sustainability risk management. We extend the empirical evidence on the financial effects of T4.0 implementation within SRM. We expect that digital transformation will start to drive financial performance and mitigate financial risk within a period of five years following the implementation of technology. Additionally, we suppose that the number of T4.0 implemented within digital transformation can be important in financial terms. Second, most of the previous studies cover technologically advanced markets, while very few

¹ According to data in Web of Science and keywords: sustainability and Industry 4.0 technologies, the number of articles published in the given years is as follows: 13 (2016), 25 (2017), 56 (2018), 110 (2019), 201 (2020), 297 (2021) (27.12.2021).

examine markets characterized by a high share of early adopters, such as the markets of Central and Eastern Europe. Our empirical study is driven by the following key research questions:

(1) *Are there differences in the impact on Financial Performance Indicators (FPI) between companies that have implemented one or more T4.0 within the SRM process?*

(2) *Are there differences in the impact on key financial indicators between companies that have implemented one or more T4.0 within the SRM process?*

(3) *Are there differences in the impact on financial risk between companies that have implemented one or more T4.0 within the SRM process?*

To answer the abovementioned research questions, we utilized an original four-stage research procedure, including a literature review, a pilot quantitative survey, a qualitative case study and an in-depth quantitative survey among 120 enterprises.

This paper is structured as follows. The next section ensures a theoretical background including a definition of “sustainability risk”, the essence of the sustainability risk management process and its digital transformation. Furthermore, the significance of financial performance and financial risk is explained. The scope of the theoretical background was sufficient to derive hypotheses for verification. We then present materials and methods used in our empirical study. Next, our attention is focused on the results of research investigating the impact of digital transformation of the SRM process on financial risk and financial performance in the short to medium term. In the next part, we discuss the empirical findings in light of the literature review and formulate implications for further research studies and business practice development. Finally, the main conclusions are highlighted, as are the research limitations, and future research directions in management, economy and finance are specified.

Literature review

Sustainability risk management in Industry 4.0

Risk management is an ongoing process. It encompasses the identification, analysis, and response to risk factors that form part of the business operations. Through the risk management process, organizations attempt to control future outcomes to the greatest possible degree by acting proactively rather than reactively. The risk management process offers the potential to reduce both the possibility of a risk occurring and its potential impact. Its purpose is to increase the organization's short-term and long-term value to its stakeholders. There are two principal approaches to risk management: Enterprise Risk Management (ERM) and Silo Risk Management (SRM) (McShane, 2018). ERM is a holistic, disciplined and top-down approach (Abd Razak *et al.*, 2016; Johnston & Soileau, 2020) while SRM operates on silos, limiting the sharing of risk information and the achievement of an organization-wide view of risks (Almeida *et al.*, 2019). Organizations began to abandon the "silo" approach in favor of an integrated one (Lndqvist, 2014). ERM international standards are helpful in this process. Four main standards have been developed so far: ISO 31000 (2009), the COSO ERM Framework (2004), the Australian & New Zealand Standard on Risk Management AS/NZ 4360 (2004), and the FERMA Risk Management Standard (2003). The abovementioned standards have been issued in different geographical regions, by different institutes and authorities. Despite the differences between them, all consider the four fundamental stages of the risk management process (although they may use different words to label them) as indicated in Figure 1.

According to the Federation of European Risk Management Associations (FERMA), on the one hand, sustainability risk (SR) is an "uncertain social and environmental event or condition that, if it occurs, can cause significant negative impact on the company"; and on the other hand, it is "the opportunity that may be available to an organization because of changing social or environmental factors" (FERMA, 2021, p. 7). FERMA paid attention to the neutral perception of sustainability-related risk, which by its very nature can constitute both a threat and an opportunity. It is also worth mentioning the definition of SR proposed from the perspective of corporate finance and SRI. In line with the EU Sustainable Finance Disclosure Regulation, SR is "an environmental, social or governance event or

condition that, if it occurs, could cause an actual or a potential material negative impact on the value of the investment” (European Union, 2019). Additionally, the perspective of different interest groups (stakeholders) should be considered in defining the risk related to sustainable development (Van Vliet *et al.*, 2020). In this regard, SR can be defined as the possibility of a deviation from the economic, social or environmental value expected by stakeholders (Ocicka & Turek, 2021). Enterprise Sustainability Risk Management (ESRM) is perceived as an extension of the enterprise risk management (ERM) concept (Abdul Aziz *et al.*, 2016). The ESRM framework integrates “the corporate goals of creating economic and financial value and the aspects of environmental and social responsibility” and “can protect, create and enhance business value through measurement and management of sustainability threats and opportunities” (Yilmaz & Flouris, 2010, p. 166).

In global business, ESRM is an integrated process that requires the adoption of a supply chain perspective. The idea of Supply Chain Sustainability Risk Management (SCSRM) is conceptualized as “the integrated management of a nexus (those specific) supply chain risks that are related to the natural environment, the society and the viability of the firm” (Gianakis & Papadopoulos, 2016, p. 456). The definition of Supply Chain Sustainability Risk (SCSR) as “a condition or a potentially occurring event” residing “within a focal firm’s supply chain”, which “may provoke harmful stakeholder reactions”, has been widely used in the literature (Hofmann *et al.*, 2014, p. 168; Busse *et al.*, 2017, p. 18). SRM in global multi-tier supply chains requires the deployment of the latest solutions, including T4.0. Furthermore, digital transformation may accelerate the development of an integrated, collaborative, and data-driven SCSRM (Ocicka & Turek, 2021). In business terms, Gong and Rebiere (2021, p. 13) noted the revolutionary character of digital transformation (DT), stressing that it refers to “a fundamental change of a whole new form, function or structure with the adoption of digital technologies that create new value”. Andriole (2017) did likewise, calling DT “a digital shock”. However, other authors define DT as a deliberate and ongoing digital evolution of, e.g., a company, business model, process or methodology (Mazzone, 2014). DT within business processes management is a fundamental change to a process using digital technologies, which results in an improvement to stakeholders (Gong & Rebiere, 2021). Today’s DT is driven by T4.0. Table 1 presents major T4.0 incorporated into SCSRM and key sources of sustainable value creation.

Recent studies conducted by Nagy *et al.* (2022) and Valaskova *et al.* (2022) in the Slovak automotive industry confirm that the development of companies and industries through the implementation of T4.0 is a vital driver of business growth and sustainable performance across value chains.

Based on the literature review, DT in the Industry 4.0 era allows organizations to improve sustainable performance. However, there are many ways to analyze and measure this influence from different perspectives and in various domains. We aim to verify whether enterprises investing in the digital transformation of the sustainability risk management process are benefitting from their investment in terms of the financial impact.

Financial performance and financial risk

Financial performance is a broad term referring to the economic health of an entity in a defined period. It describes the degree to which a company has accomplished its financial objectives and may also assess the outcomes of implemented strategies as well as the efficiency of managerial decisions and the effectiveness and efficiency of employing assets and capital to generate revenue and profit (Sun & Li, 2021). It also reflects the commercial success of the company, and can be used to compare a company to its competition and to assess the future potential of its business model (DiSegni *et al.*, 2015; Derun & Mysaka, 2018). Financial performance analysis provides essential information to different stakeholders. For example, it is a key determinant considered by prospective investors when making investment decisions (Chabachib *et al.*, 2019). Furthermore, financial institutions examine financial performance thoroughly before providing funds. Likewise, managers regularly monitor the company's financial indicators to better understand and assess the situation as they seek to ensure business continuity (Bărbuță-Mișu *et al.*, 2019). Thus, monitoring financial performance is necessary to prevent corporate distress (Andekina & Rakhmetova, 2013). High financial performance is attractive and desired by stakeholders.

Various measures are used to assess the financial health of an enterprise. They are called financial ratios or financial key performance indicators and are calculated based on data included in financial statements. Information on financial performance is obtained through economic and financial analysis. The use of a particular set of indicators depends on the addressee of the information as well as on the purpose. Among the most frequently used measures are the following: Return on Assets (ROA) for

assessing profitability, Return on Equity (ROE) for assessing financial stability, EBIT for reflecting the competitive position and valuation of a company, net profit margin for describing a company's ability to generate profit, the financial leverage ratio for assessing a company's ability to meet its financial obligations, and the current ratio and quick ratio for measuring a company's ability to pay its short-term and current liabilities (Iqbal *et al.*, 2019).

Financial performance is affected by numerous internal and external factors in both positive and negative ways. Due to the complex and rapidly changing business environment, corporate risk exposure varies. For example, climate change was treated as a black swan event until recently. Now, it is perceived as an urgent risk (AON, 2021). Moreover, "climate action failure is the most impactful and second most likely long-term risk" (World Economic Forum, 2021, p. 8). The COVID-19 pandemic has also demonstrated that this environment is more volatile and interconnected than ever before. The issues of black swan events (unpredictable events) and tail risks (events resulting in extraordinary or severe losses) have returned to public discourse. Companies face new types of risk emerging from far-reaching global challenges regarding the pandemic (short to medium term) and climate change (long term). Until now, many tail risks were accepted by managers due to a lack of effective insurance products to hedge against. Acceptance was the only available risk management strategy. Those available on the market, e.g., insurance against natural disasters, were usually very expensive due to overly simplistic probability models (prohibitively expensive to insure against). The business environment has changed drastically, so many more companies are willing to insure against low-probability high-impact risks in the short term (tail risk). Thanks to the implementation of T4.0 (e.g., artificial intelligence, machine learning or Big Data analytics), the prediction of tail risks is more accurate in terms of business impact and probability. Therefore, insurers offer customized products which provide a healthy cost-benefit ratio and are more willingly accepted by clients.

Stakeholders expect companies to respond to looming concerns on the environmental, social and governance (ESG) level, as they also do so. For example, the banking sector incorporates ESG considerations into its credit rating analysis. Feng *et al.* (2018) argue that sustainability management is a fundamental undertaking in the implementation of operations strategy to

improve corporate financial performance. A similar view is held by Afum *et al.* (2021).

Thus, companies need to take a multidimensional risk perspective and revise their risk management processes, tools and infrastructure to manage their financial performance, i.e., prevent financial losses, maximize profits and shareholder value, and eventually manage financial risk.

The Chartered Institute of Management Accountants (CIMA) defines financial risks as those related to the “financial operation of a business — in essence, the risk of financial loss (and in some cases, financial gain)” (Woods & Dowd, 2008, p. 4). The abovementioned financial loss results from the failure to achieve financial objectives. The three distinct categories of financial risk are market risk, credit risk and financing / liquidity risk. Therefore, the sources of financial risk are interest rates, currencies, equities and commodities, the nature and structure of financial markets, and the asset price generating process (Onsongo *et al.*, 2020).

A characteristic feature of financial risk is its measurability and the ability to directly capture its impact on financial results. Although financial risk factors are of external origin, the extent to which they materialize depends on management decisions and activities. Financial performance and financial risk are interdependent. They are reflected in a corporate financial rating provided by trusted credit rating agencies. A downgrade in its financial rating affects, e.g., reputation and entails higher costs of financing, which translates into worse financial results and higher financial risk.

The impact of Industry 4.0 technologies on corporate performance — previous empirical studies

The implementation of Industry 4.0 technologies undoubtedly helps companies to build their competitive advantage through the improvement of managing, optimizing, enhancing and automating numerous aspects of business processes including manufacturing, supply chain, and finally risk management processes (Fatorachian & Kazemi, 2021). T4.0 provide reliable real-time data and insights essential to making faster and more accurate business decisions (Li *et al.*, 2020). They are perceived as a new source of value generation (Martinez-Caro *et al.*, 2020). T4.0 can eventually boost the efficiency and profitability of a company’s entire business operation and potentially improve financial performance (Alkaraan *et al.*, 2022) in the long run and contribute to risk reduction. Since the announcement of the fourth

industrial revolution based on cyber-physical systems in 2012, many articles have been published on T4.0. However, the scientific literature on the effects of T4.0 on corporate financial performance is still scarce.

Li *et al.* (2019) conducted a survey in which authors identified 460 companies in China implementing T4.0. The survey revealed that the implementation of T4.0 significantly improves corporate financial performance, as well as innovation activities and stock returns, but has no significant impact on supply chain efficiency (Li *et al.*, 2019). Chen (2021) drew attention to the importance of Industry 4.0 maturity and confirmed that it significantly affects internal business process performance, which in turn affects customer performance through the mediating effect of supply chain performance. The author also proved that internal business process performance and supply chain performance fully affect financial performance through the mediating effect of customer performance (Chen, 2021).

So far, most studies have been devoted to the overall impact of T4.0 on economic, environmental or social performance. The implementation of T4.0, not only by companies but also by their stakeholders, may affect corporate financial performance. For example, insurers implementing T4.0 are able to offer tailored insurance products (Srivastava *et al.*, 2022), while banks may carry out more accurate financial analysis in the process of lending (Kumar *et al.*, 2022b).

The full benefits of implementing Industry 4.0 technologies are available to companies when they operate in a business ecosystem in which related companies (stakeholders) have also implemented T4.0 and use their potential in mutual relations. Benitez *et al.* (2020) revealed the importance of T4.0 as drivers of relationships between the companies and value co-creation, determining the evolution from the centrality of business association toward a mechanism of coordination of complex projects, and finally to a platform-driven ecosystem. Researchers emphasized the significance of multi-stakeholder relationships management driven by T4.0 for value co-creation and joint management of business processes such as e.g. new product development and commercialization (Barrane *et al.*, 2021) as well as procurement and supplier relationship management (Portna *et al.*, 2021).

Antony *et al.* (2023) investigated how performance effects vary between early and late adopters of T4.0. Based on qualitative research, authors proved that “the early adopters may see a marginal increase in profit and increased stock price compared to late adopters” (Antony *et al.*, 2023). As research on T4.0 is still in its infancy, there are several research studies on

the direct impact of T4.0 on performance, while there is no research on how the number of implemented T4.0 affects financial performance and financial risk.

Research method

In order to ensure the high quality of the research procedure, we used a methodological triangulation to collect data: a literature review, a quantitative survey and a qualitative case study. The research procedure included four stages as shown in Figure 2 and described below.

At the first stage, the in-depth literature review covered the following topics: (1) T4.0: blockchain, Big Data analytics, the Internet of Things, cloud computing, artificial intelligence, 3D additive manufacturing and technology platforms, (2) the use of T4.0 in the risk management process, and (3) sustainable supply chains.

The conclusions reached from the in-depth literature review enabled the authors to move on to the second stage of the research procedure, namely the implementation of a pilot survey. The purpose of this survey was to determine the extent to which T4.0 have been implemented and how they may affect SCSRM of an international coverage. The survey commenced in the last quarter of 2020 and lasted for two months. A Computer-Assisted Web Interviewing (CAWI) method was used, based on a web-based questionnaire that was designed and validated in collaboration with experts prior to the survey. This method allowed for the standardization and continuous monitoring of the survey, as well as facilitating contact with a group of senior managers of business processes in international supply chains. We contacted 44 managers directly by email or telephone, explaining the purpose of the study and asking them to complete an online questionnaire. We adopted the following target sample selection criteria: professional competence in supply chain management and the respondent's international scope of responsibility (covering a geographical area of several countries at a minimum). The response rate to the survey was 23%. The respondents answered questions related to the T4.0 mentioned above. Due to the relatively low number of respondents, the survey constituted a pilot study. It contributed to the development of knowledge and provided valuable lessons for the actual in-depth quantitative survey carried out in the fourth phase of the research procedure.

In the third phase, we conducted a semi-structured individual interview with a senior supply chain manager representing a global company operating in the life science industry. The in-depth interview was conducted in January 2021. Based on the results, a case study was developed to analyze the role of technology platforms for business collaboration in SCSRM in detail.

At the fourth stage of the research procedure, an in-depth quantitative survey was conducted among 120 enterprises. The sample was selected using purpose sampling from 245 entities listed on the Warsaw Stock Exchange (WSE), operating in the production and distribution sectors. We conducted the study among companies listed on the WSE, assuming that these entities are very likely to implement T4.0, due to the size of their business operations, stakeholder expectations and access to capital. The process of T4.0 implementation requires considerable financial outlays which may be beyond the reach of micro, small and medium-sized companies. Some of the companies (31 entities) in the sampling frame are included in the WIG ESG Index². To qualify for the sample, a company had to meet the following criteria included in the survey filter questions: (1) the company's supply chain has an international scope and (2) within the last five years, the company has implemented any of the T4.0 (blockchain, Big Data analytics, the Internet of Things, cloud computing, artificial intelligence, additive manufacturing or digital platforms). During the survey carried out in September-October 2021, interviews were conducted with 120 entities meeting the conditions described above. The respondents were company representatives holding senior management positions in risk, finance and the supply chain, presidents, board members, and managing directors. The study was conducted using the CATI method. It took place during the pandemic, which influenced the choice of the CATI method as it enabled high-level managers to participate in the survey by providing remote contact at convenient times. A questionnaire containing closed questions of a strictly specified order and unchangeable wording was used to carry out the study. The participants primarily represented the industrial processing sector (66.7%) and wholesale and retail trade (22.5%). From the

² The WIG ESG Index has been published since September 3, 2019. It comprises WIG20 and mWIG40 stocks listed on the Warsaw Stock Exchange (WSE). The Index tracks the performance of blue-chip companies with superior ESG index ratings for environmental, social, and governance practices provided by Sustainalytics and contains an assessment of compliance with WSE's corporate governance principles.

point of view of the position in the supply chain, the two largest groups in the sample are companies producing finished goods (46%) and Tier 1 suppliers (38%). Next are Tier 2 and Tier 'n' suppliers (15%), wholesaler distributors (12%) and retailer distributors (9%). Finally, the research sample also included 18 companies from the WIG-ESG Index (15%).

Based on the results of the CATI research study, the following hypotheses were tested:

H1. *The number of Industry 4.0 technologies implemented in sustainability risk management process has no significant impact on the company's aggregate Financial Performance Indicator.*

H1a. *There are no significant differences in the assessment of the company's position in terms of Return on Assets (ROA) depending on the number of implemented T4.0.*

H1b. *There are no significant differences in the assessment of the company's position in terms of Return on Equity (ROE) depending on the number of implemented T4.0.*

H1c. *There are no significant differences in the assessment of the company's position in terms of Operating Profit Margin (OPM) depending on the number of implemented T4.0.*

H1d. *There are no significant differences in the assessment of the company's position in terms of Net Profit Margin (NPM) depending on the number of implemented T4.0.*

H1e. *There are no significant differences in the assessment of the company's position in terms of the Financial Leverage Ratio (FLR) depending on the number of implemented T4.0.*

H2. *The number of Industry 4.0 technologies implemented in the sustainability risk management process has no significant impact on the company's level of financial risk.*

For the purposes of the analysis, two groups of companies were identified based on the number of implemented T4.0. The first of these included

the enterprises which had implemented only one technology ($N_1=79$), while the second group was made up of the enterprises which had implemented at least two Industry 4.0 technologies ($N_2=41$).

The article presents the assessment of the financial performance both on the basis of aggregate FPI and the following individual financial indicators: ROA, ROE, OPM, NPM, and FLR. Managers of enterprises were asked to assess the position of their enterprise in the industry in terms of the abovementioned financial indicators. The assessment consisted in indicating the decile of the enterprise regarding the value of selected financial indicators. During the interview, managers were informed about the current value of the indicator for the industry in which the enterprise operates. Then, for the purposes of analyzing the collected information, individual assessments were assigned ranks in the range [1, 10], where the first decile was assigned the rank of 1 and the tenth decile was labelled 10.

FPI was estimated based on five financial indicators: ROA, ROE, OPM, NPM, and FLR. An additive function was adopted in the construction of the indicator. Weights were not used for the indicators, meaning that the same impact of individual financial indicators on the aggregate indicator was adopted. The aggregate indicator values were normalized in the range [5-50]. All financial indicators have a stimulating preference function (the higher the indicator value, the better).

The Mann-Whitney U test was used to check whether there is a correlation between the number of implemented T4.0 and the assessment of the enterprise's position in terms of financial indicators and the aggregate FPI indicator. The test is a non-parametric equivalent of the classical *t*-test. The test can be used for ordinal measurement scales and does not require meeting the assumptions of the distribution normality and the homogeneity of variance. The Shapiro-Wilk test did not confirm the normal distribution of the analyzed data set. The Mann-Whitney U test made it possible to verify the hypotheses about the absence of statistically significant differences in the distribution of the assessments regarding the position of enterprises in terms of financial indicators in two groups of enterprises identified according to the number of T4.0 (hypotheses H1, H1_a-H1_e).

In order to verify the hypothesis H2, the managers' opinions on the impact of the implementation of T4.0 supporting sustainable development risk management in the supply chain on increasing the ability to manage financial risk were used. An ordinal scale with five categories was applied to measure the following opinions: "I strongly disagree", "I disagree", "I

neither agree nor disagree”, “I agree”, “I strongly agree”. For the purposes of verifying the hypothesis H2, individual categories were assigned ranks, i.e. the category “I strongly disagree” was assigned rank 1 and the category “I strongly agree” rank 5. The hypothesis was verified using a Mann-Whitney U test.

In order to verify the hypotheses presented in the paper, the significance level $\alpha=0.05$ was adopted.

Results

The financial performance of enterprises was assessed in two groups of enterprises identified based on the number of implemented T4.0. The assessment was conducted both in terms of individual financial indicators and the aggregate FPI indicator. The selected descriptive statistics for all financial indicators are presented in Table 2 and Figure 3.

The highest value of the aggregate FPI indicator was observed in group 1, yet the average indicator value was higher in the group of enterprises which had implemented at least two T4.0. At the same time, this group was characterized by the lower variation of FPI values. In the case of the remaining indicators, the lowest and the highest average values in both groups of enterprises were observed for the ROA and OPM indicators, respectively. It is also worth highlighting that in the case of the ROA indicator, the lowest values of standard deviations were recorded, which means a high level of similarity of enterprises in terms of this indicator value. For each of the indicators, higher average values were observed in the group of enterprises which implemented at least two T4.0, with the largest differences related to the FLR indicator. The statistical significance of the observed differences in the analyzed groups of enterprises, and thus the verification of the hypotheses H1, H1_a-H1_e, was performed using Mann-Whitney U statistics (see Table 3).

For each of the indicators, there are no grounds to reject the null hypothesis at the significance level of $\alpha=0.05$. Thus, the number of implemented T4.0 does not affect the assessment of the enterprise’s position in the industry regarding the following financial indicators: ROA, ROE, OPM, NPM, FLR and FPI. In response to research questions 1 and 2, there are no differences in the impact on financial indicators as well as on the Financial

Performance Indicator among companies that have implemented one or more T4.0 within the SRM process.

When assessing the impact of T4.0 implementation on improving the ability of enterprises to manage financial risk, an ordinal scale with five categories was used. The frequency of managers choosing the particular categories broken down into two groups of enterprises is presented in Table 4.

It is easily noticeable that in both groups, managers perceive the positive impact of T4.0 on the enterprise ability to manage financial risk. In order to check whether the opinions in these groups differ in a statistically significant manner and to verify the hypothesis H2, the non-parametric Mann-Whitney U test was used again. The value of the test statistics was $U=1581.500$ for $p=0.799$. Therefore, at a significance level of $\alpha=0.05$, there are no grounds to reject the hypothesis H2. The number of implemented T4.0, in the opinion of the managers surveyed, does not affect the enterprise's ability to manage financial risk. The research results address the third research question and reveal that there are no differences in the impact on financial risk between companies that have implemented one T4.0 within the SRM process and those that have implemented two or more.

Discussion

In order to contribute to a debate on sustainable business transition, our research has been focused on risk management. The growing quantification of environmental and social risks in the global business environment make it necessary to integrate sustainable objectives and initiatives into risk management in both service markets, e.g., financial and insurance, and production and trading sectors. Considering the likelihood and impact, the main risks in the global business landscape are nowadays directly linked to sustainability (World Economic Forum, 2020). SRM gained even greater significance during the COVID-19 pandemic and will probably remain a crucial issue in the post-pandemic era (Karmaker *et al.*, 2021; Sarkis, 2020). Enterprises are faced with an urgent need to create novel strategies, design innovative processes and implement new methods or tools to support risk management in the context of SD. Meanwhile, more than 70% of practitioners find that current risk management practices do not adequately address sustainable risks (World Business Council for Sustainable Development,

2020, p. 13). Furthermore, 60% of CEOs have not yet incorporated climate change into strategic risk management (PwC, 2021, p. 8). Climate change requires special attention among other key risks in the next three years, such as cyberattacks (data breaches), economic slowdown (slow recovery), commodity price risk (scarcity of materials), business interruption, accelerated rates of change in market factors, increasing competition, failure to innovate (meet consumer needs), regulatory risks (legislative changes), pandemic risk (health crises), and cash flow (liquidity risk) (AON, 2021, p. 21).

A large proportion of scientific publications are focused on the impact of sustainability on corporate performance. At the same time, both the definition and measurement of sustainability as well as a company's performance are conceptualized differently. Additionally, there is no unanimous view on whether sustainability practices impact corporate performance or not. Some of the research is inconclusive. Our study adds value to existing research. First, our study clearly defines how SRM is understood. Second, unlike other authors cited below, our study addresses a much broader range of indicators affecting financial performance: Return on Assets, Return on Equity, Operating Profit Margin, Net Profit Margin, Financial Leverage Ratio. Third, our study introduces T4.0 as a variable. This is important from a practical point of view, as these technologies play an important role in the transformation of companies and economies towards sustainable development.

Boulhaga *et al.* (2023) examine the relationship between corporate ESG rating and financial performance (Tobin's Q) in the context of the role and quality of internal control. Their research proves the statistically significant positive impact of CSR on financial performance. Similarly, the impact of the ESG rating on the financial results of companies was studied by Aboud and Diab (2019) on a sample of 30 Egyptian listed companies. The authors confirmed the positive effect. Riyadh *et al.* (2019) examined the impact of CSR disclosure on corporate financial performance (return on assets) among the top 250 global energy corporations, concluding with a finding of no significant impact. Buallay *et al.* (2020) explored the relationships between ESG reporting and its impact on operational (return on assets), financial (return on equity) and market (Tobin's Q) performance in the production and banking sectors (932 producers and 530 banks listed in 80 countries). The research confirmed that ESG positively affects all three performance dimensions in the manufacturing sector, but negatively in bank-

ing. Muhammad *et al.* (2022) examined the impact of operational excellence achieved through the Lean, Six Sigma and Sustainability practices during the COVID-19 pandemic on corporate performance (efficiency, growth and profit) of 28 companies operating in industrial zones in Pakistan. The research proved the lack of impact of sustainability on corporate performance. In contrast to our study, the authors cited above refer to a very narrow range of indicators that affect financial performance.

An interesting concept of research, going beyond the mainstream discussed above, was presented by Valdez-Juarez *et al.* (2021), who investigated the impact of an entrepreneurial-oriented strategy on CSR and business performance. They also examined the impact of CSR on entrepreneurship orientation and corporate performance. The study was conducted on a sample of 488 SMEs in Mexico. The authors confirmed that CSR is a mediating variable between entrepreneurship orientation and corporate performance. Thus, SMEs that pursue an entrepreneurial orientation and implement CSR strategies can lead to the adoption of sustainable entrepreneurship and improved business performance. It is probably worth verifying whether the T4.0 included in our study does not play a similar role as a mediating variable between corporate sustainability and financial performance.

Due to the strategic and long-term perspective of the sustainable development of enterprises and their supply chains, as well as the importance of financial performance and financial risk to their competitive advantage and value, it is worth adopting a systematic and integrated approach to reporting the effects of digital transformation on sustainability risk management. Frederico *et al.* (2021) have made a theoretical attempt to adapt a balanced scorecard for performance measurement in the Industry 4.0 era. We agree with this approach, bearing in mind that digital transformation supports the sustainable development of a company and its supply chain from a growth and learning perspective, influencing integrated risk management in business processes, which in turn might provide sustainable value for customers and other stakeholders, and finally increase financial performance and decrease financial risk, especially in the long term. We confirm a great need to adapt the existing methods or develop new methods of measuring new metrics and indicators and reporting the effects of ESRM for the needs of various stakeholders, including owners, management boards or investors. In the light of the results of our research among companies listed on the WSE, this is a very desirable area and direction for

development, especially in the context of ESG. This need has become more important as the research results highlighted by Alkaraan *et al.* (2022) prove that communication in the field of corporate transformation toward Industry 4.0 has a positive impact on financial performance and can support the strategic decisions of investors.

There is a clear research trend in the literature focused on the impact of DT on different aspects of business sustainability. Overall, the authors emphasize the significance of digital transformation for ecological transformation and business model innovations (Ghobakhloo, 2020; Szelagowska & Pluta-Zaremba (Eds.), 2021). Xu *et al.* (2023) argue that companies actively search for DT to achieve SD in a volatile and uncertain environment. Gomez-Trujillo and Gonzalez-Perez (2021) consider DT a driver and a predecessor of sustainability. These findings are positively related to our research assumptions regarding the growing role of sustainability risk management on the one hand, and the importance of T4.0 within this process on the other hand. Generally, researchers agree that T4.0 has enormous potential to influence the sustainable development of enterprises and supply chains and recommend taking advantage of their adoption. Table 1 presents both the scope and effects of DT of business and supply chain management through the application of key digital technologies, which have been examined in published studies to date. The research presented in this article provides a value-added contribution to existing literature. We reveal the empirical evidence on T4.0 implementation within sustainability risk management. DT of SRM has not yet been the subject of other comprehensive empirical studies. Bai *et al.* (2020) argue that each T4.0 should be carefully analyzed as technologies vary in terms of their impact on three dimensions of SD, depending on the industry. It is also worth noting that many risks of DT were identified and systemized in the context of sustainability; for example, Birkel *et al.* (2019) reveal economic, social and environmental risks in the Industry 4.0 sustainable risk framework. Furthermore, our study investigates the effects obtained after the implementation of T4.0, unlike other researchers who focused on exploring the relationship between corporate financial performance and willingness to implement T4.0 (Michna & Kmiecik, 2020). Also, the primary data source we used (a survey addressed to respondents occupying high managerial positions), is novel and presents the respondents' raw, unfiltered perspective.

Conclusions

This study contributes to the literature considering the financial effects of T4.0 implementation within sustainability risk management. In the opinion of the managers surveyed, the number of T4.0 implemented in the SRM process does not affect the enterprise's aggregate FPI, individual financial indicators (ROA, ROE, OPM, NPM and FLR) and the enterprise's ability to manage financial risk. We sought to verify whether enterprises which have implemented T4.0 in the last five years have benefited from their investment depending on the number of technologies implemented. We have found that there are no differences in financial effects between the enterprises which implemented only one technology and those that implemented at least two technologies. The findings can be explained as follows. First, in general, the design and implementation of sustainable development strategies imply a long-term perspective, including the achievement of risk management effects in this area. Second, the implementation of one technology, let alone two or more, is a difficult and time-consuming management challenge before synergy effects are achieved in integrated technological ecosystem. In conclusion, the time horizon is a necessary clarification to address the discussion on financial effects of sustainability risk management in the Industry 4.0 era. A five-year horizon is likely too short, especially in the economy at the early stage of T4.0 adaptation. Moreover, the significance of the COVID-19 pandemic for the re-evaluation of business priorities should be taken into account. During the last two years, the main goal of digital transformation was to maintain business continuity and manage risks, although mostly in a reactive way. Proactive development activities for sustainability in many enterprises and their supply chains were postponed. As a result, at that time, it was especially difficult to study the financial importance of the digital transformation of the SRM process.

The limitations of the research process include the geographical origin of the managers surveyed, representing 120 enterprises developing international supply chains, but working in one country (Poland). Another limitation of the analyses presented in the paper was the structure of the research sample characterized by a small representation of enterprises which implemented a larger number of T4.0. This prevented the use of statistical methods that would allow for an assessment of the strength of the potential correlation between the scale of implemented T4.0 and the values of selected financial indicators. The measurement scale of the analyzed variables

also had a great impact on the selection of methods for verifying the hypotheses put forward in the article. It should be noted that we had only the estimated values of the analyzed financial indicators at our disposal. Using the actual values of these indicators would increase the precision of the analyses and possibly affect the verification results of the formulated hypotheses. Moreover, we adopted one-time perspective (up to five years) for SRM and T4.0 implementation, without differentiating it in the medium and short term. Additionally, the study was conducted during the pandemic. On the one hand, the coronavirus outbreak caused the rapid acceleration of business digital transformation (OECD, 2020), including the implementation of Industry 4.0 technologies (Moosavi *et al.*, 2021). On the other hand, companies were focused on developing contingency plans to account for the new reality, restoring supply chains and making them more resilient. Thus, reaching the respondents and attracting their attention was extremely difficult. These factors greatly influenced the sample size.

The study has significant potential for continuation. Future research avenues may include the following directions. Firstly, we plan to expand the sample size, the research timeframe and survey coverage to include additional geographic regions and countries performing better in terms of climate protection. Secondly, future studies will integrate qualitative research that may enhance quantitative research and help to understand the research results better. Thirdly, we plan to investigate the problem of T4.0 implementation maturity as well as SRM process maturity in order to better address the potential differences in the application of T4.0 in the SRM process and its impact on financial performance and financial risk. Finally, Poland represents a group of Central and Eastern European countries which have undergone significant political, social and economic transformation since the early 1990s. Therefore, this study has great potential to be extended to other transition economies in order to verify the research hypotheses.

Considering the results of the research, we are convinced that T4.0 and ESG issues should be included in the curriculum at different levels of managerial education in order to ensure companies' future growth in the right direction, including tech-driven ESG practices. Expectations toward T4.0 and their role in achieving Sustainable Development Goals are high. In order to release their real potential and stimulate the incorporation of sustainable goals, awareness, knowledge and skills are needed together in

complementary areas of breakthrough modern technologies 4.0 and 5.0, sustainability risk management and green (sustainable) finance.

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Annex

Table 1. Industry 4.0 technology deployment for sustainability

Industry 4.0 technology	Main characteristics	Key sources of sustainable value creation
Additive manufacturing (3D printing)	A process of producing objects on a three-dimensional model by joining materials, layer by layer, directly from raw materials (Kellens <i>et al.</i> , 2017)	<ul style="list-style-type: none"> - material and energy savings - improvement of product quality and durability - lower environmental impact and higher material recycling - less high-value waste and increased equipment utilization - improvement of product utilization - reduced material consumption - efficient recycling - reduced raw material consumption while producing minimal waste - waste used to generate new value-added products by printing from recycled materials (Nascimento <i>et al.</i>, 2019; Colorado <i>et al.</i>, 2020)
Artificial intelligence	A diverse set of technologies, techniques, tools and algorithms together with the capability to imitate the human brain in decision-making processes (Jarrahi, 2018; Metcalf <i>et al.</i> , 2019)	<ul style="list-style-type: none"> - improvement of environmental governance and performance - identification of strategies to reduce carbon and water footprints and to diminish the biodiversity risk - upgrading business processes, including demand forecasting or supplier selection - modelling future scenarios to operate the entire supply chain network more effectively and better understand the interdependencies between various factors and performance (Amirkolahi <i>et al.</i>, 2017; Cavalcante <i>et al.</i>, 2019; Chai & Ngai, 2020; Mobarakeh <i>et al.</i>, 2017; Merlino & Sproge, 2017; Nishant, 2020)
Big Data analytics	Methods, technologies and techniques enabling the collection, high-speed processing and analysis of large, time-varying and diverse data sets in order to deliver reliable analysis and reporting (Brinch <i>et al.</i> , 2017; Chalmeta & Santos-deLeón, 2020; Ma <i>et al.</i> , 2020)	<ul style="list-style-type: none"> - strategy adjustment to customer preferences - improved demand forecasting accuracy - supply chain transition toward sustainable manufacturing, ship routing and scheduling, sourcing and supplier selection, inventory management, logistics and transportation including reverse logistics - increased environmental efficiency (Chalmeta & Santos-deLeón, 2020; Mehmood <i>et al.</i>, 2017; Su & Chen, 2018)

Table 1. Continued

Industry 4.0 technology	Main characteristics	Key sources of sustainable value creation
Blockchain	A distributed database running on a set of interconnected nodes (users, computers) in which information (records) about various types of transactions and operations can be recorded and stored; forms a digital ledger of records (Casado-Yara <i>et al.</i> , 2018)	<ul style="list-style-type: none"> - cost savings - higher traceability-transparency - improved sustainability (Esmacilian <i>et al.</i>, 2020; Kshetri, 2018; Saberi <i>et al.</i>, 2019)
Cloud computing	IT infrastructure, components, and applications, enabling on-demand network access to a shared pool of configurable computing resources (Benlian <i>et al.</i> , 2018)	<ul style="list-style-type: none"> - improvement of supply chain economic, social and environmental performance, and competitive advantage as a result - better sustainable mobility with respect to energy, environment, safety, security and socio-economic issues or measurement and optimisation of carbon footprints in the entire supply chain
Digital platforms	A type of communication and cooperation channels that aim to share and spread information and knowledge, manage relations and enable coordinated activities among different partners (Cenamor <i>et al.</i> , 2017; De Bernardi, 2019; Eloranta & Turunen, 2016)	<p>(Nowicka, 2016; Puičá, 2020; Schmiederjans & Hales, 2016; Singh <i>et al.</i>, 2015)</p> <ul style="list-style-type: none"> - enhanced organizational collaboration, integration and reciprocity among platform members influencing culture and “triggering mechanisms of idea-shaping and co-participation”, facilitating the spread of some common rules, and enabling value co-creation <p>(Cenamor <i>et al.</i>, 2017; Eloranta & Turunen, 2016; De Bernardi, 2019)</p>
Internet of Things	Interconnections of sensing and actuating devices that provide the ability to share information across platforms through a unified framework (Antikainen <i>et al.</i> , 2018)	<ul style="list-style-type: none"> - costs and cycle time reduction - higher customer satisfaction and profits - improvement of quality, delivery and flexibility, and hence better financial, social and environmental performance - better resource efficiency - sustainable energy management - reduction of energy consumption and power wastage <p>(Abdel-Basset <i>et al.</i>, 2018; Bashar, 2019; Beier <i>et al.</i>, 2018; de Vass <i>et al.</i>, 2020)</p>

Table 2. Descriptive statistics for financial indicators

Groups of enterprises	Statistics	Indicators					
		ROA	ROE	OPM	NPM	FLR	FPI
Group 1	Mean	3.152	3.215	6.165	5.228	3.696	21.456
	Median	3	3	7	5	3	21
	Std. Dev.	1.922	2.080	2.705	2.957	1.983	9.590
	Spread	7	8	8	8	8	38
	Min	1	1	1	1	1	5
	Max	8	9	9	9	9	43
Group 2	Mean	3.610	3.781	6.634	5.659	4.317	24
	Median	3	3	7	6	4	25
	Std. Dev.	1.961	2.185	2.385	2.670	2.018	8.815
	Spread	7	7	8	8	7	36
	Min	1	1	1	1	1	5
	Max	8	8	9	9	8	41

Table 3. Mann-Whitney U test results for financial indicators

	ROA	ROE	OPM	NPM	FLR	FPI
U Mann-Whitney	1387.5	1369	1457	1489	1299.5	1363
p-value	0.193	0.159	0.361	0.466	0.073	0.156

Table 4. The structure of responses in assessing the impact of Industry 4.0 technology implementation on increasing the ability to manage financial risk

Groups of enterprises	Categories on an ordinal scale				
	I strongly disagree	I disagree	I neither agree nor disagree	I agree	I strongly agree
Group 1	0%	2.5%	5.1%	65.8%	26.6%
Group 2	0%	0%	4.9%	68.3%	26.8%

Figure 1. Main stages of ERM process in light of international standards

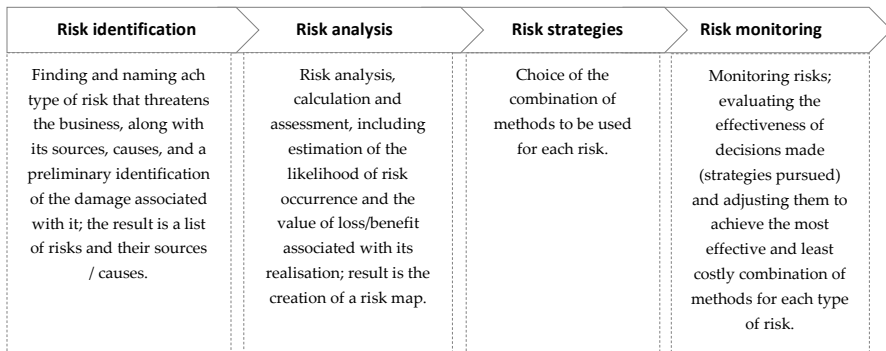


Figure 2. Stages of the research procedure

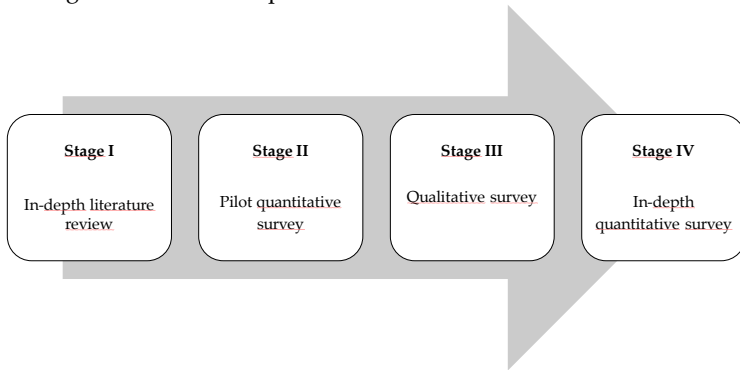


Figure 3. Box plots for financial indicators

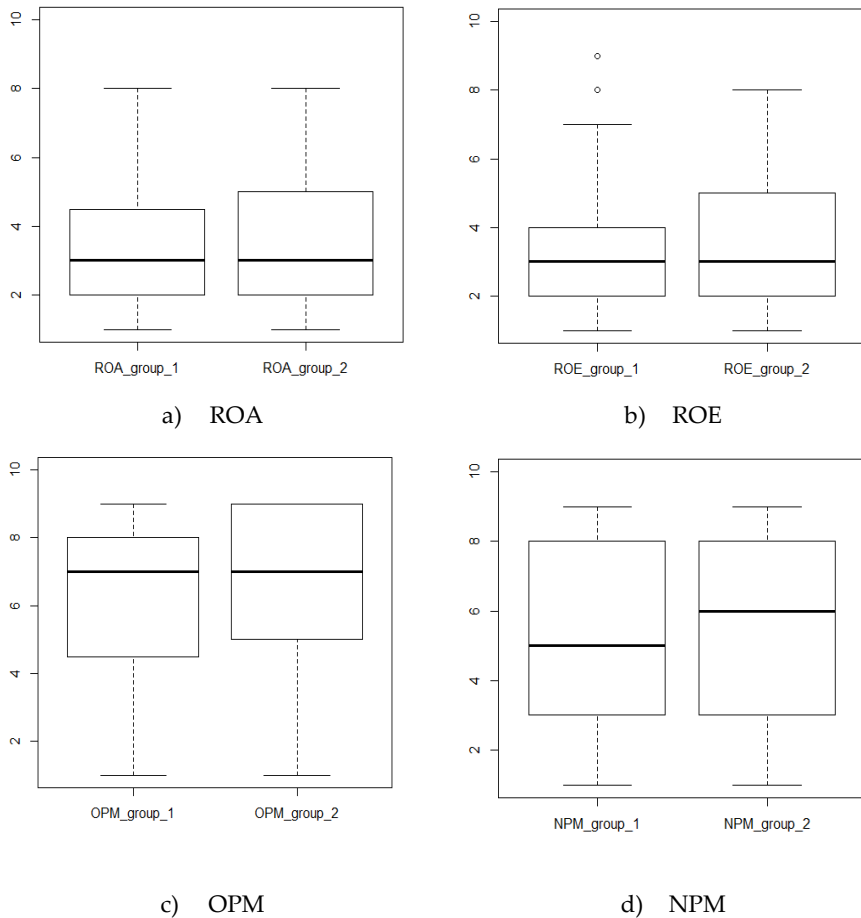
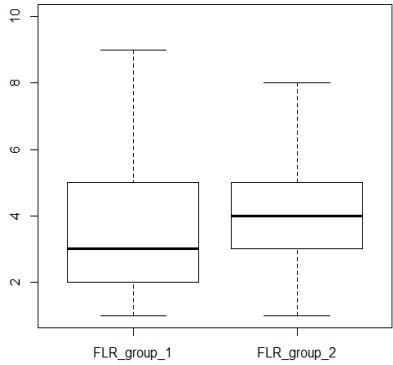
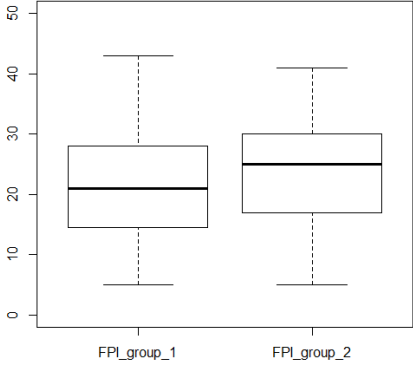


Figure 3. Continued



e) FLR



f) FPI