Challenges, innovations and opportunities in the era of globalization and industry 4.0

43

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Challenges, innovations and opportunities in the era of globalization and industry 4.0

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Contents

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Problems and challenges experienced by European institutions in the balance of payments compilation process

The continuous internationalization of economic activity raises demand for the balance of payments statistics – a concise summary of the country's economic relations with the rest of the world. At the same time, the increasing complexity of business operations impedes the ability to obtain high-quality data that reliably reflects the actual volume of cross-border flows. The study aims to identify the main methodological challenges experienced by the European reporting institutions (primarily central banks) in the process of the balance of payments compilation. The most problematic balance of payments components were identified through the analysis of the metadata responses provided individually by 41 European compilers, gathered on the standardized forms prepared by the International Monetary Fund. Despite the large methodological diversity, it was possible to distinguish two universal dimensions of methodological difficulties – the inaccessibility of data related to specific areas and the inability to compile it in full accordance with the IMF's guidelines.

Keywords: balance of payments, International Monetary Fund, International Merchandise Trade Statistics

JEL classification: F00, B41, C82

Introduction

The need for external trade statistics arose at the beginning of the 14th century along with the rapid development of early mercantilist doctrines [Pippenger, 1973, p. 6][1]. The compilation of reliable, official macroeconomic statistics became especially important after the First World War, with the increasing involvement of governments

[1] Under the mercantilist doctrine the main goal of international trade was the accumulation of the precious metals, which were associated with the wealth of a country. Consequently, the utmost importance was assigned to the positive balance of trade, where exports regularly exceeded imports [Pippenger, 1973, p. 6].

in economic processes [South African Reserve Bank, 2002, p. 1]. In its current form, the balance of payments serves as a powerful tool for economic analysis, providing extensive information about the country's economic relations with the rest of the world. The external sector statistics are especially important for central banks and monetary authorities, allowing them to, i.a., assess the vulnerability to external shocks, understand and predict the exchange rate movements, or explain changes in the money supply [IMF, 2004, pp. 170–171; Van den Bergh, 2009, p. 115].

The wide use of the balance of payments statistics emphasizes the need to constantly monitor their accuracy, reliability, and relevance to the end user. The objectives could not be achieved without the international harmonization of the compilation methodology, ensuring the international comparability of data. Unified standards for the balance of payments reporting were first introduced in 1922 when the League of Nations began gathering data from the respective governments [Alves, 1967, p. 541]. Later that task was inherited by the International Monetary Fund (IMF), which cyclically publishes the subsequent editions of the *Balance of payments manual* (BPM – currently BPM6), along with the more technically oriented *Balance of payments compilation guide*[2]. Furthermore, to enhance both the quality and transparency of the compilation practices, the IMF developed a set of Data Standards Initiatives (e-GDDS, SDDS, SDDS Plus), which oblige the participants to prepare publicly accessible methodological notes (metadata) on, i.a., the legal environment, the scope of the data, concepts, and definitions, as well as quality management policies. Concerning the EU and EFTA, similar information (with recommendations) is gathered by Eurostat and published regularly in its annual *Quality reports on balance of payments (BOP), international investment position (IIP), international trade in services (ITS) and foreign direct investment statistics (FDI)* [Eurostat, 2021] and *European Union balance of payments and international investment position statistical sources and methods* [ECB, 2016], authored by the European Central Bank.

The purpose of the study is to identify the biggest challenges in the balance of payments compilation process through the information provided by official European compilers in the standardized questionnaires developed by the IMF and ECB. The results will allow to identify the balance of payments components at risk of a lower practical relevance of the data. From a cognitive perspective, the study provides insight into the structure and content of the balance of payments, as well as the rarely discussed methodological principles of its compilation and the institutional framework governing its development.

[2] The IMF is currently working on the 7th edition of the manual, the publication of which is planned for March 2025.

1. Methods

As mentioned, the external flows of the highest difficulty from the methodological perspective were identified with the complementary use of two sources of information. The basis for the analysis comprised the responses of 41 European countries to standardized metadata questionnaires developed by the IMF[3]. Each form consists of two main parts:

– the general section, where the countries disclosed information related to the legal framework, the agency responsible for the balance of payments compilation, adherence to basic reporting principles, and data coverage for each institutional sector,
– the specific section, presenting the solutions and difficulties related to the specific types of transactions, following the standard balance of payments accounts layout.

The findings obtained through the IMF questionnaires were supplemented by the conclusions drawn from the quinquennial report prepared by the European Central Bank, called *European Union balance of payments and international investment position statistical sources and methods* [ECB, 2016], which contains methodology used by 28 EU member states pertaining to:

– institutional environment – professional independence and mandate for data collection,
– statistical processes – adherence to basic BPM methodological principles, definitions, sources and methods, and internal consistency of data.

In both cases, the analysis was limited to methodological aspects – data coverage, statistical techniques, and accounting principles employed. In the case of the standardized IMF questionnaire, the level of methodological difficulty was determined based on the compilers' ability to implement guidelines set by the IMF for a given type of flow or institutional sector. The results of the analysis will be presented in an order corresponding to the balance of payments structure and pertain to:

– merchandise trade and service flows recorded on the current account,
– remaining current account components – primary and secondary income,
– financial flows – foreign direct and portfolio investments, financial derivatives, other investments, reserve assets.

The degree of BPM6 implementation was most often expressed as a percentage, representing the fraction of European countries adhering to a given rule.

The investigation of the non-standardized ECB questionnaire was mainly complementary, intended to assess the subjective importance given by the compilers to the problems identified at the previous stage of the study. The subject of analysis was the *Coverage gaps and room for improvement* section, in which the compilers

[3] A detailed list of European countries participating in the survey is provided in Appendix 1.

identified an arbitrary set of obstacles observed in their practice. At this stage, the analysis sought to identify the balance of payments components mentioned in that context by at least two national compilers.

2. Results

2.1. The IMF metadata questionnaire

2.1.1. Current account – the merchandise trade and service flows

The proper recording of merchandise trade flows can be described as potentially challenging, which primarily stems from significant conceptual and methodological discrepancies between BPM6 and the main source of obtained data – the International Merchandise Trade Statistics (IMTS). The IMTS system recommends that all goods be recorded at the time they enter or leave an economic territory [IMF, 2014, p. 73], which does not have to coincide with the change of economic ownership, as required in the BPM6[4]. Therefore, the correct use of ITMS data for balance of payments purposes will require several adjustments from the reporting body, including:

– exclusion of the goods temporarily exported or imported with no change of ownership involved: goods for storage, repair, or processing; migrants' personal effects; goods imported for projects by non-resident construction enterprises, if the project is not substantial enough to constitute their branch (an recording the flow on a construction services account),
– determining the time of ownership change in the case when it substantially differs from the moment of crossing the customs border: this applies in particular to the registration of non-monetary gold (which is often exchanged without physical delivery), as well as the recording of high-value capital goods (i.e. ships, heavy machinery).

The second significant divergence between the IMTS and BPM6 statistical principles is the valuation of goods imported into the economy. In the case of BPM6, the uniform principle for merchandise goods valuation is the market value at the customs frontier of the exporting economy, i.e. the free on board (FOB) price [IMF, 2009, p. 156]. The IMTS recommends, however, determining the statistical value of exported goods in accordance with the free on board rule, and that of imported ones – as the cost, insurance, and freight (CIF), simultaneously encouraging compilers to calculate their FOB-type value as supplementary information [United

[4] According to BPM6, the change of ownership takes place when the parties enter the goods in their books as a real asset and make a corresponding change to their financial assets and liabilities [IMF, 2009, p. 155].

Nations, 2011, p. 40][5]. Correct registration of the merchandise trade flows will therefore require reducing the value of imported goods derived from the IMTS system by the value of freight and insurance. As these values are heavily determined by the transaction's characteristics (e.g. distance travelled, type of goods transported, mode of transport), the IMF advocates adjustments on the most disaggregated level possible to the compiler [IMF, 2009, p. 156].

The full summary of conceptual and methodological differences between IMTS and BPM6 that have fallen within the scope of the IMF metadata questionnaire is presented in Table 1.

Table 1. The comparison of fundamental statistical principles between the IMTS and BPM6

Item	IMTS	BPM6
valuation of imports	CIF (cost, insurance, freight)	FOB (free on board)
goods for processing	included, regardless of ownership status	excluded, if there is no change of ownership involved
migrants' personal effects	recommended to be included	excluded, if there is no change of ownership involved
non-monetary gold	included, based on the physical movement of goods	included, regardless of the physical movement of goods
exports/imports of international organizations located in the economy	included	excluded, as they are not considered a resident of the host economy
goods imported for projects by non-resident construction enterprises	included	excluded, if there is no separate entity involved
goods entering/leaving the economic territory illegally	excluded, with the suggestion to be estimated separately	recommended to be included
high-value capital goods	included, recorded at the time they enter or leave an economic territory	included, recorded

Source: [IMF, 2014, pp. 74–75].

The degree of practical implementation of the guidelines presented in Table 2 is highly heterogeneous. A routinely implemented adjustment, confirmed by 100% of the respondents, was the CIF to FOB conversion in relation to imported goods. The comment section related to the merchandise trade measurement provided examples of the following methods employed to extract the transport and insurance component from the CIF price:

– using a fixed conversion factor for CIF to FOB value,

[5] A FOB-type valuation includes FOB (for goods dispatched by sea or inland waterway) and FCA (for goods dispatched by other means of transports). Analogously, the CIF-type valuation is based on CIF or CIP delivery terms [IMF, 2009, p. 156].

– using variable conversion factors, depending on the direction of trade exchange (e.g. for intra- and extra-EU trade; CIS countries[6]),
– using a highly individualized conversion factor depending on different transaction parameters (e.g. country of origin, mode of transport, weight of the goods).

Usual adaptations to the BPM6 principles also encompassed the exclusion of the goods for processing without a change in ownership (incorporated by 78% of reporting institutions) and the estimates for the flows of illegal or smuggled goods (63.4%). Among the few examples of methods for estimating illegal merchandise trade flows (disclosed mainly by states of the former Soviet bloc) were:

– using estimated unregistered trade rates obtained through a foreign trade survey,
– using the commodity flow model to compare the sum of imports and production with the sum of consumption, exports, and changes of stocks; the excess of the former over the latter implies unrecorded merchandise exports, and the opposite – unrecorded imports,
– using expert estimates based on multiple inputs: volumes of sale of consumer goods to individuals, turnover, number of privately imported cars, taxes and duties paid by individuals, and data on the country's main trade partners.

The remaining solutions recommended by the IMF were incorporated much less frequently – the prevalence of their implementation is summarized in Table 2. The respondents, however, did not discuss the methods of adjustment and did not provide reasons for abandoning their use.

Table 2. The scope of adjustments to the BPM6 principles undertaken by European countries

Adjustment	Frequency
deduct insurance and freight components from goods imports at CIF value to arrive at FOB value	100.0%
exclude goods for processing without change in ownership	78.0%
include estimates for illegal or smuggled goods	63.4%
include transactions in non-monetary gold that involve a change in ownership but do not involve the physical transfer of gold	39.0%
exclude migrants' personal effects	34.1%
exclude exports/imports of international organizations located in the economy	22.0%
exclude goods imported for projects by non-resident construction enterprises	19.5%

Source: Own calculations based on: [IMF, 2023].

The questionnaire section related to cross-border service flows was limited to the sources of data and an optional comment section. As such, the most methodologically challenging items within the "services" category were identified based on the prevalence of indirect methods of estimation, combining multiple sources

[6] CIS – Commonwealth of Independent States, a regional intergovernmental organization in Eurasia formed after the dissolution of the Soviet Union in 1991.

of data. In addition to values of transport and insurance services obtained through the previously discussed CIF to FOB conversion, indirect calculation is required for financial intermediation services indirectly measured (FISIM) charged by the lenders or deposit-takers. The value of the service component is derived as the difference between the interest payable/receivable on loans or deposits and the amount that would apply if the reference rate were used [IMF, 2009, p. 174]. Statistical models are used to determine the value of money spent by foreign visitors, where the basis for estimation is the number of overnight stays and the traveller's average daily expenditure. The expenses of residents travelling abroad are obtained through household surveys and analysis of the external operations of domestic banks (ITRS), irrespective of their form (cash, debit and credit card, checks, transfers, etc.).

2.1.2. Current account – primary and secondary income flows

Among the remaining components of the current account, a lot of methodological challenges are posed by the "personal transfers" recorded on the secondary income account, containing cash or non-cash flows between households residing in different economies[7]. The most common method of determining the value of personnel transfers (or, more precisely, remittances of migrant workers) is statistical modelling, indicated as the main source of data by 31.7% of European countries. An estimation obtained in this way utilizes multiple inputs: information obtained from the banking system, surveys, censuses, migration, customs and administrative data, insurance premiums, etc. An obstacle in collecting the data is the low average value of money transfers (often falling below the reporting threshold) and the large share of money transferred through informal channels, estimated to constitute as much as 35–75% of the officially recorded transfers [Freund, Spatafora, 2005, p. 1].

Some challenges also pertain to two main components of primary income – "investment income" and "compensation of employees". In the case of the former, the issue was the inability (or unwillingness) of compilers to record the investment income on an accrual basis, where the flows are recorded at the time economic value is created, transformed, exchanged, transferred, or extinguished [IMF, 2009, p. 35]. Contrary to the recommendations, investment income was often recorded on a cash or due-for-payment basis, which may not reflect the cyclicality and continuity of the provision of financial assets. In the case of the latter, the problem lies in the calculation of compensation of seasonal and cross-border workers (undertaken by 80.5% of countries), which was typically estimated with the use of complex statistical models, combining the information related to:

[7] Household and non-profit institutions serving households have been identified as the most challenging sector from the methodological standpoint – around 50% of surveyed national compilers pointed out to significant gaps in the data coverage in this area.

– the number of foreign employees and the average salary in the sectors they represent,
– average tax rates and/or total tax revenues,
– the average amount of insurance premium and the value of total premium receipts from non-residents employed in the country.

The estimation was based on the data obtained from direct reporting questionnaires, immigration offices, insurance, tax, and customs authorities, local government statistics (related to the number of work permits issued), as well as bilateral partner data.

2.1.3. Financial flows

The balance of payments financial account shows the (net) flows of financial assets and liabilities between residents and non-residents of the reporting economy. There are two ways to determine the value of cross-border financial flows:
– directly, based on the value of current transactions,
– indirectly, where the values of transactions are derived from changes in stocks, with adjustments for exchange rate, price, etc.

The majority (70.7%) of countries relied on the first method of compilation, gathering the data through direct reporting/surveys of various frequencies: monthly (31.7%), quarterly (53.7%), and annual (46.3%). Complementarily, depending on the type of transaction, the following data sources are used:
– foreign direct investment: company reports or financial statements (mentioned by 85.4% of the respondents), media reports (63.4%), ITRS (43.9%),
– portfolio investment: surveys of custodians (65.9%), administrative-based or regulatory reports (39.0%), stock exchange data (26.8%),
– other investment: ITRS or bank reports (20.7%), administrative-based or regulatory reports (8.1%).

Concerning specific financial account components, the most difficulties pertained to financial derivatives and the cross-border activity of special purpose entities (SPEs), both characterized by the lowest data coverage[8]. In the case of the former, the coverage was described as comprehensive by 58.5% of the respondents, with 10% of them completely omitting the item in the compilation process. The accessibility of data was even worse with regard to the subcategory of financial derivatives – employee stock options, offered to employees as a form of remuneration [IMF, 2014, p. 160]. Although the coverage of special purpose entity data seems satisfactory (full or partial coverage was declared by 82.9% of the respondents), numerous gaps in the SPE section can raise some questions about the compilers'

[8] BPM6 defines special purpose entities as "flexible legal structures in particular jurisdictions, which offer various benefits that may include any or all of low or concessional tax rates, speedy and low-cost incorporation, limited regulatory burdens, and confidentiality" [IMF, 2009, p. 58].

attitude towards developments in this area. The majority of European reporting institutions have refused to provide the required information regarding institutional collaboration for facilitating the collection of resident SPE cross-border statistics, sources of data, or definitions used.

Table 3. Level of data coverage in relation to financial derivatives and employee stock options

Financial derivatives	
comprehensive	58.5%
partial	31.7%
not covered	9.8%
Employee stock options	
yes	14.6%
no	46.3%
no (insignificant in the economy)	39.0%

Source: Own calculations based on: [IMF, 2023].

2.2. ECB questionnaires

Largely in line with previous observations, the synthesis of European Central Bank questionnaires [ECB, 2016] portrays the household sector as particularly challenging from the compilation standpoint. Difficulties can be attributed mainly to the lack of a direct source of information (as households are generally not obliged to report) and the limited availability of data on transactions (mainly outward portfolio investments) carried out directly with non-residents, without the involvement of national intermediaries. It is worth noting that the latter is not specific to households, but can be generally applied to all private-sector residents. Some countries take measures to obtain this data indirectly, using bilateral partner data from the databases of the Bank for International Settlement.

Table 4. Cross-border transaction types indicated by the EU-28 as the most problematic from the balance of payments compilation perspective

Type	Number of countries	Percent of countries
transactions of households	17	60.7%
transactions in the insurance sector	8	28.6%
FISIM	8	28.6%
portfolio investments of residents without intermediation of a domestic institution	7	25.0%
real estate purchased abroad	4	14.3%
goods sent abroad for processing	3	10.7%
transactions of SPEs	2	7.1%

Source: Own calculations based on: [ECB, 2016].

Another problem area identified by a significant percentage (28.6%) of European countries concerns international transactions in the insurance sector. The reasons for non-coverage include the lack of significance in a given economy and/or severe methodological deficiencies in this area. Many countries (28.6%) also do not

undertake efforts to separate the service component (FISIM) from the prices of loans or deposits. The issues mentioned at least twice also include cross-border transactions of SPEs (7.1%), real estate purchased abroad (14.3%), and inability to determine the processing margins for goods (10.7%). The last of these problems is most likely related to the methodological changes introduced with the sixth edition of the BPM manual.

Conclusions

Despite the long history of use, balance of payments statistics remain challenging to compile. The degree of adherence to the methodological principles proposed by the IMF in the sixth edition of its *Balance of payments manual* is highly individual and largely depends on the country's internal capacity, as well as its legal and institutional environment. Despite the large methodological diversity, it was possible to distinguish two universal dimensions of methodological difficulties, which include:

- general inaccessibility of data sources related to specific sectors, entities, or flows,
- inability to compile data in full accordance with the IMF's guidelines.

In the first category, the highest importance can be assigned to the cross-border transactions of the household sector, which, due to the low average value, typically remain under the reporting thresholds. The biggest risk of inaccuracies (probable underestimation of the actual value) in this regard pertains to the "secondary income – personal transfers" item, which refers solely to the households' cross-border flows. In broader terms, the risk of underestimation was also present in the case of foreign assets acquired (and held) without the intermediation of domestic institutions. Low data coverage was also observed in the case of the cross-border activities of special purpose entities, as well as the financial derivatives and employee stock options. Lack of direct data sources enforces the use of complex estimation methods, which may lead to measurement errors.

In terms of strict adherence to the IMF guidelines, it is worth noting the considerable conceptual inconsistencies between the BPM6 and the IMTS, which universally serves as the primary data source on merchandise trade. The implementation of adjustments included in the metadata questionnaire (e.g. inclusion of illegal trade estimates) varies considerably, which negatively impacts the international comparability of balance of payments statistics, as well as the practical relevance of bilateral mirror data. What is more, a relatively large group of the respondents did not separate the service component (FISIM) from the pure interest payable or receivable, which might artificially inflate the corresponding "investment income"

entries within the primary income account, with the opposite effect for the "financial services" account.

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Appendix 1. European countries participating in the IMF metadata questionnaire

Country	Last updated	Reporting institution	Country	Last updated	Reporting institution
Albania	6 Nov 2018	Bank of Albania	Luxembourg	9 Nov9 2016	Banque centrale du Luxembourg
Austria	23 Aug 2018	Oesterreichische Nationalbank	Malta	26 Sep 2018	National Statistics Office
Belarus	23 Nov 2022	National Bank of the Republic of Belarus	Moldova	3 Jan 2023	National Bank of Moldova
Belgium	11Jan 2023	National Bank of Belgium	Montenegro	26 Sep 2018	Central Bank of Montenegro
Bosnia and Herzegovina	27 Feb 2023	Central Bank of Bosnia and Herzegovina	Netherlands	7 Oct 2015	De Nederlandsche Bank
Croatia	7 Mar 2017	Croatian National Bank	North Macedonia	2 Nov 2021	National Bank of the Republic of North Macedonia
Cyprus	3 Aug 2015	Central Bank of Cyprus	Norway	23 May 2016	Statistics Norway
Czech Republic	13 Jan 2022	Czech National Bank	Poland	22 Oct 2012	National Bank of Poland
Denmark	16 Oct 2019	Danmarks Nationalbank	Portugal	8 Nov 2021	Banco de Portugal
Estonia	1 Nov 2018	Bank of Estonia	Romania	13 Jan 2022	National Bank of Romania
Finland	23 Nov 2022	Statistics Finland	Russian Federation	22 Feb 2022	Central Bank of the Russian Federation (Bank of Russia)
France	21 Sep 2015	Banque de France	Serbia	26 Sep 2018	National Bank of Serbia
Germany	7 Feb 2018	Deutsche Bundesbank	Slovak Republic	17 Oct 2012	National Bank of Slovakia
Greece	7 Aug 2019	Bank of Greece	Slovenia	24 Dec 2014	Bank of Slovenia
Hungary	5 Nov 2020	Magyar Nemzeti Bank	Spain	9 Feb 2022	Banco de España
Iceland	18 Sep 2019	Central Bank of Iceland	Sweden	27 Feb 2023	Statistics Sweden
Ireland	7 Oct 2022	Central Statistics Office	Switzerland	15 Oct 2015	Swiss National Bank
Italy	22 Feb 2022	n/a	Turkey	5 Nov 2020	Central Bank of the Republic of Turkey
Kosovo	25 Aug 2022	Central Bank of the Republic of Kosovo	Ukraine	26 May 2021	National Bank of Ukraine
Latvia	11 Jan 2023	Bank of Latvia	United Kingdom	2 Dec 2022	Office for National Statistics
Lithuania	11 Oct 2019	The Bank of Lithuania			

Source: [IMF, 2023].

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Big data in supply chain management – a case study of a printing enterprise

The aim of the article is to identify the benefits of applying the concept of big data as a significant tool for managing and optimizing the supply chain and logistic processes to gain a competitive advantage in the printing industry. The article explains the concept of big data and presents its main characteristics. Subsequently, it highlights the areas of application of big data and provides examples of its usage in the supply chain of printing enterprises. Research indicates that big data analysis can significantly contribute to the development of the printing industry and the functioning of its supply chain links.

Keywords: big data, supply chain management, logistics, analysis

JEL classification: D24, L69, O14

Introduction

Big data refers to vast or complex data sets that typically exceed the scale of exabytes. They surpass traditional systems in terms of storage, processing, monitoring, analysis, and data visualization capabilities [Kaisler et al., 2023]. Currently, the volume of data is growing exponentially, and it is predicted to reach several or even tens of zettabytes annually [Dragun, Kuczyńska, 2023].

Scientists and experts agree that the rapid growth of data opens up new, innovative possibilities. Companies worldwide are striving to develop and enhance their capabilities to analyse large datasets to gain a deeper understanding of their value. The concept of big data is constantly evolving, with most of its features now encapsulated in the "5 V" concept: variety, veracity, velocity, volume and value [Alsolbi et al., 2023]. The world of science has long emphasized that big data is a key factor influencing company performance [Kozłowska, 2020]. Thanks to advances in big data, businesses can better understand customer needs, improve service levels, enhance sales performance and revenue, and explore new markets.

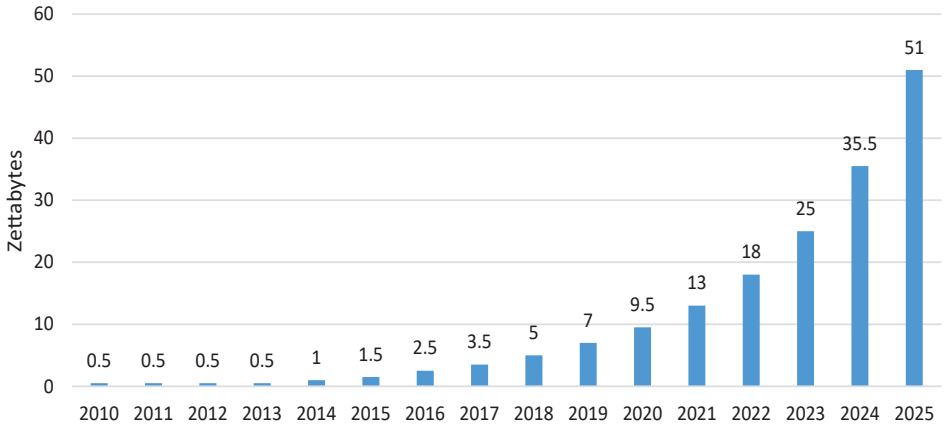

Figure 1. Annual data volume worldwide in zettabytes (trillions of gigabytes)
Source: [Statista].

Scientific research has shown that the utilization of big data in various sectors such as finance, marketing, banking, insurance, logistics and manufacturing can significantly contribute to their development [Tamym et al., 2020]. This article also presents the benefits of utilizing big data, but this time in the printing industry, focusing on creating new value and enhancing relationships in the supply chain. To achieve this goal, the article first defines key concepts related to big data and discusses their role in predicting the future in the supply chain. It then focuses on the importance of statistical analysis, simulation, and optimization in supply chain analytics. Finally, it presents specific applications of big data in various areas of the supply chain in the printing industry, followed by conclusions regarding the benefits of big data analysis in the supply chain in this industry.

1. Purpose and research methodology

The aim of the study was to identify the benefits of implementing the new concept of big data resulting from its characteristics. The analysis also aimed to assess the significance of this concept for supply chains and logistics in a printing company that has already adopted this solution. Data for the analysis were collected from literature on big data, company reports and information provided by employees involved in analysis, logistics and supply chain management within the discussed company. Additionally, information from articles published on platforms focusing on logistics, analysis and business, both in Polish and English, was included.

2. Characteristics of big data

To fully understand the impact and application of big data, we must first have a solid understanding of what this concept entails. Put simply, big data refers to a massive amount of data. This term specifically refers to datasets of such a large size that they no longer fit into computer memory. These data can be captured, stored, transmitted, aggregated and analysed. As the volume of data has grown, there has been a need to modernize the tools used for their analysis. Accordingly, these data do not fit into the traditional model where they are organized in columns and rows. Big data comes from various sources and encompasses diverse types of data: structured, semi-structured and completely unstructured. According to a different approach, these data can include numbers, images, sound, text and discourse. They can originate from technologies such as radio frequency identification (RFID), global positioning system (GPS), point of sale (POS), as well as from social media platforms like Twitter, Instagram, Facebook, call centres or customer blogs. Today's advanced analytical technologies allow for knowledge extraction from various types of data. Analytics is the combination of mathematics and statistics with large datasets. Big data analysis involves using statistics and mathematics to analyse large datasets. Big data without analytics is simply a vast amount of data. Over the years, individuals and companies have amassed huge amounts of data. On the other hand, analytics without large datasets is simply mathematical or statistical tools and applications. Nowadays, companies can extract insights from massive datasets thanks to the enormous computational power available at lower costs than ever before. The combination of big data and analytics allows for the creation of various tools that assist decision-makers in gaining valuable, meaningful insights and transforming information into business analysis.

3. Supply chain analytics

A supply chain is a collection of firms, from raw material suppliers to manufacturers or central organization, wholesalers, retailers, customers and end-users. In addition to physical flows such as material and product transfers, the supply chain also includes flows of information and finances. Supply chain analytics involves the use of big data analysis techniques to extract hidden, valuable knowledge from this process [Wamba, 2018a]. This analytics can be divided into descriptive, predictive and prescriptive analysis [Johnson, Bohle, 2019]. Well-planned and implemented decisions have a direct impact on financial outcomes by reducing costs of procurement, transportation, storage, inventory depletion and disposal. The use of big data

analytics techniques in solving supply chain management problems contributes to improving its efficiency. Managers and researchers have long applied statistical and operational research techniques to balance supply and demand [Johnson, Bohle, 2019]. However, recent developments in analytics have opened up new opportunities for managers and researchers. Figure 2 also shows the relationships between descriptive, predictive and prescriptive analytics in decision-making or actions.

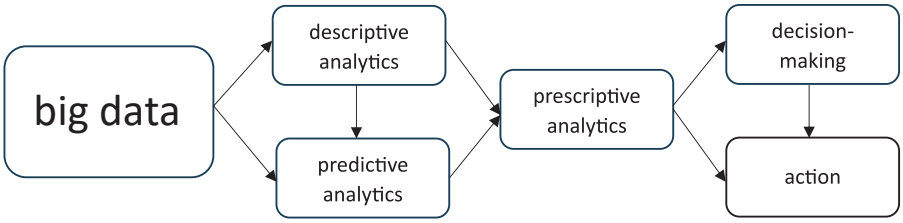

Figure 2. Utilizing descriptive, predictive and prescriptive analytics in decision-making and actions

Source: [Wyrembek, 2022].

The diverse potential benefits of data-driven decision-making have led researchers and scholars to explore the integration of large datasets in supply chains. As a result, the number of scholarly articles on this topic has increased in recent years. The significance of employing big data analytics techniques in supply chains is particularly crucial because organizations cannot succeed in today's competitive markets without utilizing these tools. Since 2010, many articles have been published emphasizing the importance of big data analytics in supply chains and the achievements in this field [Barbosa et al., 2018; Lamba, Singh, 2017; Nguyen et al., 2018; Wamba, 2018b]. Mishra et al. [2017] also identified influential researchers and articles with the highest number of citations by conducting a bibliometric analysis of large datasets. The results showed an increase in the number of articles related to big data analysis. Barbosa et al. [2018] conducted a systematic literature review examining the application of big data analytics in the supply chain area. They demonstrated that analytical techniques typically employ predictive and normative approaches, rather than descriptive ones. Dubey et al. [2018] conducted a study to identify the impact of large datasets and predictive analytics on aspects of sustainable development. Data were collected from 205 manufacturing firms and analysed using partial least squares structural equation modelling. The results showed a positive and significant impact of big data on the social and environmental aspects of sustainable development. Gupta et al. [2017] conducted a systematic literature review based on 28 articles in journals, examining the impact of big data analytics techniques on humanitarian supply chains. They proposed several important research directions based on key organizational theories. Zhao et al. [2017] proposed a green supply

chain optimization model using big data analytics, considering three different optimization scenarios. They utilized a data-driven approach for data acquisition and management. Song et al. [2018] investigated issues and challenges related to big data in the context of environmental performance evaluation, summarizing the latest achievements in environmental management based on big data technologies.

In descriptive analytics, the following issues are examined: what happened, what is currently happening, and why. This process utilizes visualization tools and online analytical processing systems, supported by reporting technology (e.g. RFID, GPS, transactional barcode), and real-time data to identify new opportunities and problems. Descriptive statistics are used to collect, describe and analyse raw data related to past events. This allows for the analysis and description of past events, enabling their interpretation and understanding by humans. Descriptive analytics enables organizations to draw conclusions from the past and understand the relationships between variables and their impact on future outcomes. It can be applied, for example, to present average amounts of money, inventory levels and annual changes in sales. Descriptive analytics is also useful in financial reporting, sales, operations and production within organizations

Predictive analytics techniques are used to answer the question of what may happen in the future by examining data trends from the past using statistical techniques, programming and simulation. The aim of these techniques is to discover the causes of events and phenomena and to accurately predict the future or supplement data or information that no longer exists. Statistical techniques do not provide predictions of the future with 100% accuracy. Predictive analytics is used to forecast purchasing patterns, customer behaviours, and sales trends to identify and forecast future sales actions. These techniques are also used to predict customer needs and manage inventory and operations.

Prescriptive analytics deals with the question of what should be done and how to achieve it. It is based on predictive and descriptive analysis, utilizing descriptive and predictive techniques, simulation, mathematical optimization, or multi-criteria decision-making techniques. The use of prescriptive analytics is complex, and most companies still struggle to apply it in their daily business operations. Proper use of prescriptive analytics techniques can lead to optimal and effective decision-making. Many large companies use data analysis to optimize production and inventory management. Key scenarios that prescriptive analytics allows companies to address include, but are not limited to:

- What offer should be proposed to each end customer?
- What should be the shipping strategy for each retail location?
- Which product should be introduced to the market and when?

In making decisions in the supply chain, statistical analysis, simulation, optimization and various techniques are utilized [Wyrembek, 2022].

4. Application of big data and supply chain management in a printing enterprise

There are numerous potential applications of big data analysis in various areas of enterprises. Virtually every area within a company can benefit from big data analysis. A literature review also indicates that big data analysis can be applied in many areas of enterprise supply chains [Nowakowska, 2023].

In the case of the discussed printing enterprise, data analysis is primarily used in areas such as supplier relationship management, product design and development, demand forecasting, procurement management, customization of products for customers, inventory management and broadly defined logistics. Data comes from both external channels and internal networks. A particular emphasis is placed on customer data, which enables precise determination of their needs and effective adaptation of offerings. This allows for selling them appropriate solutions, and analysing their purchasing behaviours helps predict their needs. Combining various data sources, such as demand and customer data, seasonality, historical data and trends in goods flow, enables demand forecasting. This, in turn, facilitates planning and optimizing distribution processes. Data is also generated in the production department, where it includes a network of sensors, devices on the production floor and production-supporting software updated by employees with various required data in real-time. Thanks to machine learning algorithms, inventory management devices can predict the completion date of new orders, facilitating planning and optimizing logistics processes. By using big data for more precise analysis and integration of all these data, the efficiency of the production, distribution, and sales processes is regularly monitored, and processes and devices are constantly observed. The enterprise consistently utilizes large data sets and analytical techniques to develop its supply chain areas, thereby reducing analytical errors or uncertainties in strategic decision-making to less than 5%.

5. Big data analysis and supplier relationship management in a printing enterprise

Supplier relationship management involves establishing discipline in strategic planning and managing all interactions with the organization's suppliers to mitigate the risk of failures and maximize the value of these interactions. For the discussed printing enterprise, building close relationships with key suppliers and strengthening cooperation with them is a key factor in discovering and creating new value, as well as reducing the risk of failures in supplier relationship

management. Strategic resources and supplier relationship management are critical success factors for the enterprise, which focuses on relationship management and collaboration [Nowakowska, 2023]. The big data analysis techniques used by the enterprise provide precise information on organizational spending patterns, which helps in supplier relationship management. For example, big data provides the enterprise with accurate data on the return on investment of any investment and supports in-depth analysis of a potential supplier. In the process of evaluating and selecting suppliers in the discussed enterprise, fuzzy synthetic evaluation and analytic hierarchy process are also utilized, considering the effectiveness of processing large data sets as one of the evaluated factors. Through big data analysis with the aforementioned indicators, the enterprise maintains a very stable position in the market, ensuring continuity of supplies to its customers. The aim of conducting big data analyses is to select a supplier partner who will be able to adapt, among other things, to future challenges related to large data sets [Wang et al., 2018].

6. Designing a big data analytics and supply chain network in a printing enterprise

In every enterprise, the design of the supply chain network constitutes a strategic decision that encompasses all aspects related to selecting supply chain partners and establishes the policies and programs of the enterprise aimed at achieving long-term strategic objectives [Prasad et al., 2018].

In the context of a printing enterprise, designing the supply chain network involved determining the physical configuration of the supply chain that impacts most business units and functional areas of the enterprise. In this context, a key element was also considering customer satisfaction and supply chain efficiency. The primary goal of supply chain design was to create a network of members capable of meeting the long-term strategic objectives of the enterprise. The following steps were applied in supply chain design:

- defining long-term strategic goals,
- determining the scope of the project,
- choosing the form of analysis to be conducted,
- selecting the tools to be utilized.

Ultimately, the optimal supply chain project was chosen, which entailed appropriate planning to gain significant competitive advantage. This project proposed a nonlinear mixed-integer model for the location of distribution centres, utilizing large datasets and randomly generated data for warehouse operations, customer demand forecasting, and transportation planning. It was also assumed that behavioural data would be analysed using marketing analytics tools, and large datasets

would provide essential information regarding costs, penalties, and service levels. It was deemed to be a powerful tool for designing complex distribution networks.

In selecting the appropriate project, consideration was also given to the application of big data analysis in project interventions, such as healthcare, disaster relief and education in the supply chain. The chosen project fully met the expectations of the enterprise, significantly contributing to its development and operational improvement.

7. Big data analysis and product design and development

One of the main challenges in the analysed printing company is ensuring that their products align with customer preferences. As customer preferences and expectations change throughout a product's lifecycle, those responsible for sales and distribution need tools to predict and measure these preferences and expectations. Insufficient information about customer preferences and expectations has always been a significant issue in the product design and sales process. However, with ongoing monitoring of customer behaviours and access to real-time data on customer preferences, sales representatives can now effectively meet customer expectations, achieving a prediction accuracy level exceeding 90%, which is a significant improvement compared to the pre-big data analysis tool implementation, which was around 60%. Through continuous monitoring of customer behaviours, sales representatives, along with the team responsible for production processes, generate vast amounts of data, considered as big data. Collecting and managing this vast data, as well as applying modern data analysis methods to derive valuable insights and information, and then translating them into actions, have significantly reduced the level of uncertainty.

Product design and development are often defined as the process of transforming customer needs into design specifications. Although there are various approaches to product design [Labbi et al., 2015], all these methods are applicable in the context of data science. The general outline of the design process is depicted in Figure 3.

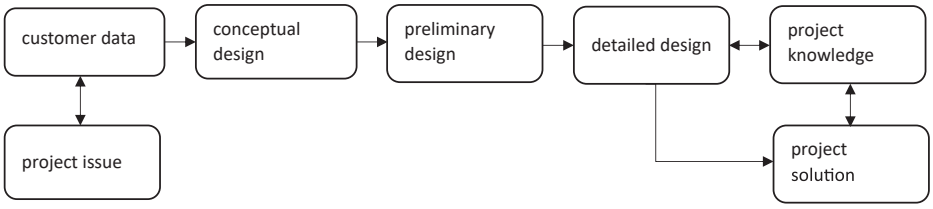

Figure 3. The design process from an analytics perspective
Source: [Suh, 2001].

The analysis of big data has an impact on numerous industries, and product design is no exception. This stems from the fact that an increasing number of businesses are leveraging various tools for designing manufacturing processes, which also integrate communication technologies. Consequently, it is essential to consider the specificities of a company's product during supply chain design and to integrate all partners and constraints of this chain. Designing the supply chain according to the product design allows for the creation of competitive advantage and flexibility in supply chain operations [Labbi et al., 2015].

The introduction of big data analysis into the product design process at the discussed printing company has led to the creation of new, unique products that perfectly align with customer preferences, effectively meeting their expectations. Utilizing big data analysis in product design has enabled the company to fully understand customer preferences and expectations, resulting in the creation of tailor-made products that meet their needs and preferences. Sales representatives continuously leverage available online data regarding customer behaviours and purchase histories to anticipate and understand their needs. Through constant access to data, they can identify product features and forecast future trends, continuously monitoring customer behaviours and needs and gathering insights from their feedback.

8. Big data analysis and demand forecasting in a printing enterprise

Many managers from various enterprises aim to improve demand forecasting and production planning using large datasets. Accurate demand forecasting has always been a crucial issue in supply chain management [Feng, Shanthikumar, 2018]. Current access to big data analytics in the printing enterprise allows for determining customer loyalty, predicting demand, and presenting optimal pricing data. Access to analytics also enables the identification of new market trends and the determination of root causes of issues, failures and defects.

Data analytics also enables predicting customer preferences and needs by analysing their behaviours, thereby stimulating creativity and innovation. Through the utilization of big data analysis tools, the enterprise manages to achieve over 90% accuracy in forecasting the demand of its loyal customers each year. Prior to the introduction of big data analysis tools, such high accuracy in demand forecasting was not achievable.

9. Big data analysis and procurement management in a printing enterprise

As tactical and operational decisions, procurement involves a range of mechanisms and contracting processes [Johnson, Bohle, 2019]. In a given printing enterprise, procurement planning encompasses a large volume of widely distributed data generated across various operations, systems, and geographic regions. The enterprise utilizes advanced analytical systems to manage this vast data and a team of skilled specialists capable of analysing the data and deriving valuable insights and knowledge from it.

In the past, the enterprise struggled with difficulties in manually collecting and analysing data. Such an approach would take many days or even weeks to obtain internal and structural data regarding the company's operations and transactions, as well as those of its partners. However, nowadays, with the utilization of big data analytics programs, diverse structural, unstructured, internal, and external data generated as a result of automated processes are analysed in real-time or in a very short period.

Additionally, by utilizing big data analytics tools, the enterprise analyses supplier performance and continuously evaluates supply chain risks, which was previously impossible. Such predictive analysis of large datasets has enabled the identification, assessment, mitigation, and management of risks within the supply chain. Through the utilization of this analysis, the enterprise achieves a procurement planning accuracy level of over 90% each year, whereas prior to the implementation of analytics, the enterprise achieved a maximum procurement planning accuracy of 60%.

10. Big data analysis and customized production in a printing enterprise

Thanks to big data analysis, manufacturers have the opportunity to discover new information and identify patterns that allow them to streamline processes, increase supply chain efficiency, and recognize factors influencing production. In today's global and highly complex environment, supply chains and production processes involve lengthy and intricate procedures. There is also the possibility of thoroughly examining all elements of each process and link in the supply chain to simplify processes and optimize the supply chain. Data analysis programs used in the discussed printing enterprise enable precise determination of actions and tasks for each employee on the production line through timely and accurate analysis of data from every part of the production process and detailed examination

of the entire supply chain. This capability enables the identification of bottlenecks and reveals poorly functioning processes and production components. In the past, centralized and large-scale production was not rational, as it focused solely on the needs of a small group of strategic clients. However, today's big data analysis used in the printing enterprise allows for very accurate prediction of requirements and preferences of all customers, including especially preferences for non-standard products, enabling the enterprise to create products perfectly tailored to customer needs.

11. Big data analysis and inventory management in a printing enterprise

Inventory control encompasses processes of demand forecasting, inventory management, procurement, and supply synchronization. Key objectives of inventory control project include:

- monitoring inventory levels and required stock quantities,
- facilitating timely replenishment of inventory through automatic recording and handling of pending orders,
- minimizing inventory levels through analysis of past purchasing and consumption patterns,
- utilizing automated inventory management, handling, and procurement tools,
- improving financial control through regular inventory checks and physical counts.

These objectives aim to enhance operational efficiency, optimize inventory levels, reduce costs and ensure smooth supply chain operations in the printing enterprise.

The integration of business systems supported by big data has significantly increased operational efficiency in the printing enterprise, simultaneously bringing greater profitability. Through continuous monitoring and analysis of operational data, sales representatives have better access to metrics, resulting in increased efficiency and the elimination of bottlenecks. Big data analysis has also improved the performance of the entire supply chain, with real-time data access enabling immediate response to changes in demand and consumer trends. Directors, including those in finance, can constantly monitor and analyse data, enabling them to make better investment decisions, thereby increasing profitability. Sales representatives have the ability to adjust inventory levels to current orders and customer preferences, contributing to increased customer satisfaction. Additionally, data analysis is used to predict increases and decreases in demand as well as seasonal trends, allowing for more accurate inventory planning in different periods.

12. Big data analysis and logistics in a printing enterprise

In recent years, every industry has experienced significant transformation driven by the increasing volume of data, growing emission concerns, complex regulatory requirements, evolving business models, and limitations related to human resources, infrastructure, and technological development. In the discussed printing enterprise, a priority has been the standardization of data exchange structure and content to streamline communication and collaboration across various logistics sectors, such as freight forwarders, manufacturers, logistics companies, distributors, and end customers, for example, printing houses. Cost reduction through inventory optimization, real-time event response, and resource sharing has become crucial for effective supply chain management and big data analysis in the enterprise.

Currently, due to the vast amount of data from various sources and the integration of business intelligence and data, advanced systems are being used to enable rapid data analysis and provide real-time information for quick decision-making. With the exponential growth in the number of orders, the enterprise requires huge datasets and real-time analysis methods to manage orders and maintain high-quality production. Through the daily generation of large amounts of data related to shipped parcels, such as size, weight, origin and destination, the enterprise utilizes the best available system solutions for data analysis and improving operational efficiency and customer service.

The data platforms and data analysis processes in the discussed enterprise have been designed to translate insights into actions and adapt them dynamically in line with the company's strategic vision, which emphasizes the aspiration to be a progressive enterprise leveraging comprehensive analysis to gain valuable insights and invest in advanced analytical systems and tools.

The discussed enterprise actively strives to stay ahead of market changes in the printing industry by leveraging advanced management and data analysis technologies and transitioning to modern, sophisticated data management and analysis techniques. It aims to be a knowledge-based enterprise, utilizing the latest analytical systems to acquire valuable insights and continuously analysing various observations in both internal processes and relationships with customers and business partners.

The company also aims to embrace the concept of "information without borders" in communication among customers, business partners, and suppliers in the printing industry, with whom it maintains strategic alliances. The vast array of data generated by these entities is integrated into logistics technologies, such as supply chain management solutions and IoT devices, enabling data sharing and access for all involved parties.

The supply chain platform of the enterprise manages and integrates diverse data originating from various internal and external systems, while also ensuring

appropriate validation and management to enhance data reliability. It also provides business users with suitable tools for conducting exploratory analyses and generating insights independently.

Conclusions

Big data analysis has become a critical practical issue in today's enterprises, offering a wide range of development opportunities through the appropriate utilization of analytical techniques. This article attempts to illustrate both basic and latest applications of big data analysis using a printing enterprise as a case study. Special attention is given to key techniques used in supply chain management, which are significant from a managerial perspective.

The article demonstrates the importance of proper data analysis in the context of the entire supply chain, including areas such as supplier relationship management, product design, demand planning, inventory management, logistics network design, production, procurement, logistics, and distribution. The utilization of large datasets and advanced analytical techniques in the discussed printing enterprise has led to significant improvements in supply chain processes, enabling the achievement of over 90% accuracy in predicting customer demand each year.

Furthermore, big data analysis supports sustainable development of the supply chain in the enterprise, aiding in the management and integration of diverse data in the global supply chain. These innovative approaches have contributed to the establishment of a significant competitive advantage for the printing enterprise in the market.

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The importance of economic openness for the economic growth of OECD countries in the years 1990–2020

This study analyses the impact of economic openness on economic growth in OECD countries over the years 1990–2020. Utilizing panel data and dynamic panel estimation methods, it examines the relationship between various aspects of economic openness – such as international trade, migration, foreign direct investment and political and economic integration – and the dynamics of economic growth. The results indicate a positive impact of economic openness on economic growth, with varying strength depending on the factor. The analysis also highlights the importance of further research in the context of new global challenges, such as digitization and climate change, for understanding the relationship between openness and economic growth in a changing global environment.

Keywords: economic growth, economic openness, panel data analysis, international trade, economic integration

JEL classification: F43, F63, O47, C23

Introduction

The extremely dynamic economic growth observed in the last century has inspired economists to conduct intensive research focused on identifying its sources. Numerous attempts have been made to create a theoretical model that would satisfactorily explain this phenomenon and provide researchers with appropriate tools for empirical studies, as well as a basis for formulating relevant economic policy recommendations.

The first model meeting these criteria was independently formulated by Solow [1956] and Swan [1956]. Today, it is considered a milestone in macroeconomic research and serves as the primary tool for explaining how capital accumulation, technological progress and population growth impact economic growth. Despite its fundamental role, it has several limitations. These include the assumption of constant returns to scale, which may be increasing due to, for instance, knowledge

accumulation and diffusion or innovations, which this model omits by treating technological progress as an exogenous variable. Furthermore, it predicts the occurrence of absolute convergence, which, as shown by Barro and Sala-í-Martin [1992], among others, has been questioned by other growth models and is not empirically confirmed.

In the dynamically changing post-war world, the elegant simplicity of the Solow–Swan model, due to its limitations, could no longer sufficiently explain economic growth driven by phenomena that were not observed before. The extraordinarily rapid technological progress also introduced new and previously unknown phenomena, setting new directions for social science research. By the late 20th century, successful attempts were made to endogenize technological progress. Among the pioneers of endogenous growth theory are researchers like Lucas [1988], who focused on the role of human capital accumulation, and Romer [1990], who introduced the concept of knowledge spill-overs and emphasized its non-rival nature. Alternative theories were also proposed by Aghion and Howitt [1992], who formulated a model based on innovation and growth through "creative destruction", explaining the replacement of old technologies with new ones. Grossman and Helpman [1991] also created an interesting theory emphasizing the importance of international trade and innovation-friendly policies, among many other researchers over the years.

The significant pace of globalization, the enormous increase in international trade volume, mass migration of people from poorer to richer regions, unprecedented international integration and cooperation, and many other phenomena have resulted not only in new theoretical papers but also numerous empirical studies. Among engrossing examples of such studies are those of Barro [1991] and Rodrik and Rodríguez [2000]. Interesting analyses for Central and Eastern European countries have been conducted by Ciołek [2003] and Rapacki and Próchniak [2014]. A relatively extensive meta-analysis of various studies on the relationship between economic openness and economic growth was presented by Domańska [2011].

Despite numerous empirical studies [e.g. Dallinger, 2013; Ya Wen et al., 2023], there is still no unequivocal answer to the question of the impact of various aspects of economic openness on economic growth, how varied this impact is depending on the region under study, and what the potential causes of this variation might be. Moreover, there seems to be a lack of a theory that satisfactorily and comprehensively explains how economic openness affects economic growth and development. This study provides an empirical attempt to answer the question of the direction and strength of the impact of economic openness on the economic growth of 38 OECD economies in the years 1990–2020, a period of the most dynamic deepening of economic integration among various countries belonging to

this organization, particularly the European Union countries, which constitute the majority of OECD member states.

A review of contemporary research and detailed description of the identified research gap will be discussed in the next section of the article. The third section will provide a concise overview of the changes in GDP per capita levels in the examined economies. The fourth section will present a description of growth regression for panel data, a method popular in the literature for analysing the impact of various variables on the dynamics of economic growth. The fifth section will briefly discuss the methods of estimating dynamic panel models, particularly the FD GMM estimator proposed by Arellano and Bond [1991] and the SYS GMM developed by Blundell and Bond [1998] and improved by Blundell et al. [2001]. The final section will present the results of the growth regression estimation, conducted in three-year intervals to eliminate as much as possible potential business cycle effects that could distort the obtained regression model estimates.

1. Openness and economic growth in empirical research

In the 21st century, quite a lot of empirical efforts are being made to identify the impact of economic openness, understood in various ways, not only on economic growth but also on development, the general standard of living, and socially significant issues such as the wage gap, social inequalities and the demand for social protection. The effects of rapidly progressing globalization and the opening of economies undoubtedly constitute a crucial issue for researchers worldwide.

Dallinger [2013] undertook an analysis of the impact of economic openness and globalization on the demand for social protection and social expenditure. The main premise of her study was the assertion that economic openness, by increasing labour market uncertainty, leads to a higher demand for social protection from voters. However, results obtained using multilevel logistic models did not confirm the main assumption of this study. Economic openness was found to have a negative impact on the demand for social protection. Furthermore, the response to increasing levels of economic openness is class-differentiated – unskilled workers and lower-class employees in the service sector show a higher demand for social protection than skilled workers. Subjective employment uncertainty also negatively affects the demand for social protection. A similar study, but for Latin American countries, was conducted by Burrier [2014]. Including the political orientation of governments, he found opposite conclusions. Based on a panel analysis of seventeen South American countries, he stated that economic openness promotes an increase in social protection expenditure, as does a left-wing government orientation, unlike right-wing governments. According to the author, governments use

this approach to compensate for citizens' uncertainty associated with increased levels of economic openness.

Many studies have also been conducted on income distribution, inequality or the wage share in GDP. For instance, Guschanski and Onaran [2016] analysed factors determining the wage share in GDP in selected OECD countries. They demonstrated that globalization has a strong and negative impact on the wage share in GDP in all the countries they studied. This impact is mainly exerted through variables such as FDI and imports. Among other factors affecting the wage share, they also mentioned union activities and collective bargaining, which had a positive impact, with unions being most influential in Germany and collective bargaining in France and the UK. Technological changes had an ambiguous impact, while the growing role of the financial sector in the economy had a negative impact. Gülsün et al. [2016] conducted a similar study, examining the influence of both globalization and liberalization. According to their findings, both globalization and liberalization contribute to increasing wage inequality, especially in OECD countries. However, economic policies aimed at creating a stable monetary system can help reduce inequality. Özdemir [2019] also studied the relationship between economic openness and income distribution. He found that economic openness promotes the growth of income inequality, with trade openness having a greater impact than financial openness. Thus, contemporary studies confirm the theses of Rodrik [1998] and Stiglitz [2002] that economic openness has an ambiguous impact on the standard of living, which can often be negative, and the potential problems are not limited to developing countries but also affect highly developed economies such as OECD countries.

In studies on economic openness, the approach often focuses mainly on trade openness. Navaratnam [2014] conducted such a study on the economy of Sri Lanka. His findings showed a positive impact of trade openness on Sri Lanka's economic growth. The example of Sri Lanka also shows that trade openness leads to increased employment and capital investment, and positively affects the country's macroeconomic stability. Iyke [2017] conducted a similar study for a slightly larger group of countries. Based on his analysis of seventeen Central and Eastern European countries, he found that trade openness was a significant factor in economic growth in this group of countries. He also analysed trade liberalization policies, but according to his findings, their impact remains ambiguous, indicating the need for further research in this area. An interesting analysis of regional dependencies between economic openness, innovation, and economic growth in China was conducted by Ya Wen et al. [2023]. According to their analysis, the increase in the level of economic openness promotes the optimization of regional development, with technological innovations being a significant channel of optimization, which

seems to be in line with Romer's [1986; 1990] theory of the importance of innovation for economic growth.

Various aspects of economic openness thus seem to have a very diverse impact on macroeconomic variables such as economic growth, the level of income inequality in the economy, government spending on social protection, and many other economic, social, and political variables. Contemporary studies on the impact of trade liberalization are partly contradictory to studies by Sachs and Warner [1995] and Rodrik et al. [2004]. Moreover, studies often focus on the effects of globalization and openness, primarily understood as trade openness, measured by the share of imports and exports in GDP, or financial openness, including FDI.

There seems to be a lack of analyses of the impact of non-financial factors, such as migration or membership in various multilateral agreements and integration groups. The impact of different aspects of openness is usually studied separately. Thus, there is a need for a study that comprehensively takes into account the impact of various factors on economic growth, including all, macroeconomic and social and political ones. This analysis aims to fill this gap by using explanatory variables from each of the mentioned categories, both individually and collectively. It thus aims to answer not only the question of the impact on economic growth of individual variables separately but also whether different combinations of them can affect growth in various ways.

2. Evolution of openness in global economy

As mentioned in the introduction, in the second half of the 20th century, the global economy underwent a profound transformation, marked primarily by a rapid increase in economic openness and a departure from isolationist policies that sometimes prevailed before World War II. This pivotal moment in economic history, initiated by the end of the global conflict, marked the beginning of a new era in global trade and investment. The decisions made during the Bretton Woods Conference in 1944, aimed at post-war economic reconstruction, played a crucial role. Institutions such as the International Monetary Fund and the World Bank were established to support economic stability and post-war recovery. Furthermore, in 1947, the General Agreement on Tariffs and Trade was concluded, later replaced by the World Trade Organization in 1995. The goals of these organizations – promoting international cooperation and the liberalization of trade and capital flows – formed the foundations of the new economic order. As noted by Keynes [1936] and White [1942], the architects of the Bretton Woods system, financial stability and the reduction of trade barriers were seen as key to ensuring long-term economic growth and global prosperity.

The Cold War and its consequences, including the collapse of the Soviet Union, also significantly shaped the global economy. The fall of the Iron Curtain and the establishment of the European Union through the Maastricht Treaty in 1993, culminating a long process of deeper integration in Europe, opened new opportunities for international trade and investment. The economic transformation of the former Eastern Bloc countries, including reforms implemented in Poland and Hungary, as well as economic reforms in China initiated by Deng Xiaoping, profoundly impacted the evolution of the global economy, contributing to increased volumes of international trade, capital flows, and foreign direct investment.

Analysing the various aspects of economic openness and its impact on economic growth reveals the complex and multidimensional nature of this phenomenon. This study primarily distinguishes between economic, social, and political openness. Economic openness is understood as the free flow of goods, services, and capital, manifested through international trade and FDI. Social openness mainly refers to the free movement of people, facilitated by the removal of borders between countries or simplified visa procedures. Political openness is understood as membership in international integration organizations and multilateral political-economic treaties, leading to economic and political integration, access to new markets through the removal of tariffs and various economic blockades. The literature indicates numerous potential benefits from greater integration with the global economy, but many researchers also emphasize the challenges and risks associated with it.

Rodrik [1998] points out that openness may require greater government involvement to stabilize the economy and protect society from the negative effects of globalization, suggesting a complex relationship between openness and economic growth. Sachs and Warner [1995] provide empirical evidence that countries that chose to liberalize their economies experienced accelerated growth, indicating potential benefits from openness. Similar conclusions are drawn by Rodrik et al. [2004], who highlight that trade liberalization, market deregulation, and capital flow facilitation are key elements supporting growth by increasing competition, efficiency, and innovation. An interesting study on the relationship between international trade and per capita income was conducted by Frankel and Romer [1999].

However, as Stiglitz [2002] notes, globalization and economic openness can also bring disappointments, especially for developing economies, highlighting the uneven distribution of benefits and costs of increasing openness, which can hinder economic growth in some regions. He emphasizes the need for reforming global financial and trade institutions to make globalization more fair and beneficial for all. Baldwin [2016] expands this discussion by arguing that the new globalization, driven by technological progress, has a different impact on economies than traditionally understood trade openness. He emphasizes that in the digital age, the

importance of knowledge and information in the global economy is greater than ever, pointing to the necessity for governments and businesses to adapt to new driving forces that will shape the global economic landscape in the future, potentially leading to profound changes in policy and business strategies. Shaping economic policy in the era of globalization will require balancing the opportunities and limitations that economic openness brings to ensure economic growth along with social and economic stability.

The impact of economic openness on economic growth can therefore vary, depending on many factors such as the stage of economic development, the quality of institutions, the economic policy of the country, and adaptive capacities. Developed countries may more quickly reap the benefits of openness due to better infrastructure and institutions, while developing countries may face challenges in fully leveraging the benefits without appropriate investments in socio-economic development.

3. Economic growth of OECD countries in 1990–2020

The OECD was established under the Convention on the Organisation for Economic Co-operation and Development signed in Paris in 1960. Many of the countries that make up this organization today are among the world's largest economies and have had a significant impact on shaping the global economy in the post-war years. These countries, too, have observed and participated in significant economic transformations over the last three decades, closely linked to the processes of opening up their economies. Particularly interesting examples of economies that have achieved spectacular success in recent decades are certainly the countries of the former Eastern Bloc, which transitioned from centrally planned economies to market economies after the collapse of the Soviet Union in the early 1990s.

The transformation process of these economies included a series of reforms, such as the liberalization of prices and exchange rates, privatization of state-owned enterprises, liberalization of international trade and capital flows, and integration with European and global markets. Countries like Poland, the Czech Republic, Hungary, and the Baltic states have demonstrated the ability to adapt and implement deep structural changes that enabled rapid economic growth. As demonstrated by Ciołek [2003], they also exemplify a gradual convergence to the living standards and economic development levels of Western countries.

Table 1 uses GDP per capita PPP in constant 2017 international dollars, as a measure of economic size. According to the data in the table, the most spectacular growth between 1995 and 2020 was achieved by Lithuania, whose GDP per capita increased by 249.42% during this period. Similarly impressive growth was

recorded by Latvia (208.11%), Estonia (181.86%), Poland (162.51%), and Slovakia (133.59%). Among the countries formerly behind the Iron Curtain, somewhat smaller but still impressive growth was noted in Hungary (88.01%) and the Czech Republic (69.78%). It should be emphasized, however, that the GDP figures for 2020 were significantly distorted due to the outbreak of the COVID-19 pandemic. It can be expected that if this black swan event had not altered the global economy, the GDP per capita of the countries studied would likely be much higher[9].

An interesting example of economic success outside Europe is South Korea (133.97% growth). Among others, Rodrik [1995] showed that the export-led growth policy pursued by Korea is not sufficient to explain the country's rapid economic growth. He particularly emphasizes the role of strategic government interventions, including subsidies, coordinated investment strategies and policies aimed at creating a favourable investment climate that fostered technological progress, one of the most important factors in economic growth. Additionally, the external orientation of the economy resulted from increased demand for imported capital goods, driven by the government's increase in private capital returns. Rodrik's study can be seen as a kind of confirmation of the theory developed five years earlier by Romer [1990].

However, among OECD countries, there are also those that did not achieve such economic success. Greece (8.38% growth) can be cited as a primary example of poor policy. Over the last three decades, the growth trajectory of this country has been a sine wave of prosperity, crises, and gradual recovery. The 1990s brought a period of moderate growth driven by integration within the European Union and entry into the Eurozone at the beginning of 2001. However, poor fiscal management led to a huge increase in public debt due to the constant maintenance of a deficit in the public finance sector, which contributed to the reversal of the growth trend for Greece. The global financial crisis of 2007–2008 also wreaked havoc on the country's economy, eventually leading Greece into a debt crisis in 2009. This necessitated multiple international bailout packages from the European Union, conditional on austerity measures and structural reforms. These reforms led to deep recession and social difficulties but were necessary for economic stabilization. Signs of recovery appeared from 2017 onwards, with GDP growth and declining unemployment, although the legacy of the debt crisis and the impact of the COVID-19 pandemic still pose challenges for the country's economy.

In summary, the analysis of the economic growth of OECD member countries reveals a diversity of development trajectories, largely dependent on historical conditions, economic policies and the adaptive capacities of individual economies.

[9] An example of the greatest distortion of results by the COVID-19 pandemic is Italy, whose growth in the years 1995–2020 was only 0.38% due to the significant decline in GDP in 2020. The increase in Italy's GDP in 2019 compared to 1995 precipitated 9.78%.

The complexity of economic processes and the importance of appropriate economic policies, which together shape the prospects for economic growth, are clearly visible. Ultimately, it seems that economic success depends not only on internal factors but also on the ability to adapt to the changing global economic environment.

4. Empirical growth regression for panel data

In studies involving groups of countries, their individual characteristics, such as the level of wealth and the various inputs of different production factors, and thus a diversified production function, can be of significant importance. Also crucial can be the unobservable characteristics of individual economies, such as the level of technology or various institutional, social, historical, and geopolitical conditions. These factors can also change over time. When using models based on cross-sectional data or time series, all unmeasurable or unobservable factors are included in the error term, leading to a violation of the assumption of no correlation between explanatory variables and random disturbances, resulting in a biased model when estimated using methods like OLS and its derivatives [Caselli et al., 1996]. In such a situation, the best solution seems to be estimating a regression model using panel data, which allows the individual specifics of units and periods to be included in the model [Ciołek, 2003].

Due to the emphasis by researchers like Rodrik [1998], Sachs and Warner [1995], and more recently Iyke [2017] and Navaratnam [2014] on the importance of trade openness, it has been included in this study as a variable representing the share of imports and exports in GDP. Financial openness, also frequently mentioned in studies, has been included in the form of variables related to FDI. Additionally, social variables such as the net migration share in the population, and political variables such as membership in international integration groups, have also been included. Thus, the following panel data regression and its various variants with a smaller number of variables have been applied in this study:

$$\begin{aligned}\ln(y_{i,t}) = \alpha_0 + (1-\beta)\ln(y_{i,t-1}) + \alpha_1 s_{i,t} + \alpha_2 \ln(\rho_{i,t}) + \alpha_3 H_{i,t} + \alpha_4 TRADE_{i,t} + \\ \alpha_5 MIG_{i,t} + \alpha_6 PFDI_{i,t}^{IN} + \alpha_7 INT_{i,t} + \varepsilon_{i,t}.\end{aligned} \tag{1}$$

where:

$\ln(y_{i,t})$ – the natural logarithm of real GDP per capita at PPP in the *i*-th economy in the year *t*,

$(1-\beta)$ – autoregressive parameter, used to take into account the occurrence of possible β-convergence[10],

$\ln(y_{i,t-1})$ – the natural logarithm of real GDP per capita at PPP in the i-th economy, lagged by one period,

$s_{i,t}$ – share of gross fixed capital formation in real GDP in the i-th economy,

$\ln(\rho_{i,t}) = (n_{i,t} + g + \delta)$ – the natural logarithm of the sum of the population growth rate (n), the rate of technical progress (g) and the rate of capital depreciation (δ) in the i-th economy,

$H_{i,t}$ – investment rate in human capital per capita, based on the number of years of education and the return on education for the i-th economy,

$TRADE_{i,t} = \left(\frac{I_{i,t} + X_{i,t}}{Y_{i,t}}\right) \times 100\%$ – share of imports (I) and exports (X) in GDP (Y) in the i-th economy,

$MIG_{i,t} = \left(\frac{NM_{i,t}}{P_{i,t}}\right) \times 100\%$ – the ratio of net migration (NM) to population (P) in the i-th economy,

$PFDI^{IN}_{i,t} = \left(\frac{FDI^{IN}_{i,t}}{Y_{i,t}}\right) \times 100\%$ – ratio of foreign FDI inflows to GDP (Y) in the i-th economy,

$PFDI^{OUT}_{i,t} = \left(\frac{FDI^{OUT}_{i,t}}{Y_{i,t}}\right) \times 100\%$ – ratio of domestic FDI outflows to GDP (Y) in the i-th economy[11],

$INT_{i,t}$ – membership in various types of integration groups of the i-th economy,

$\varepsilon_{i,t}$ – error term for the i-th economy in period t.

Since on the right side of equation (1) there is an explanatory variable lagged by one period, it is a dynamic autoregressive model. This study used such an approach to take into account the occurrence of conditional β-convergence among OECD countries, which may be interesting due to the relatively high level of differentiation of individual economies, both in terms of development and the distance between the countries covered by the study.

5. Estimation methods

As mentioned above, this model considers conditional β-convergence and is a dynamic autoregressive model, thus requiring appropriate estimation methods. The presence of a lagged dependent variable, which is correlated with the error term, as well as individual effects indicating the heterogeneity of the countries studied, necessitates the use of suitable estimation methods. Traditional estimators

[10] $\beta = \frac{(1 - e^{\lambda T})}{T}$, where λ – rate of conditional convergence, T – number of observations over time.

[11] This variable was not included in formula (1) because domestic FDI and foreign FDI cannot be combined in one model. It would then be impossible to estimate it correctly.

such as OLS or generalized OLS cannot be used to estimate such a model because their application in this case leads to biased and inconsistent parameter estimates [Baltagi, 2021]. Furthermore, since these estimators do not account for individual or period effects, the results of the autoregressive parameter estimation obtained with these estimators are also incorrect. Consequently, the rate of β-convergence and the impact of the analysed explanatory variables on economic growth cannot be correctly assessed. As shown by Blundell et al. [2000], similar problems occur when using the Within estimator. Although it solves problems related to omitted variables or individual effects, the endogeneity of explanatory variables remains an issue, leading to an incorrect estimation of the autoregressive parameter.

To address these problems, various methods have been proposed, mostly based on the GMM estimator developed in the 1980s by Hansen [1988]. Two approaches dominate in particular. The first is the application of the GMM estimator in the form of first differences (FD GMM), proposed by Holtz-Eakin et al. [1988], and later developed by Arellano and Bond [1991]. The second approach is the use of the so-called System GMM (SYS GMM), proposed by Blundell and Bond [1998].

To eliminate the problem of endogeneity of the variables, the method proposed by Arellano and Bond involves a two-step procedure. The first step is to estimate the equations for the first differences. This solution eliminates the need for the model to meet the assumption of no correlation between explanatory variables and individual effects, as differencing removes them from the regression. However, this does not yet resolve the problem of potential endogeneity of the explanatory variables, so it is also necessary to use appropriately chosen instruments. The Arellano–Bond estimator uses lagged levels of the dependent variable as instruments for the lagged differences of the dependent variable.

In the case of growth regression with conditional β-convergence, the FD GMM estimator can be biased. This occurs when the variance of the individual effects is significantly larger than the variance of the error term, as well as when the autoregressive parameter approaches values close to unity. The reason for this bias is that lagged levels of the dependent variable are weak instruments for the lagged differences of the dependent variable, as they are weakly correlated with each other. In this case, using the FD GMM estimator results in a significant underestimation of the autoregressive parameter, leading to an overly rapid convergence rate [Ciołek, 2001; Blundell, Bond, 1998]. Blundell and Bond proposed addressing this problem by estimating, in addition to the equations for first differences, additional equations for levels. This approach led to the development of the SYS GMM estimator, an extension of the Arellano–Bond estimator. In this study, the SYS GMM estimator was used to estimate the growth regression model.

6. Estimation results

This model was estimated using data from the Penn World Table and the World Bank database. To satisfactorily eliminate the time effects associated with business cycles, the growth rate was determined for three-year intervals. Due to data gaps for some countries in the early years of the study period, an unbalanced panel was used. The study period covered the years 1990–2020. The aim of this study was to demonstrate the impact that various aspects of economic openness have (or do not have) on the economic growth of 38 OECD economies. The Solow–Swan model, extended to include human capital, served as the basic starting point for the first regression, which included the human capital index among the explanatory variables. This approach was used in theoretical models by Lucas [1988] and Mankiw et al. [1992]. Subsequent regressions were estimated by extending the basic model with additional variables representing different aspects of economic openness, mentioned and described in section 3 of this paper. Migration, for instance, can account for the diffusion of technology between countries, according to Romer's theory [1990]. Membership in integration groups significantly facilitates migration within such groups, which can enhance this effect. It is also associated with the removal of trade barriers, such as tariffs, which contributes to increasing the volume of international trade and, therefore, the flow of technology and know-how. This can impact growth by enabling countries with higher innovation costs to imitate technological leaders, according to Barro and Sala-í-Martin's technology diffusion model [1990]. The estimation results are presented in Table 2.

The results of the baseline model estimation (1) indicate statistical significance at the $p = 0.01$ level for all explanatory variables, except for the natural logarithm of the sum of the population growth rate, technological progress rate, and capital depreciation rate (this variable is not statistically significant in any estimated model, likely due to the relative homogeneity of the analysed countries in this respect). They also confirm the occurrence of conditional β-convergence. Additionally, there is a noticeable positive impact on economic growth from the human capital index, which aligns with the theories of Lucas [1988] and Mankiw et al. [1992].

Subsequent regressions were progressively extended by adding variables representing different aspects of economic openness. In the case of model (2), the explanatory variable used was the combined share of exports and imports in GDP. This variable is statistically significant at the $p = 0.01$ level and the parameter is positive, suggesting that international trade seems to have a positive impact on the economic growth rate, although the strength of this factor is rather weak. Model (3) extends the baseline model by including the net migration share in the population. This variable is also statistically significant at the $p = 0.01$ level and shows a positive impact on the economic growth rate, which is significantly

Table 2. Estimation of growth regression for panel data models with openness variables (SYS GMM estimator)

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\ln(y_{i,t-1})$	0.858*** (0.023)	0.865*** (0.020)	0.831*** (0.029)	0.852*** (0.022)	0.841*** (0.023)	0.842*** (0.025)	0.858*** (0.021)	0.792*** (0.036)	0.808*** (0.0320)
$s_{i,t}$	0.574*** (0.095)	0.498*** (0.082)	0.535*** (0.098)	0.558*** (0.092)	0.550*** (0.095)	0.568*** (0.096)	0.505*** (0.087)	0.515*** (0.096)	0.454*** (0.087)
$\ln(\rho_{i,t})$	0.006 (0.037)	0.012 (0.035)	0.001 (0.039)	0.0004 (0.037)	−0.003 (0.036)	0.007 (0.039)	0.007 (0.035)	0.001 (0.043)	0.002 (0.039)
$H_{i,t}$	0.054*** (0.019)	0.043** (0.017)	0.0635*** (0.022)	0.060*** (0.018)	0.065*** (0.019)	0.055*** (0.020)	0.051*** (0.018)	0.072*** (0.023)	0.064*** (0.021)
$TRADE_{i,t}$	–	0.0003*** (0.0001)	–	–	–	–	0.0003* (0.0001)	–	0.0003* (0.0002)
$MIG_{i,t}$	–	–	0.031*** (0.011)	–	–	–	–	0.044*** (0.012)	0.038*** (0.010)
$PFDI^{IN}_{i,t}$	–	–	–	0.001** (0.0005)	–	–	0.0009** (0.0004)	–	0.0009* (0.0005)
$PFDI^{OUT}_{i,t}$	–	–	–	–	0.001*** (0.0005)	–	–	–	–
$INT_{i,t}$	–	–	–	–	–	0.038*** (0.013)	–	0.056*** (0.017)	0.040*** (0.015)
$\alpha_{0i,t}$	1.235*** (0.229)	1.203*** (0.202)	1.473*** (0.284)	1.265*** (0.219)	1.348*** (0.227)	1.378*** (0.241)	1.237*** (0.207)	1.812*** (0.346)	1.674*** (0.309)
Number of instruments	48	49	49	49	49	49	50	50	52
Number of observations	325	325	325	322	322	325	322	325	322
Number of countries	38	38	38	38	38	38	38	38	38

Notes: Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Own calculations based on the Penn World Table and World Bank.

stronger than that of international trade. Model (4) extends the baseline model by including the ratio of foreign direct investment inflows to GDP. This variable is statistically significant at the $p = 0.05$ level and also appears to have a positive impact on economic growth, though this impact is weak, however somewhat stronger than that of international trade. Similar estimation results were obtained for model (5), which uses domestic FDI outflows as the explanatory variable, although this variable is statistically significant at the $p = 0.01$ level. The last model with a single additional explanatory variable, model (6), extends the baseline model with a binary variable representing membership in various integration groups. This variable is also statistically significant at the $p = 0.01$ level, and the sign of the estimated structural parameter for this variable is positive. This variable seems to have the strongest positive impact on economic growth among all explanatory variables.

Models (7) and (8) are mixed models, with model (7) using variables related to financial macroeconomic factors, namely the share of imports and exports in GDP and foreign FDI inflows. In this model the variable $TRADE_{i,t}$ is statistically significant only at the the $p = 0.1$ level, while the variable $PFDI^{IN}_{i,t}$ is significant at the $p = 0.05$ level. In both cases, the sign of the parameter estimate is positive. These variables, when examined together, show a weaker impact than when analyzed separately. Model (8) uses socio-political variables, namely the net migration share in the population and membership in integration groups. Both variables are statistically significant at the $p = 0.01$ level, and their parameter estimates have positive values. The combined impact of these variables is stronger than individually.

The last estimated model (9) is a comprehensive model that includes all variables related to economic openness, except for domestic FDI outflows. This variable could not be included in the comprehensive model due to multicollinearity. All variables in this model are statistically significant at the $p = 0.01$ level, except for $TRADE_{i,t}$ and $PFDI^{IN}_{i,t}$, which are significant at the $p = 0.1$ level. The parameters for all variables have positive signs, indicating a positive impact on the economic growth rate. In this model, socio-political variables also exhibit a stronger influence than in the models considering them individually. Therefore, they undoubtedly play a more significant role in economic growth than trade or financial openness, which may be related to the free movement of human capital in the form of know-how, knowledge, and high qualifications, thereby fostering the technology diffusion process. This aligns with the theories of Lucas [1988], Romer [1990] and Mankiw et al. [1992]. In light of these results, Baldwin's [2016] theory on globalization driven by technological processes also remains relevant.

It should also be emphasized that each model confirms the occurrence of conditional β-convergence. This may be related to the fact that OECD countries exhibit relatively high economic openness and are relatively homogeneous. They mostly

have similar structural characteristics, such as income distribution in society, education levels, or demographic structure, particularly considering that a significant part of OECD countries also belong to the European Union.

Conclusions

The results of the growth regression estimation indicate that the various aspects of economic openness have a positive impact on the economic growth of OECD countries. Particularly noteworthy is the fact that variables related to social and political aspects of openness, such as migration and membership in integration groups, appear to have a significantly stronger influence than purely macroeconomic variables like imports, exports or foreign direct investments. Identifying the reasons behind this phenomenon could form an interesting basis for further research. However, trade and financial openness still remain significant, aligning with the findings of Rodrik et al. [2004], Navaratnam [2014] and Iyke [2017]. Frankel and Romer [1999] also pointed to the significant impact of international trade on economic growth and societal incomes. According to them, the main channels through which trade influences economic growth are the accumulation of physical and human capital and increased productivity. The positive impact of globalization on growth does not necessarily translate into a positive impact on societal well-being, as it may lead to increased income inequality, as demonstrated by Guschanski and Onaran [2016], Gülsün et al. [2016] and Özdemir [2019].

It is essential to emphasize that the impact of economic openness on growth can vary depending on the stage of economic development, institutional quality and economic policies of a country. Developed countries tend to derive greater benefits from economic openness due to better infrastructure and institutions, while developing countries may face challenges in fully leveraging the benefits without appropriate investments in socio-economic development. Addressing this diversity will be a subsequent stage of research on the relationship between economic openness and growth.

Furthermore, in the context of future research and policy discussions, it will be crucial to conduct further analyses of the dependencies between openness and economic growth, particularly in light of new challenges such as digitalization, climate change, and geopolitical shifts. Understanding these dependencies will enable the formulation of more effective development strategies that harness the benefits of global integration while minimizing its potential negative consequences. It will also be intriguing to examine the impact of economic openness on the economies of developing countries, such as those in Sub-Saharan Africa or certain countries in Asia and South America, where the effects may not be as straightforward.

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Polish SMEs on the road to Industry 4.0 – opportunities, challenges and barriers to innovation

This article explores the implementation of Industry 4.0 within Polish small and medium-sized enterprises (SMEs), offering insights into the region's digital transformation patterns. By examining technology adoption patterns, we map the progression of Industry 4.0 among these firms. The study applied a mixed-methods approach, analysing Eurostat and IFR databases for quantitative data on digital technology and robotics use, and comparing Poland's digital maturity with other EU states. For qualitative insights, we conducted interviews and site visits with 12 industrial firms and 17 digital solution providers. Our analysis highlights two critical factors influencing Industry 4.0 adoption: the firm's global value chain position and the need to revise development models due to labour shortages. Polish firms predominantly automated distinct segments of their production, integrating robots with existing lines and tasks, and utilized systems that bridged older technologies with newer ones. Yet, they were hesitant to fully embrace comprehensive systems like intelligent factories, unlike Western firms that favoured automation in large-scale production due to labour scarcity and cost. A significant barrier identified for Polish SMEs was a deficient datafication level, evident from the inadequate practices in data collection, analysis and application. These firms often preferred reliance on experience over data-driven decision-making. Additionally, limited capital access hindered their ability to pursue advanced technological investments, impeding their innovation capacity. Polish industrial SMEs prefer a modular digitalization approach over comprehensive overhauls, reflecting a pragmatic strategy to tackle immediate issues and lay groundwork for future technological advancements.

Keywords: Industry 4.0, digital transformation, small and medium enterprises, manufacturing

JEL classification: L6

Introduction

After over a decade of the Industry 4.0 concept being present in public and academic debate, the argument regarding the benefits of implementing technologies related to Industry 4.0 is both voluminous and undifferentiated in its message as to its overwhelming benefits. Industry 4.0 can be most concisely understood as the integration of information and communication technology into the industrial development. Recently, it has been assumed that Industry 4.0 essentially refers to digital transformation in the manufacturing sector. Horváth and Szabó [2019, p. 120] note that one can view digital transformation as the broader idea, with Industry 4.0 nested within it. In this article, we will also adopt this perspective, using the terms Industry 4.0 and digital transformation within the manufacturing sector interchangeably. Industry 4.0 involves the implementation of technologies such as: additive or advanced manufacturing, augmented and virtual reality, automation and industrial robots, block-chain, big data analytics, cloud data and computing, cybersecurity, cyber-physical production systems, internet of services, internet of people, industrial internet of things, and simulation and modelling (digital twin) [Ghobakhloo, Iranmanesh, 2021].

Recent perspectives emphasize that digital transformation relies on the implementation of datafication technologies [Śledziewska, Włoch, 2021]. Specifically, these technologies allow for extracting value from rich data sources about a company's internal processes and external environment using artificial intelligence algorithms. Implementing these technologies require significant technical, infrastructural, and human resources, the use of new knowledge, competency reconstruction, and the introduction of broad organizational and process changes.

Importantly, introduction of these technologies is to bring increased competitiveness, efficiency, greater flexibility, organizational improvement, better decision-making [Horváth, Szabó, 2019], and adaptability to companies that embark on the path of digital transformation. For companies acting as suppliers, integration into the value chain and competitiveness resulting from the adoption of widely accepted global standards are also crucial [Da Silva et al., 2022]. Implementing digital technologies has become a business imperative, a sign of a company's progressive attitude and a foundation for creating new business models. There is also a consensus that the pace and level of Industry 4.0 technology implementations influence how companies deliver, create and appropriate value [Nwaiwu et al., 2020] due to principles such as decentralization, modularity and product personalization [Ghobakhloo, Iranmanesh, 2021]. Abdulnour et al. [2022] observe that "Industry 4.0 (I4.0) is increasingly presented as the new paradigm for improving productivity, ensuring economic growth, and guaranteeing the sustainability of manufacturing companies".

In this article we assume that it is important to recognize that the principles and application frameworks of Industry 4.0 are predominantly designed for the complexities of large-scale manufacturing, which can sometimes eclipse the distinct hurdles faced by smaller firms. Digital transformation, while challenging for all, particularly tests small and medium-sized enterprises (SMEs) in their journey towards Industry 4.0 adoption [Abdulnour et al., 2022]. At the same time, researchers consistently emphasize that the pace and level of technology implementation within the scope of Industry 4.0 in SMEs is especially relevant because they make up the vast majority of firms in most markets.

What specific challenges do SMEs face in implementation of Industry 4.0? For SMEs, a main concern is their tendency to avoid risks and experimentation with new technology, mainly because of limited financial, technical and skill resources [Horváth, Szabó, 2019; Estensoro et al., 2022]. Limited financial resources mean these businesses often plan for the short-term costs and benefits and are hesitant to invest in things that might not pay off until much later; consequently, SMEs are rarely the first to adopt new technologies. Instead, they prefer specific technological updates at the production level. Specifically, smaller companies are not inclined to engage in broad organizational and procedural changes leading to the creation of a smart factory, mainly due to financial reasons. However, they are more willing to engage in specific technological implementations at the production level [Masood, Sonntag, 2020].

A significant obstacle for SMEs is their constrained experience in adopting new technologies [Masood, Sonntag, 2020]. Yu and Schweisfurth [2020] demonstrated that knowledge about technology and its expected benefits significantly influences the implementation of Industry 4.0 technologies by SMEs. Interestingly, their analysis showed that, contrary to assumptions, neither the cost of technology nor the size of the company (number of employees or revenue) had a significant impact on the pace of implementation. However, production specifics mattered: the more diverse the products a company offered and the higher the level of automation it had already achieved, the more motivated it was to implement Industry 4.0 technologies. Additionally, the authors observed that "smaller SMEs focus more on operational aspects of technology implementation, while larger SMEs develop strategic planning, business formalisation and control systems to support the implementation process" [Yu, Schweisfurth, 2020, p. 78]. SMEs often lack adequate knowledge and digital skills, from the top management down to regular employees. This gap in knowledge means that leaders might not see the benefits of digital changes and might not even know where to start. As Mittal et al. observed [2018], SMEs are "often overwhelmed with decisions (i.e., strategic and operational) about what, why, when, where, who and how they can incorporate the different SM or Industry 4.0 technologies". Managers might struggle with how

to put these changes into practice, and employees might question or even resist them [Orzes et al., 2018].

Mittal et al. [2018] and Horváth and Szabó [2019] delved more systematically into the differences between MNEs and SMEs in the process of technology implementation. The former examined various studies to contrast SMEs and MNEs across seventeen criteria, underscoring their distinct opportunities within the framework of Industry 4.0. The dimensions were financial resources, use of advanced manufacturing technologies, software umbrella, research and development, nature of product specialization, consideration of standards, organization culture or leadership flexibility, company strategy, decision-making, organizational structure, human resources engagement, exposure to human resource development, knowledge and experience of the industry, alliances with universities or research institutes, important activities, dependence on collaborative networks, and customers and suppliers. The authors determined that SMEs have weaker network connections and fewer suppliers, making them more dependent on them.

Horváth and Szabó also noted that due to limited resources in the areas of skills, infrastructure, technology and budget, SMEs tend to be reactive and are reluctant to implement innovations with an ill-defined benefit catalogue. As a result, they show lower driving forces and higher barriers than MNEs in most dimensions of company operations. "MNEs and SMEs do not have equal opportunities in the context of Industry 4.0", conclude Horváth and Szabó [2019, p. 129]. At the same time, they noted that in some respects, SMEs might be in a better position when it comes to implementing Industry 4.0. This advantage arises mainly due to lower profitability expectations, less complex organizational factors enabling change, fewer technological dependencies, and lower barriers to cooperation. They often also see opportunities for themselves in market niches related to digital technologies.

A comprehensive discussion on barriers that that SMEs encounter in the implementation of Industry 4.0 technologies was presented by Orzes et al. [2018]. They analysed the experiences of 37 SMEs from Italy, Thailand and USA, concluding that current Industry 4.0 technologies are not tailored to the specific needs of SMEs. Moreover, most established models, theoretical frameworks and recommendations that should support implementation are developed for, or by, large enterprises. Judging the pace and scope of technological implementations in SMEs through the lens of these big companies misses the mark. "There is no clear method to evaluate I4.0 technologies against the needs and requirements of specific SME organizations" [Orzes et al., 2018, p. 2]. This viewpoint is shared by Mittal et al. [2018, p. 210], who write as follows: "Most maturity models, roadmaps, frameworks, etc. currently available for SM or Industry 4.0 consider mainly the needs and resources of MNEs, e.g., regarding the IT/OT infrastructure. Therefore, the reality of many

SMEs today is that their 'level 1' or starting point is often a disconnect from the average level of smartness (i.e., digitalization and (smart) automation capabilities".

The mismatch of the sociotechnical imaginary associated with the notion of Industry 4.0 to the real use cases and experiences of small companies often makes them feel unmotivated to translate these abstract concepts into practical actions which may be associated with uncertain return on costly investment. As noted by Amaral and Pecas [2021, p. 3], "this type of companies seems to fail to grasp or trust these notions without real, tangible examples. This results in an ineptitude of SMEs to embrace I4.0 as the larger firms, since the latter can afford to take more 'risks' related, for example, to R&D investment. Naturally, SMEs are positioned behind in the ladder of full implementation of I4.0, as already mentioned".

The aim of this article is to fill the research gap concerning the optimal paths for implementing Industry 4.0 in small and medium-sized enterprises, taking into account their specific challenges and barriers. In the first step, we analyse available data to characterize the level of implementation of individual digital technologies among Polish SMEs, treating it as an approximate indicator of the advancement of Industry 4.0 in Poland. Then, drawing on data from our qualitative study, we identify two specific factors shaping the implementation process of Industry 4.0 in this group of companies: (a) position in global value chains, (b) the need to change the existing development model due to a labour shortage. In the next part of the article, we show that Polish industrial SMEs adopt a modular or selective digitalization as a coping strategy. The value of our study lies in identifying an optimal approach for implementation of Industry 4.0 in SMEs, namely a modular digital transformation. It also highlights the importance of local conditions for implementing Industry 4.0, which originate from varieties of capitalism, and in particular – the semi-peripheral location of the country's economy, as well as macrostructural economic factors such as changes in the labour market.

1. Methodology

The analysis presented in the article uses data from Eurostat, which we supplemented with data from the International Federation of Robotics (IFR) for the analysis of robot implementations. Data from the Digital Economy and Society database at Eurostat are collected through surveys conducted among households and businesses. These statistics provide insights into the access, adoption, and utilization of digital technologies across all EU member states, covering aspects such as mobile internet access, social media usage, e-commerce, internet security, cloud services, digital skills, and information and communication technologies (ICT) specialist employment. Statistics related to ICT in this section are available

separately for households or individuals and businesses or enterprises. Data from IFR pertains to global statistics on industrial and service robot implementations.

The collected data allowed us to conduct an analysis of the level of digital technology adoption in Polish industrial enterprises. On the one hand, we present Poland in comparison to other EU member states, enabling us to determine in which areas Polish enterprises are advanced and in which areas they do not fully utilize their digital potential. On the other hand, we examined industrial production compared to other sectors. In the analysis, we also considered the aspect of digital competence among human capital, i.e., employees. Digital transformation is not only about digital technologies but primarily – as we emphasize in our publications – about a change in organizational culture and business models. The success of implementation depends on employees with the right competencies, who should receive training and support at every stage of their careers.

Interpreting the findings from the quantitative study, which repeatedly highlight the theme of technological lag in Polish industrial enterprises, is made possible by insights from the qualitative study. Empirical data was collected from October 2022 to March 2023. We conducted 20 qualitative interviews in 12 industrial companies, and in 11 of these companies, we also conducted on-site visits to their production facilities. The selection of companies for interviews was based on availability, with consideration for diversifying the companies in terms of size, production specificity, and geographic location. We also considered the companies' positions in national rankings of innovation or Industry 4.0 development.

In the second phase of the study, we focused on understanding the perspective of companies providing digital solutions to the domestic and international markets. We analysed the websites of selected companies to familiarize ourselves with their specificities, and then we conducted qualitative interviews with representatives from 17 of these companies, each lasting no less than an hour. In these interviews, we asked for an introduction to the characteristics of their solutions, as well as information about their cooperation with other companies and insights regarding the development of the Polish industry. We also utilized research notes from the on-site visits.

The transcripts of the conducted interviews were anonymized, and codes were assigned to individual interviews randomly (manufacturing companies P1–12; digital solution providers D1–17). We encoded and analysed the data using computer software for qualitative data analysis, extracting thematic threads related to the determinants, motivations, barriers, challenges, and specificities of Industry 4.0 implementations in Polish industrial companies. The results of the analysis were used to supplement and deepen the conclusions drawn from the quantitative analysis.

2. Results

Embarking on the exploration of the digital transformation journey within the Polish small and medium-sized enterprise sector reveals a nuanced landscape of adaptation and innovation. This section presents the empirical evidence garnered from our comprehensive study, aimed at unravelling the practical realities and strategic approaches undertaken by Polish SMEs in navigating the complex terrain of Industry 4.0. Through examination of data, interviews, and case studies, we shed light on the variegated experiences of these enterprises, uncovering the pivotal factors that influence their digital adoption pathways, the challenges they face, and the innovative strategies they employ to harness the potential of digital technologies.

3. Digitalization of industrial SMEs in Poland is low

The implementation of digital technologies that enable harnessing the potential of data to enhance production efficiency and the functioning of a company is a key element of digital transformation, also in the form of Industry 4.0. In this respect, Polish companies lag far behind the European Union leaders.

The level of digitalization in Polish enterprises can be assessed using the Digital Intensity Index (DII). This index serves as an approximate measure of digitalization adopted by Eurostat and is based on survey results conducted by statistical institutions in EU member states. Each company is classified into one of four digitalization groups: very low, low, high, and very high DII, based on the assessment of technological implementations in twelve areas. These areas include internet access, the implementation of information systems, the utilization of IoT (Internet of Things) technologies, the presence on social media, the use of artificial intelligence and cloud services, among others. A high DII score indicates that many companies in a given country have adopted advanced digital solutions and are using modern digital technologies. Enterprises with low or very low DII are less digitally advanced and may have limited capacity to harness the potential of digitalization. The Digital Intensity Index is a useful tool for assessing the digitalization level of enterprises. Its analysis suggests that there is room for improvement in Poland, especially in comparison to more digitally advanced European countries: the Polish industry lags behind the European Union average. A relatively small percentage of industrial enterprises in Poland achieve a high or very high DII. Scandinavian enterprises are the most digitally intensive, with Austria and Denmark particularly standing out in Central Europe.

Only large Polish enterprises are not lagging behind the EU average in terms of a high DII. Over 40% of large companies in Poland have a high digital intensity index, similar to Finland and Sweden. However, small and medium-sized enterprises are significantly less digitized compared to EU businesses as a whole. In Poland, only 11% of small businesses (compared to over 40% in Sweden and Finland) and 25% of medium-sized businesses (compared to around 70% in Sweden and Finland) have a high or very high digital intensity index. This may indicate that while Polish SMEs are (slowly) adopting digital solutions, the implementation does not take on a comprehensive character.

Against the backdrop of these low digitalization indicators among Polish SMEs, industrial enterprises face additional unfavourable circumstances. In general, industrial enterprises in Poland have a significantly lower level of digitalization compared to other sectors. Only 2% of industrial enterprises are classified as having a very high DII, and 10% fall into the high DII category. This means that only 12% of Polish industrial enterprises have implemented at least 7 out of 12 digital solutions included in the DII index. Only one in 62 industrial enterprises in Poland has a very high DII, while every tenth has a high DII. In comparison, in Sweden, this applies to approximately every tenth and nearly every second industrial enterprise, respectively.

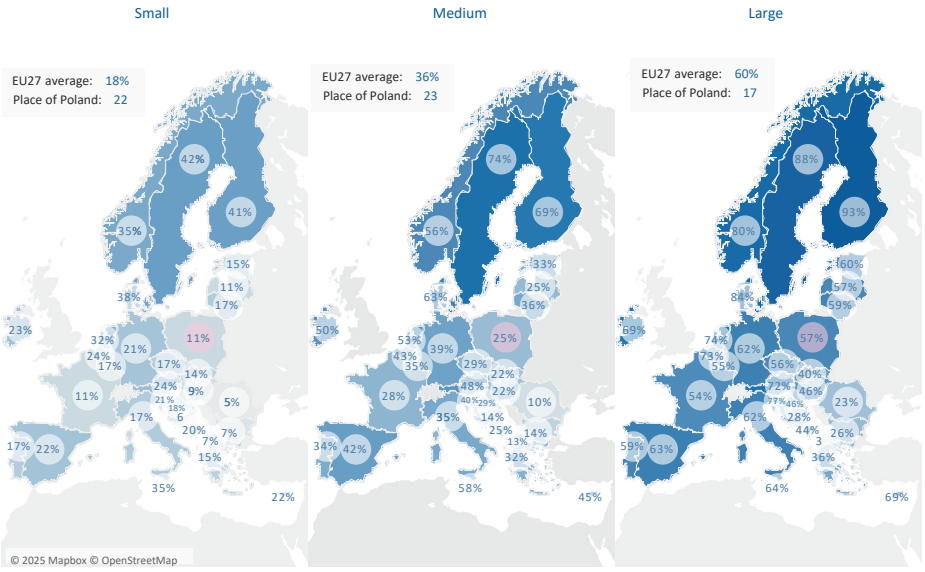

Figure 1. The digital intensity index of Polish companies

Source: [Eurostat].

The low level of digitization in Polish industrial enterprises is also confirmed by data on the adoption of specific digital technologies, often considered essential in the context of digital transformation. A good example is digital systems used for managing a company's resources or customer contacts. Only one in three industrial enterprises in Poland uses ERP systems. In the EU27 countries, on average, half of industrial enterprises have implemented this type of IT system. Poland has made progress compared to 2019, but still ranks 19th among the EU27 countries. The use of CRM systems by Polish industrial enterprises is not significantly different from the EU average. Positive factors contributing to this situation can be attributed to the inclusion of Polish companies in international supply chains and the need to adapt to foreign customer requirements, such as e-invoicing.

Table 1. The implementation of key Industry 4.0 technologies in manufacturing enterprises

Technology	Poland	EU27
ERP systems	34%	49%
CRM systems	32%	34%
industrial robots	14%	17%
Internet of Things	16%	30%
RFID	10%	17%
cloud computing services	28%	40%
big data	7%	10%
AI	2.3%	7.3%
3D printing	8%	12%
ICT security measures	94%	93%

Notes: Data for RFID for 2017, industrial robots, big data, 3D printing – 2020, ERP systems, CRM systems, IoT, cloud services, AI – 2021, ICT – 2022.

Source: [Eurostat].

However, when it comes to the adoption of technologies considered to be flagship technologies of Industry 4.0, Polish industrial companies achieve relatively low results compared to other European countries. Only one in ten Polish industrial enterprises uses robots, ranking Polish companies 21st in the EU27. In the EU, there are as many as 1,975,000 robots, accounting for 18% of the total number of robots worldwide. The largest number of robots is found in China, where they make up 32% of the total. In comparison, Poland's share in global robot utilization is only 0.5%. The installation of industrial robots is consistently increasing in both Poland and the EU, with the exceptions of 2009 and 2020. Compared to countries such as China, Japan, South Korea or the US, Poland lags significantly in terms of robotization. In terms of robot utilization by enterprises, Poland ranks 19th in the world, with 17,000 robots operating in the country in 2020.

Only one in four Polish industrial enterprises utilizes cloud computing, ranking 17th among the EU27 countries. In Polish industrial enterprises, these technologies are most commonly used for office programming, while in the EU27 countries, the most common use is for file storage. Polish industrial enterprises are slow to adopt the Internet of Things technologies. One in five Polish industrial enterprises

implements IoT technologies, which is a weak result compared to the rest of the EU27 countries, where one in three industrial enterprises uses IoT. In Poland, this only applies to 16% of such enterprises. In the EU27 countries, IoT technologies are most commonly used for ensuring the security of objects, while in the Polish industry, they are used for monitoring or automating production.

The most concerning aspect is the low utilization of the potential of big data. In terms of utilizing big data, Polish industrial enterprises rank 18th among the EU27 countries. Data for analytics are mainly generated from the geolocation of mobile devices, smart devices, sensors, and social media in Polish industrial enterprises. Only 7% of Polish industrial enterprises have declared the use of data analytics, while in the information and communication sector, this percentage exceeds 20%. This indicates that industrially producing enterprises in Poland have much to do in terms of using data analytics to improve efficiency, competitiveness, and innovation. The AI revolution is bypassing Polish industrial enterprises.

Only 2% of Polish industrial enterprises implemented artificial intelligence systems in 2021. Overall, EU enterprises make relatively little use of this technology (8%). Denmark leads in this area, with almost one in three industrial enterprises using artificial intelligence. Larger companies are more likely to use AI – in Poland, one in five does, ranking 19th in the EU. Industrial enterprises implement AI in production processes, for ICT security, or in business administration organization. If a company uses AI, it is most commonly applied in production processes. It seems that the main barriers to the adoption of AI technology are high costs and a lack of specialized knowledge.

The above data pertains to industrial enterprises as a whole. Regarding the situation of small and medium-sized industrial enterprises, one can infer by comparing them to the previously discussed Digital Intensity Index, reasonably assuming that they achieve significantly lower adoption rates of the mentioned technologies than large enterprises, which generally do not deviate from the EU average. Polish industrial companies are less digitized than their European counterparts, and concurrently, Polish small and medium-sized enterprises are considerably less digitized than large ones. This prompts us to pay special attention to industrial SMEs in Poland.

These statistical descriptions were validated during the qualitative interviews: as a rule, the representatives of companies providing technological solutions emphasized very low levels of digitalization of the Polish companies, primarily manifested in a low level and slow pace of digital system implementations. One of the frequently cited reasons for this state of affairs was the limited business maturity of Polish companies, most of which began their history after 1989.

"Mature companies are in short supply in Poland because even thirty-year-old firms, in my opinion, are not as mature as those that are eighty or a hundred years old in the West. Poland has a relatively young economy. In general, we are

catching up. We have a significant technological debt in the Polish industry, and we need to make up for it" (D3).

As a result, the situation of Polish companies was characterized as a pursuit of the peloton in the context of significant technological lag in the implementation of more basic ICT (information technology) technologies. From the experiences of digital technology providers, it is evident that not many Polish companies demonstrate sufficient readiness to implement advanced solutions. As one of the interviewees noted, "in Poland, we want to build Industry 4.0 before we have even built Industry 1.0, 2.0, or 3.0". Often, industrial firms in Poland decide to adopt technologies based on trends without considering their actual applicability in their production cycles.

"Many people approach Industry 4.0 with enthusiasm, trying to introduce these technologies into their companies, sometimes even forcefully. Later, disappointment sets in when these solutions do not perform as expected. However, Industry 4.0 is not a magic wand that brings success on its own. These technologies are merely additional tools that require the right foundation and infrastructure to function effectively" (D5).

Many SMEs lack a strategic approach to Industry 4.0, hindering their progress and adaptation. While financial resources and robust internet infrastructure are undeniably vital, it is essential for companies to recognize the business justification for adopting technology, ensuring it aligns with their unique needs. Still, many companies fail to see the need for changes in their operational model, driven by a short-sighted belief that the current model must be good since it ensured the company's survival over the past three decades. Paradoxically, if such a company decides to adopt technology, it often sets unrealistically high expectations for quick and substantial returns on investment. However, because they are unwilling to invest in solutions that enable the full utilization of this technology (such as adapting the system to changing needs, adjusting other processes in the company to fit new systems), it often results not only in disappointment but even in the abandonment of already implemented technologies.

4. Industrial SMEs in Poland take mid-upstream positions in global value chains

Poland ranks a high fourteenth in the group of countries with the highest influx of Foreign Direct Investment (FDI). Poland has slightly weaker GVC connections compared to other Central and Eastern European countries. Foreign value-added accounts for no more than one-third of Poland's exports [Chilimoniuk-Przeździecka, 2018]. It is worth noticing that this share grew steadily and considerably in the

last 30 years and can be treated as a manifestation of transformation of the Polish economy towards integration with the European and global trade. The primary sources of these investments are other European Union countries, notably Germany and France. Between 2004 and 2020, the volume of FDI increased six-fold (from 8.2 billion to 24.8 billion USD) [UNCTAD, 2023]. The inflow of foreign direct investment into Poland has consistently been seen as a means of technology transfer, a factor that contributes to the modernization of the Polish economy and supports economic growth through various mechanisms. Currently, companies with foreign capital are deeply integrated into the specifics of the Polish industry. Yet only a small portion of these investments find their way to Polish small and medium-sized enterprises, with the majority going to large automotive or electronics plants. This effect is amplified by the fact that foreign capital was primarily invested in labour-intensive segments of production based on relatively lower labour costs.

"A decade ago, in countries like Germany and France, where the population was aging, and young people were reluctant to work in the industry, there emerged an idea to seek what yields the highest margins. The idea arose: let us focus on the end of the process and create the entire process, design the product, but let's avoid all the tedious work in the middle that often requires human labour. Let us outsource that to the East" (D15).

The Polish SMEs integrated into global value chains mostly function as suppliers who provide intermediate resources, which are then utilized in the production of goods and services in the next step of this network. Polish industrial companies typically occupy middle upstream positions within the value chain. Companies positioned at the beginning of the value chain (suppliers of raw materials, materials, or even components) tend to achieve lower profit margins compared to companies located at the end of the value chain (final sellers). This occurs because companies at the beginning of the value chain must compete with numerous other firms offering similar products and services. To succeed, they need to offer competitive prices and high-quality products and services. Moreover, they are more exposed to the risk of fluctuations in raw material and material prices, while being less susceptible to short-term changes in demand for end products.

Both the design and sale of the final product are often located outside of Poland. It is a rare occurrence for the entire production cycle to be executed by Polish companies based on Polish technological innovation.

"The primary constraint is that Poland produces very few things from A to Z and at a high technological level. While many components are manufactured for various industries, very few products are made entirely from start to finish, and even fewer are designed in Poland. This is a significant problem because the highest technologies often require decisions to be made outside of Poland, and even when they are made, the machinery arrives in Poland without the involvement

of Polish engineers or technical expertise. From my perspective, it is also rare in Poland to encounter someone actively engaged in technology development" (D5).

The position of a company in the value-added chain can have a significant impact on its digital maturity. Companies located at the beginning of the value chain usually have lower profit margins, which can result in a reduced inclination to invest in digital innovations. Polish SMEs also tend to adapt to the particular needs of business customers introducing selected functions of digital systems, e.g., electronic invoicing, without implementing more advanced procedural or organizational changes.

Importantly, the position of Polish industrial companies in international value chains largely determines the nature of their production, which is based on small batches of products manufactured at short intervals. The situation has its advantages. The focus on short series allows Polish small and medium-sized enterprises to respond more quickly to customer needs and precisely tailor their production (e.g., producing specific spare parts based on customer-provided designs. This flexibility is the foundation of the competitive advantage for Polish SMEs. Because Polish SMEs are geared towards frequent machine changeovers, they can respond faster to declining demand, reducing potential losses. Additionally, diversified production aimed at multiple customers also helps mitigate risk. However, short-run production places significant demands on management, which must be dynamic and responsive to market signals. This explains why Polish SMEs are prompt in implementing management systems, as confirmed both by Eurostat data and our qualitative interviews. Native technology providers play a crucial role in this implementation process, tailoring their offerings to the needs of smaller businesses. Manufacturing execution systems (MES) come to the aid, supporting the management of rapidly changing production batches and aiding in planning variable material or semi-finished goods demand.

At the same time, short-run production, largely stemming from the position of Polish companies in the GVC, poses challenges in terms of implementing digital transformation. Production processes are subject to continuous changes, and the cost and time of changing equipment between production batches reduce efficiency. The process also requires more labour, and work often takes place in difficult or even hazardous conditions. As noticed by a representative of one of the manufacturing companies from the metal industry:

"We specialize in 'high mix, low volume' production, which means a wide variety of products and short, small orders. The average order size is below ten units. It is essential to remember that our current technologies are very labour-intensive and not so easy to automate, nor are they straightforward to adopt the latest solutions related to automation or even process autonomy" (P10).

Furthermore, short production series mean that not every company experiences an increase in efficiency when implementing digital transformation. This especially

applies to companies that produce short runs of highly personalized products. Many companies find it more cost-effective to utilize the machine park of external contractors. At the same time, for medium-sized companies with more complex production processes, the introduction of ERP and MES systems becomes increasingly important.

"Analysing our observations from the past few years, we have come to the conclusion that it is better to invest in systems. Robotics is the last consideration, especially if we do not have large production runs. In the case of custom production, such as machines tailored to a specific project, the cost of reconfiguration can be comparable to the time needed to complete all other machining operations. It is better to utilize the services of other companies that already have the appropriate machinery" (P9).

5. Workforce shortage is the main motivation for Industry 4.0 implementation

The main challenge currently faced by Polish companies is the burnout of a developmental model based on competitiveness derived from relatively low wages. In Poland, there is relatively high employment in production, although it has been declining since 2010.

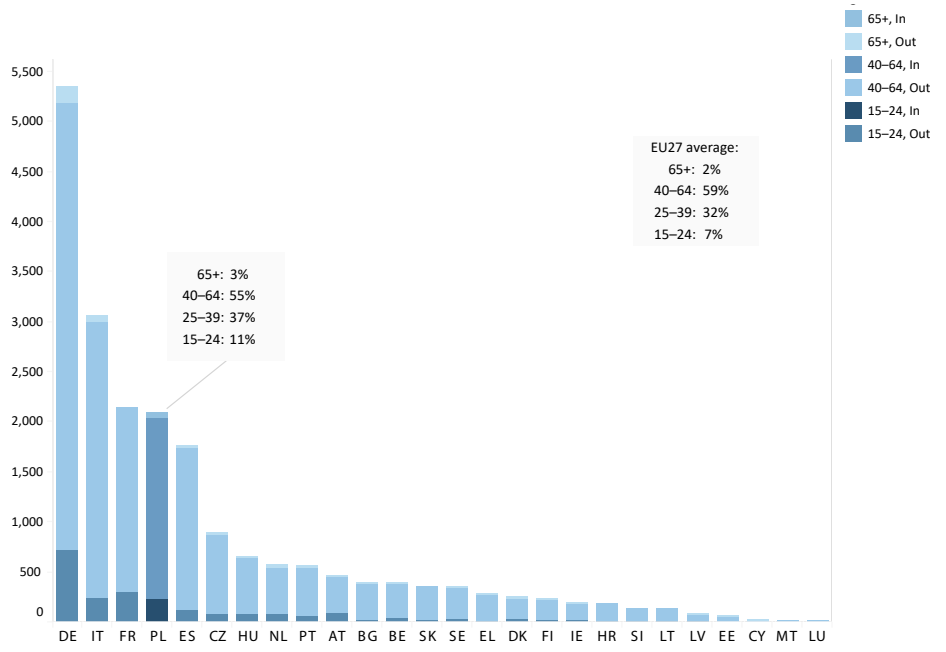

Figure 2. Number of persons employed in manufacturing (thousands of persons)
Source: [Eurostat].

Employment primarily relies on individuals aged 40–64 (55%), which is a relatively lower proportion compared to the EU average. Wages have been increasing faster than employment since 2014. This growth rate is higher than in other countries in the region, indicating that Poland is losing its advantage (labour-intensive production based on relatively low production costs) on which it has built its competitiveness so far.

As one of the technology providers noted, Polish industrial companies need to find another source of competitive advantage than low worker wages. A way out of this situation could be the implementation of technologies ensuring higher productivity and production stability, from ERP systems to intelligent robotic systems.

"It is not the same as it was 15 or 20 years ago when a production efficiency that was twice as low in Poland made it worthwhile because the wages were still four times lower" (D15).

A related challenge is the decreasing motivation of young workers to take on difficult, dirty, often hazardous, and frequently repetitive jobs in manufacturing. "Today, one has to do everything to become an attractive employer", noted the owner of one of the surveyed industrial companies. Rising social aspirations discourage young people entering the job market from taking on professions that require excessive physical effort, in challenging and health-damaging conditions (such as noise and air pollution). Young workers are also particularly averse to shift work.

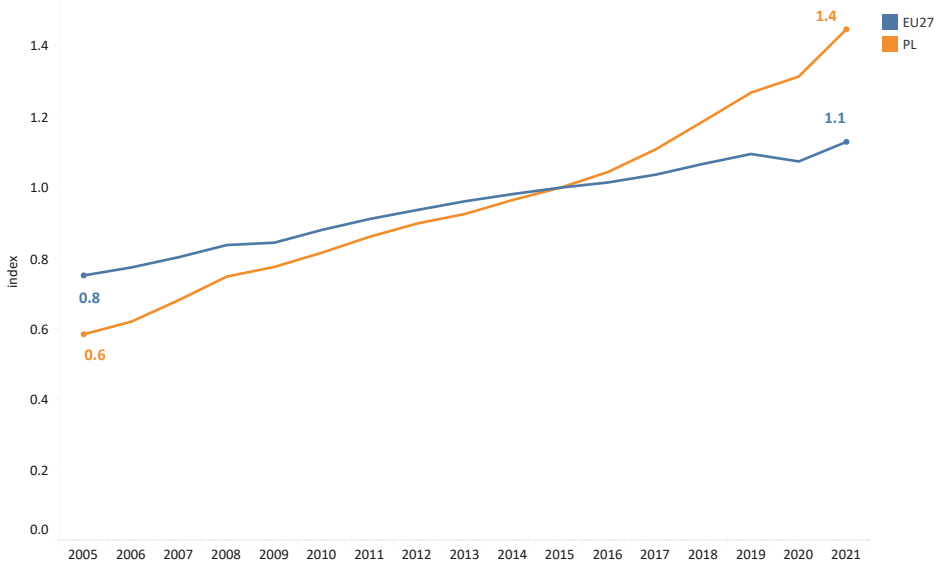

Figure 3. Index of wages and salaries per index of employment in manufacturing (2015 = 100)
Source: [Eurostat].

"Especially young people do not want to engage in such monotonous tasks as transferring jars on the assembly line. They prefer someone else to do this kind of work. These jobs are considered boring, uninteresting, exhausting, and harmful to the spine. Moreover, the younger generation is not willing to work in three shifts" (D3).

High employee turnover in industrial also partially results from the reluctance to perform work that is considered unsatisfying in terms of professional and personal development. "If you want to retain an automation specialist, buy them a robot", succinctly explained a representative of one of the companies integrating robotic solutions.

"Jobs in maintenance departments are becoming increasingly unattractive. Our clients face challenges in ensuring the right personnel, so they take various actions to counteract this. One trend is to combine maintenance work with projects or innovation implementation. Individuals working in maintenance are engaged both as executors and supervisors of external implementing companies. Another trend we observe is an attempt to make the work more attractive by introducing new tools and means, such as maintenance management systems and the use of virtual reality. The goal is for those responsible for maintaining machinery or technological processes to interact with modern and appealing technologies" (D2).

Some industrial companies openly acknowledge that their motivation for replacing human labour with machines in certain areas of their operations is driven by the desire to ensure greater operational stability. From this perspective, digitalization serve to enhance the safety and repeatability of the production process and to become less dependent on the variable availability of workers. "Introducing robots can be not only cheaper but also more predictable, especially in the context of pandemics and other crises" (D8).

Noteworthy, in the analysed companies digital transformation typically do not lead to employee layoffs; instead, they trigger a restructuring of employment within a given manufacturing facility. Individuals performing repetitive and routine tasks are reassigned to other roles that may require some degree of skill adjustment or competency enhancement. Workers are transferred to positions that are less "dirty, difficult, and dangerous", where they are tasked with overseeing machines and systems; "the machine follows orders, and the human becomes a machine park supervisor" (D13).

"You can count on one hand the situations where the introduction of automation or robotization led to a reduction in employment in a given manufacturing facility. In most cases, these employees are reassigned to other tasks, to different areas that have not yet been automated or for some reasons will not be automated at this time" (D2).

This restructuring of employment allows for the avoidance of job loss due to automation and enables the continuous improvement of employees' skills, adapting

them to changing market demands. The implementation of new technologies becomes a benefit for both companies and workers, as it provides new opportunities for professional development and skill enhancement. Robots and automated systems take over tasks that are physically demanding, mentally exhausting, or harmful to health. One of our respondents aptly noted that especially robotization makes work in manufacturing facilities more "humane". According to a manager from one of the surveyed companies, employees quickly understand that the priority should be "working smarter, not harder" (P2), and digitization greatly facilitates this approach.

For most of the examined companies, digital transformation of production processes, as well as digitization of business processes, are solutions that enable better management of human resources in the era of demographic crisis, which results in a reduced pool of workers in the labour market. However, the key factor for the success of digital transformation is the employees who have the skills to work in digitizing enterprises. Polish companies are facing a labour shortage not only in absolute terms: they especially lack employees who can actively participate in the company's digital transformation due to their adequate digital and technical skills.

The data confirms that Polish businesses may encounter difficulties in adapting to new technologies and harnessing their potential due to a lack of employees with the necessary skills. Polish employees have lower digital competencies compared to workers from other European Union countries. This is evident both from the Human Capital Index and from a detailed analysis of ICT and non-ICT worker skills. 69% of ICT workers possess advanced digital skills, whereas only 31% of non-ICT workers and 13% of physical workers do so. Poland ranks 24th in terms of digitalization of human capital according to the DESI index. Interestingly, only one in five industrial companies in Poland provide training to enhance the digital skills of their employees. Furthermore, not many industrial companies invest in training ICT specialists. Poland holds a high 5th position in terms of employing ICT professionals in industrial firms, with one in three companies doing so. However, the challenge lies in the increasing salary expectations of candidates, and to a lesser extent, their availability. In other EU countries, the most common issue is the limited number of applications for ICT specialist positions.

The implementation of new digital technologies requires a significant organizational effort: streamlining or changing production processes, training the workforce, and sometimes even altering business strategies. However, the most crucial factor in digital transformation is the quality of human capital: the skills of employees, their knowledge, and the willingness of management to embrace change.

"Our technology is innovative and demands substantial commitment from the customer. To implement it, the necessary investment resources, courage, and implementation skills are required" (D2).

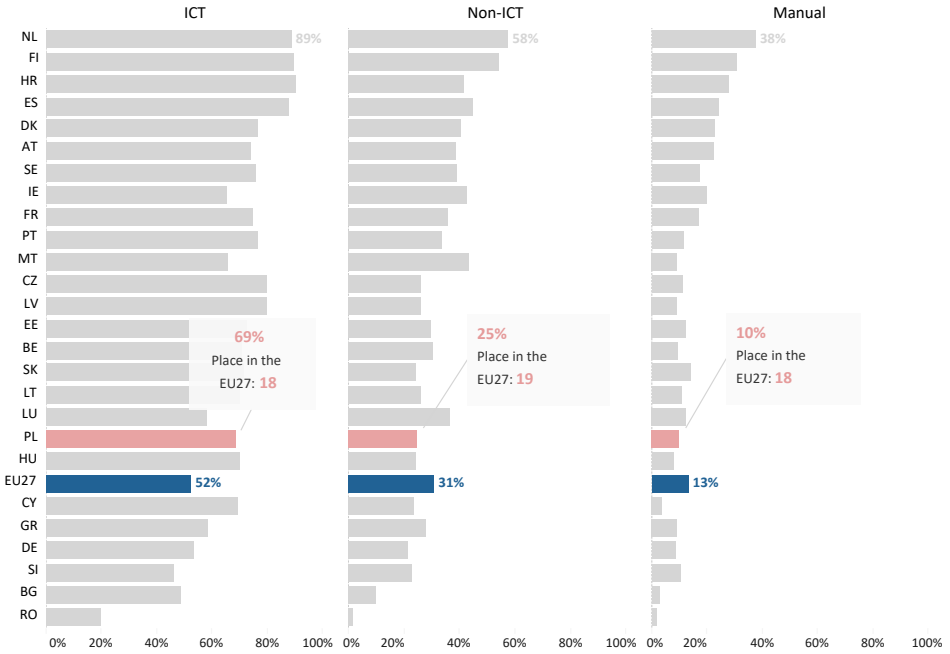

Figure 4. Comparison of employees with above-basic digital skills in EU27 countries

Notes: Data for 2021.
Source: [Eurostat].

During qualitative interviews, representatives of industrial firms and technology providers emphasized that the limited availability of appropriately skilled workers is also influenced by the long-standing crisis in vocational and engineering education that has affected Polish education during the systemic transformation. One representative of an industrial firm put it bluntly: "It seems that as a country, we have lost the ability to provide technical education".

There is also a specific deficiency in data literacy, especially regarding the importance of data utilization for company operations, observed at various organizational levels. Eurostat data shows a low level of big data technology implementations in Polish companies. During the interviews representatives of technology companies particularly highlighted the insufficient knowledge about rendering data utilization into value generation among management representatives. This translates into a lack of actions in developing digital transformation strategies and building an organizational culture conducive to implementing new technologies. Resistance to change is often encountered, notably from IT departments, if they are distinct within a given company. Their employees usually focus on cybersecurity issues and often lack competencies in data-related work and an understanding of digital transformation mechanisms. Frontline workers

often resist changes because they do not understand their significance and fear their impact on job security. In the surveyed companies, engineers, mechanics, and automation specialists played the role of change drivers. They perceived changes as opportunities for professional advancement and viewed new solutions as instruments to improve their own and other employees' work quality.

6. Industrial SMEs in Poland undertake modular digital transformation

In the prior section, we approached Industry 4.0 objectively as an innovative production paradigm based on digital technologies, signifying a comprehensive technological revolution – the fourth industrial revolution. However, beyond the technology, Industry 4.0 carries a narrative shaping business expectations and attitudes. It is not just a tech suite; it is a vision of an automated, integrated, market-responsive future. This narrative influences how companies view their capabilities, make choices, and perceive barriers. In this context, it is important to emphasize that the concept of Industry 4.0 is not ideologically neutral [Pfeiffer, 2017]. Its narrative and implications are deeply intertwined with broader socio-economic and political discourses, potentially influencing not just technological choices, but also organizational structures and business strategies. It is closely linked to a specific political-economic development strategy adopted by the German government several years ago. This concept quickly spread in the business discourse in Europe, especially in the Nordic countries. At its core, it assumes that we are dealing with a linear process of technological and industrial development: to enter the phase of Industry 4.0, one must go through phases 1.0, 2.0, and 3.0. Often, this concept is used in a value-laden manner: a company that cannot reach the level characteristic of Industry 4.0 is seen as backward, unable to leverage development opportunities, and ultimately destined for elimination from the market [Fuchs, 2018]. It may be ventured that the way the concept of Industry 4.0 is described in the media, by consulting firms, and public institutions can indeed discourage efforts towards modernization. Especially for small and middle companies, the implementation of new digital technologies appears as a costly and time-consuming process that requires advanced digital skills from production workers and management [Orzes et al., 2018; Amaral, Peças, 2021; Abdulnour et al., 2022; Da Silva et al., 2022]. Companies often struggle to translate abstract terms like "digitization", "datafication", "platformization", "Industry 4.0" (or even "5.0") and the use of AI into everyday production practice. They also fail to grasp the necessity of radically rearranging processes and organizations,

which are perceived as an integral part of the concept of the "smart factory" and the associated successful digital transformation.

The interviews we conducted revealed that for Polish industrial companies, especially small and medium-sized ones, the label "Industry 4.0" was often seen as limiting. For some companies, Industry 4.0 is seen as an imperative – they have a sense that without the introduction of digital systems and robotics or automation, their company will lag behind. However, this is not necessarily tied to a strategic approach. As a result, implementations are often carried out in a non-systematic manner and do not align with the company's business strategy, leading to their abandonment when they do not deliver quick and substantial profits. A paradox of digital technology implementations is the often-present increase in product quality accompanied by a decrease in productivity, leading to customer disappointment expecting a rapid and measurable return on investment. Yet most of the manufacturing companies which took part in our research rejected this perspective, pointing out that technological development often takes on a branching (rhizomatic) or networked form: solutions that can be puristically considered characteristic of Industry 3.0 – such as robots – become the impetus for datafication of a specific segment of the production process and subsequently, the overall digitization of the entire production process.

In attempting to address the mandate of digital transformation, Polish industrial companies typically adopted a selective or modular approach to digital change. They put in impressive efforts to implement new digital technologies, but seldom can boast of implementing comprehensive solutions that fit the model scenario of a production facility functioning based on intelligent automation. Digitization processes are often fragmented and cautiously introduced in selected segments of the production process; however, even then, they represent a significant step towards digital transformation.

Polish companies usually have limited investment capital, which affects their willingness to experiment with new technologies and their readiness to incur costs associated with their implementation. As a representative of one of the surveyed companies accurately pointed out, "we cannot afford to change everything all at once" (P9). In most of the surveyed companies, there is a significant technological debt; few companies can afford to replace their entire machinery fleet. Instead, companies purchase newer machines and systems, which they then integrate with older machines and systems using bridging solutions. Technological debt may make it challenging to introduce datafication-based integration of production processes, but it does not make it impossible. The datafication of the production process often does not require large or highly complex datasets; typically, simple but well-calibrated data is needed.

Modular transformation is an approach that does not require the elimination of isolated organizational structures. It focuses on creating functional systemic overlays that support communication, coordination and collaboration. This approach stimulates innovative impulses at various organizational levels and moves away from the concept of centralized standardization of IT systems. Importantly, module boundaries are not defined by formal organizational divisions, such as branches or departments, but by the specifics and distinctiveness of technological and business processes while integrating them throughout the organization. The gradual introduction of implementations also helps reduce the fear of change and allows for adjustments in implementation to achieve better results. The analysis of the interviews indicated that this model of digital transformation is particularly suited to the situation of Polish small and medium industrial enterprises. Both representatives from these enterprises and digital technology suppliers recognize this suitability.

"Our solutions are based on a modular structure, which means we offer many different functionalities embedded in our application. In practice, implementations often have a partial character, focusing on the implementation of a specific element that is most needed by a given company" (D1).

Modular transformation is gradual and evolutionary in nature. Most often, companies undertake individual digital initiatives that are easy to implement and yield quick, visible benefits. These initiatives can include process automation projects, the implementation of monitoring systems, or the introduction of basic IT solutions.

"We do not yet have sufficient capital or experience, and generally, we lack employees who can take a systemic view. That is why we design the structure of our production plant in such a way that we can modify it if necessary. We are entering the transformation slowly, step by step. This way, we reduce risk" (D10).

Polish companies tend to automate individual segments of the production process more often, integrating modern robots with automated production lines or manual labour, and implementing production management systems that allow for the integration of older technological solutions with the latest technologies. They also less frequently opt for holistic solutions like the smart factory. Meanwhile, Western companies focus on mass production, which lends itself better to automation and robotics and requires less labour, which is becoming increasingly scarce due to rising labour costs and growing social aspirations.

Countries like Germany and France prefer robotization and the production of repetitive series, while Poland specializes in the production of heavier and more complex series, which are harder to automate. The resistance to introducing new technologies and robotization in manufacturing plants is not solely due to a lack of knowledge among employees but also because Poland receives orders for less repetitive series that are transferred by other countries specializing in mass and

repetitive production. These countries are technically aware that repetitive production is easier, simpler, and cheaper, allowing them to pay higher wages to their workers. Poland, on the other hand, is often referred to as the "welding shop of Europe", signifying its specialization in more complex and non-standard productions (D11).

Importantly, technology providers often emphasized with a fair amount of satisfaction that even isolated technological changes implemented in one area of a company begin to affect its overall functioning, encouraging the expansion of implementations.

"When someone observes the effectiveness of a point solution, they start to want it for themselves. Then, other departments in the organization express a desire to use this solution, while also realizing that we have another solution that can help them even more. This marks the beginning of another stage, with new champions emerging – individuals who are very positive about change and are essential for its implementation" (D14).

Technology providers particularly emphasize the trend of economizing on additional hardware and software that could contribute to a more efficient utilization of digital systems. A holistic approach supports the preparation of a digitalization strategy with defined objectives, values, and implementation methods. They argue that industrial companies must realize that digital transformation is a complex process encompassing technological, process-related, cultural, and organizational changes.

"An example of this is when a company has implemented a system in one area but not in another. When employees move from an area with a system to one without, they feel its absence and realize that the system would help them solve problems. Thus, the system becomes a powerful source of data that is operationally used in production. Moreover, the introduction of the system changes how production communication works. Thanks to the system, data is transmitted in real-time in both directions – operators have access to the current plan and are informed about any changes in real-time. Managers also see what is happening in production in real-time. Communication regarding maintenance is also changing – breakdowns and problems are reported in the system, and information is relayed almost instantly via televisions and other notification methods. Previously, this required running around, writing notes, making phone calls, and waiting. It is evident that the factory is now much better connected at various levels. Along with the implementation of the system, the roles of managers and analysts also change. Instead of spending a lot of time creating reports, they now focus on working with data, seeking optimization, and improving processes. The workload shifts from report creation to data analysis. This is a significant change that becomes apparent after the system is implemented" (D4).

Manufacturing companies clearly identify several benefits stemming from introduction of digital technologies, such as operational efficiency and problem solving, enhanced production monitoring, and, more importantly, role transformation connected with shift in workload. The introduction of digital systems changes the fundamental roles of managers and analysts. Rather than being bogged down by the tedious task of report creation, they can focus on more value-added activities such as data analysis, seeking optimizations, and enhancing processes. Modular digitalization offers manufacturing companies a pathway to become more efficient, connected, and data-driven. It not only improves current operations but also paves the way for further innovation and optimization.

Conclusions

The study sheds light on the current level of Industry 4.0 implementation among Polish SMEs, serving as a vital benchmark for understanding the digital evolution of such businesses within the region. Our findings suggest that the advancement of Industry 4.0 in Poland can be mapped through the observable patterns of technology adoption in SMEs. Two paramount factors were identified that play a crucial role in the adoption process of Industry 4.0 by Polish SMEs. Firstly, the enterprise's position in the global value chains significantly affects their readiness and approach to digital transformation. Secondly, the pressing need to amend the ongoing development model, primarily driven by labour shortages, acts as a catalyst for change. It is notable that instead of a broad, sweeping digital overhaul, Polish industrial SMEs predominantly favour a modular or selective digitalization approach. This strategy seems to be a pragmatic response to address immediate challenges while simultaneously building a foundation for future advancements.

The analysis underscores the imperative nature of local conditions in determining the path and pace of Industry 4.0 adoption. The unique aspects related to Poland's semi-peripheral economic positioning, coupled with its distinctive capitalist variety, significantly influence the way SMEs approach and experience digital transformation. This study also accentuates the intertwining of digital advancement with larger economic factors, most prominently the labour market's dynamics. Such connections indicate that the push for Industry 4.0 is not solely a technological endeavour but is deeply rooted in broader economic structures and trends.

In conclusion, the research not only narrows down the existing knowledge gap concerning the conditions for implementing Industry 4.0 in Polish SMEs but also offers a lens to appreciate how regional nuances and macroeconomic realities intertwine to shape the digital trajectory of businesses. Future endeavours in

this domain would benefit from recognizing and addressing these multifaceted determinants.

From the practical point of view, it is important to emphasize that current discussion on Industry 4.0 focuses on standard patterns (use cases) of digital transformation, primarily on the creation of intelligent factories characterized by advanced vertical and horizontal integration of digital systems and the incorporation of cutting-edge digital technologies. Such an approach, which emphasizes the scale of the endeavour and the required funding, can, however, intimidate smaller companies and may not be well-suited to their needs and business models. Meanwhile, for SMEs, the introduction of basic ERP or MES systems or the automation of specific production processes, like robotic automation, can bring significant benefits.

The widespread dissemination of knowledge regarding the advantages of implementing new technologies tailored to the specific needs of SMEs, considering their position in value chains is crucial for the development of modern industry in Poland. This dissemination should take the form of modular or selective transformation based on relatively simple and financially accessible solutions for small and medium-sized enterprises.

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