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Assessing the Industry 4.0 European divide through the country/industry dichotomy

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A B S T R A C T

Industry 4.0 refers to the application of new technologies to production and supply chain processes under the fourth industrial revolution (4th IR) paradigm and has been studied mainly in manufacturing. The present study looks to understand how the 4th IR manifests itself in the EU countries and across different industries through an Industry 4.0 perspective. Following a five-step research protocol that used a multivariate approach, Industry 4.0 Infrastructure, Big Data Maturity and Industry 4.0 Applications were identified as characterizing elements of Industry 4.0. Cluster analysis showed five homogeneous profiles of Industry 4.0 implementation across different industries and European countries. Our findings unveil a strong Industry 4.0 divide across (and within) European countries and industries. Industry 4.0 is much more determined by the industry than by the country. Knowledge of Industry 4.0 development conditions would greatly benefit from further research on the elements that drive the Industry 4.0 divide at the industry and country levels.

1. Introduction

The application of new technologies to production and supply chain processes has been commonly designated as Industry 4.0, a term derived from the undergoing 4th IR (Kagermann et al., 2013). Industry 4.0 refers to a set of disruptive technologies being used together to transform the current manufacturing paradigm and offer clients and organizations products and services with increased added value (Kagermann et al., 2013; Pacchini et al., 2019). Technologies such as the internet of things (IoT), cyber-physical systems (CPS), cloud computing (CC), additive manufacturing (AM), and big data analytics (BDA) are playing a crucial role in developing and integrating the manufacturing (Frank et al., 2019; Li, 2018; Pacchini et al., 2019) and logistics (Hofmann & Rüsch, 2017) industries' business needs and objectives.

The Industry 4.0 label was created as a policy-driven innovation discourse directed to the German high-tech manufacturing sector, supported by innovation encompassing enterprises, academia, and politics (Reischauer, 2018). European countries have been implementing public policies to develop Industry 4.0 with a strategic focus on technological development and innovation (Teixeira & Tavares-Lehmann, 2022). As one of the outcomes of the 4th IR, Industry 4.0 is grounded on the concept of the smart factory: the possibilities allowed by the new technologies to connect the physical and digital components of the factory, further allowing for greater automation and autonomy in the production and decision-making processes (Kagermann et al., 2013; Osterrieder et al., 2020). The smart factory is itself connected horizontally, across different production units, and vertically, across the supply chain, benefiting from the digital integration of the entire value chain (Culot, Orzes, et al., 2020; Frank et al., 2019; Kagermann et al., 2013).

However, while Industry 4.0 remains mainly associated with manufacturing, some definitions refer to other industries (Culot, Nassimbeni, et al., 2020), implying that Industry 4.0 concepts might be used to characterize the technological evolution of other activities beyond manufacturing. In fact, boundaries between industries may become diluted from the rapid spread of innovation - also fostered by institutional policies that do not exclusively target manufacturing - and from the joint contribution from manufacturing and non-manufacturing firms to common value propositions that aggregate different products and services (Weber & Schaper-Rinkel, 2017). Not only are many Industry 4.0 technologies used in non-manufacturing contexts, but also services are increasingly associated with goods encapsulated in a single value proposition (Culot, Orzes, et al., 2020).

The study of Industry 4.0 implementation tends to be focused on manufacturing from the smart factory perspective (Osterrieder et al., 2020). Extending the Industry 4.0 concept to other industries beyond manufacturing implies recognizing that several technologies associated

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with the 4th IR can also be applied in the services domain (Mariani & Borghi, 2019). While some authors have been looking at how these technologies benefit specific industries like construction (Dallasega et al., 2018; Oesterreich & Teuteberg, 2016), tourism (Pencarelli, 2020), commerce (Fernandez-Carames & Fraga-Lamas, 2018) or transportation and logistics (Ben-Daya et al., 2019; Hofmann & Rüsch, 2017), there has been little discussion on the implementation of Industry 4.0 across multiple economic activities. Furthermore, while the identification and measurement of the dimensions that impact productivity and business models have traditionally been available through institutional surveys directed to manufacturing companies across different geographies - the International Manufacturing Strategy Survey (IMSS) or the European Manufacturing Survey (EMS), being significant examples – the possibilities for comparisons across industries remain limited.

The present study addresses this knowledge gap by understanding how the 4th IR is manifesting itself in the EU countries and across different industries under an Industry 4.0 perspective. The study is based on Eurostat data collected through the European Statistical System (ESS), which ensures comparability across countries and industries. By performing two analyses simultaneously, the study exposes the partial nature of an analysis focused solely on the country or region level, which is the standard practice in the literature (Castelo-Branco et al., 2019; Teixeira & Tavares-Lehmann, 2022), susceptible to hiding domestic divides. One country may be performing well in a specific industry in which Industry 4.0 is concerned but, at the same time, lagging in another. Moreover, the simultaneous analysis of the EU countries sheds light on existing asymmetries, paving the way for implementing the European single market strategy (European Commission, 2021). Consequently, this study aims to answer the following questions:

RQ1: How many Industry 4.0 dimensions are there, and how are the different industries and EU member states performing concerning those?

RQ2: How do the different EU countries and their respective industries place themselves in comparison to one another regarding Industry 4.0 dimensions?

RQ3: Is the gap between Industry 4.0 implementation levels stronger within industries or countries, i.e., is the implementation of Industry 4.0 more determined by the firms' economic activity or the country?

A five-step research protocol was devised to answer these questions: the relationships between Industry 4.0 and industries were identified from the literature and a set of variables from different industries that reflect the most important features of Industry 4.0 was collected. A multivariate framework was applied with a principal component factor analysis, followed by cluster analysis. It was possible to find the most important dimensions and how countries/industries score on them. Additionally, important implications for policymakers, practitioners, and scholars were identified. The remainder of this paper is organized as follows: Section 2 describes what can define Industry 4.0 in depth and how it can manifest itself in other industries beyond manufacturing; Section 3 details the research design; Section 4 describes the methodology and presents the results; Section 5 discusses the findings, elaborates and presents the study's contributions and limitations; Section 6 concludes and presents the study's proposed research directions.

2. Theoretical Background

2.1. Industry 4.0 in Manufacturing

The concept of Industry 4.0 was first introduced in 2011 by the German government as part of its High-Tech strategic initiative (Kagermann et al., 2013). Since then, the idea has been widely accepted in business and academia to characterize the effects of the integration of emergent technologies into manufacturing and supply chain processes. The concept has been associated with the usage of IoT and CPSs within manufacturing, also including CC, BDA, artificial intelligence (AI), autonomous robots, AM, and augmented reality (AR) (Culot, Orzes, et al., 2020; Frank et al., 2019; Pacchini et al., 2019). Simulation, blockchain technology and vertical and horizontal system integration are also some of the features of the Industry 4.0 paradigm (Culot, Orzes, et al., 2020; Frank et al., 2019).

These technologies have facilitated the advancement of the smart factory, which relies on an architecture based on four layers (Osterrieder et al., 2020). The first, the physical layer, collects data through sensors and interconnected physical machines. The second and third are responsible for transferring data from those machines to the cloud, where the data are stored, processed, and analyzed. In the last one, the control layer, a program that can be monitored by human personnel, controls the entirety of the smart factory. The four layers are compatible with the four design principles described by Hermann et al. (2016) interconnectivity, information transparency, decentralized decisions, and technical assistance.

Industry 4.0 can also be seen as a combination of technologies, devices, and processes integrated into the production procedures in the entire supply chain and value chains, promoting self-sufficient production processes and decentralized decisions requiring minimum human intervention. This integration is possible due to consistent and flexible connectivity and computerization, which permits a higher level of automation and self-adapting production systems, and thus enables autonomous and decentralized decision-making (Hofmann & Rüsch, 2017). Under a broader view, Industry 4.0 can be identified as a set of disruptive technologies changing how enterprises in all industries plan, perform, and evaluate their business strategies (Culot, Orzes, et al., 2020).

2.2. Industry 4.0 beyond manufacturing

The 4th IR builds upon the knowledge and systems of the previous industrial revolutions, particularly digital capabilities made possible by the third industrial revolution (Schwab, 2018). It corresponds to the transformations that derive from the new technologies with an impact not only on the economy but also on society, the government, and human identity (Sung, 2018). Like the three previous industrial revolutions, this one is changing the paradigm of production and work (Kagermann et al., 2013). While the Industry 4.0 term and the 4th IR have many times been used as synonyms (Mariani & Borghi, 2019; Sung, 2018), Industry 4.0 is the specific outcome of the 4th IR that deals with the new paradigm in manufacturing (Culot, Nassimbeni, et al., 2020). It may also be viewed as a sub-category of digitalization, as digital transformation impacts not only the production and supply chain processes but also the business model and the overall organizational management (Horváth & Szabó, 2019).

Some authors admit the possibility that the Industry 4.0 construct might be extended to other industries beyond manufacturing. The growing trend of complementing products with services requires manufacturing companies to compete with non-manufacturing ones more and more, raising conceptual issues about industries boundaries (Culot, Orzes, et al., 2020; Weber & Schaper-Rinkel, 2017). Servitization has been blurring the distinction between products and services (Olsen & Tomlin, 2020) as service providers start to offer more technologies while technology-based and manufacturing companies offer more services and Industry 4.0 solutions (Müller et al., 2018; Rehse et al., 2016)

Non-manufacturing industries have been adapting to the 4th IR at different paces and with different outcomes. The transportation and logistics and wholesale and retail trade industries are linked to supply chain activities and therefore benefit from the integration possibilities allowed by Industry 4.0 technologies. IoT, CC, AM, and BDA allow for the integration of supply chain and production processes, facilitating planning and reducing disruption, thereby improving the supply chain's resilience (Ben-Daya et al., 2019; Ivanov et al., 2019). Auto-ID technologies such as radio-frequency identification (RFID) tags and readers, cloud-based enterprise resource planning (ERP) systems, blockchain, and CPSs enable access to demand information in real-time, facilitating "Just-in-Time/Just-in-Sequence" processes, where warehouse

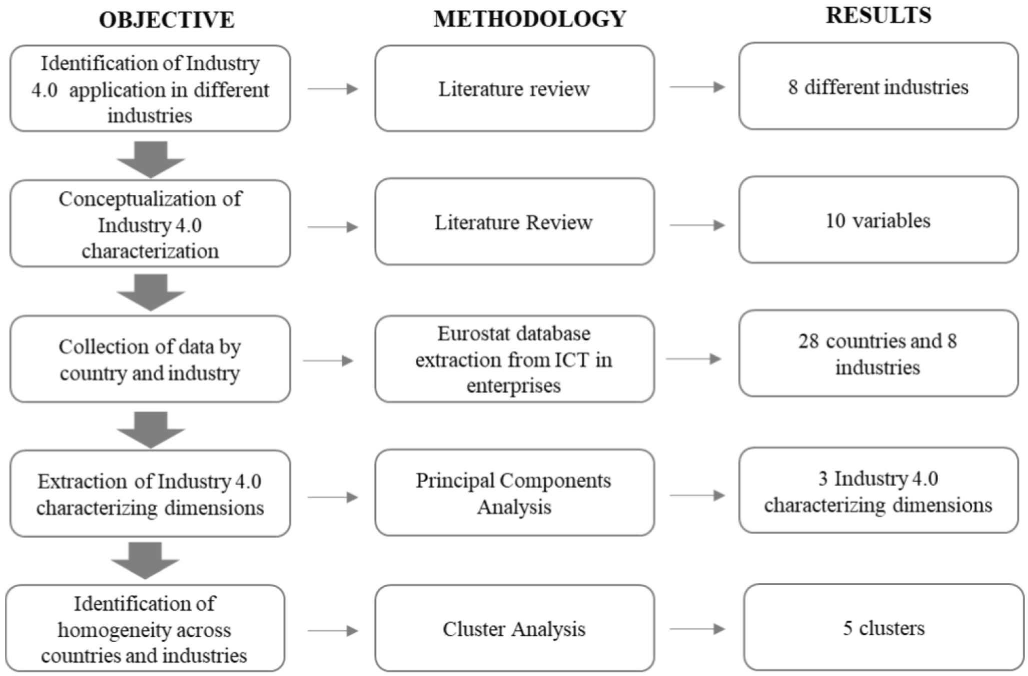

Figure 1. Research design

Table 1
Economic activities.

Industry	Identifier	NACE Rev2Section - description(Eurostat, 2008)	Industry 4.0 relationship	References
Accommodation and food and beverage service activities	Hospitality	I - short-stay accommodation and the provision of meals and drinks as a service	Automated tourism and service robots	(Tussyadiah, 2020)
Construction	Construction	F - construction or repair of any type of buildings or structures and civil engineering works	Building information modelling and materials supply chain	(Dallasega et al., 2018; Oesterreich & Teuteberg, 2016)
Electricity, gas, steam, air conditioning, and water supply	Utilities	D - provision of utilities through a physical infrastructure to enterprises or households	Smart grids	(Faheem et al., 2018)
Information and communication	ICT	J - production and distribution of information and cultural products, IT and data processing activities	Mobile publishing and broadcasting; smart TV	(Sheng et al., 2005; Wong et al., 2014)
Manufacturing	Manufacturing	H -physical or chemical transformation of raw material or products into new material products (goods)	Smart factory	(Mariani & Borghi, 2019)
Retail trade, except for motor vehicles and motorcycles	Retail	G 47 - intermediation of goods for final consumers	Supply chain management: smart labels	(Fernandez-Carames & Fraga-Lamas, 2018)
Transportation and storage	Logistics	H - transport of goods or people by any means and related logistics activities	Supply chain management: smart transportation and warehousing	(Barreto et al., 2017; Hofmann & Rüsch, 2017)
Wholesale trade, except for motor vehicles and motorcycles	Wholesale	G 46 - wholesale trade, domestic or international (import/export)	Supply chain management: integration with manufacturing	(Ben-Daya et al., 2019; Ivanov et al., 2019)

management and transport management systems communicate (Barreto et al., 2017; Hofmann & Rüsch, 2017). Trade, either wholesale or retail, benefits from smart labelling: beyond the QR codes, barcodes, and RFID tags that are used to manage stocks, IoT allows the introduction of further content in the context that can be used to communicate with the smart factory or simply be read by the consumer's mobile phone, for example (Fernandez-Carames & Fraga-Lamas, 2018).

The impact of Industry 4.0 on other service industries is also visible. Tourism can benefit from intelligent automation technologies such as AI, robotics, and IoT, which drive the concept of smart tourism ecosystems (Tussyadiah, 2020). For construction, CC, BDA, and AR potentiate the simulation benefits of building information modelling (Oesterreich & Teuteberg, 2016), while collaborative technologies supported on CC and web platforms facilitate proximity and supply chain management (Dallasega et al., 2018). In utilities, interconnection and autonomous data exchange between producers and consumers allow for the development of smart grid systems with optimized controls and the ability to manage the available capacity in the most efficient way (Faheem et al., 2018). Finally, information and communications, which include publishing, broadcasting, telecommunications and data processing and storage activities, is a natural frontrunner in using several Industry 4.0 technologies. Firms rely on wireless communication and cloud computing to improve internal operations as well as extend services to customers (Sheng et al., 2005). Wireless communication makes mobile TV and radio possible simultaneously with other internet services (Wong et al., 2014).

3. Research design

A five-step research protocol was devised to answer the research questions. Initially, a literature review was performed to identify how Industry 4.0 is implemented across different economic activities. The conceptualization of Industry 4.0 variables was devised also through a literature review. In the third step, the variables data were collected

Table 2
Variables used, acronyms, and support.

Theme	Acronym	% of companies	Support
Interconnectivity	MCDS_100	The maximum contracted download speed of the fastest fixed internet connection is at least 100 Mb/s	(Hermann et al., 2016; Hofmann & Rüsch, 2017; Li, 2018; Mariani & Borghi, 2019; Pacchini et al., 2019; Rehse et al., 2016; Tussyadiah, 2020)
Interoperability	ERP	Enterprises that have ERP software packages to share information between different functional areas	(Belaud, Prioux, Vialle, & Sablayrolles, 2019; Hermann et al., 2016; Hofmann & Rüsch, 2017; Li, 2018)
Virtualization	HighCC	Buy high CC services (accounting software applications, CRM software, computing power)	(Bai et al., 2020; Frank et al., 2019; Li, 2018; Mariani & Borghi, 2019; Oesterreich & Teuteberg, 2016; Pacchini et al., 2019; Rehse et al., 2016)
Collaboration	CollabPartn	Collaborate with business partners (e.g. suppliers, etc.) or other organizations (e.g. public authorities, non-governmental organizations, etc.)	(Annosi et al., 2019; Büchi et al., 2020; Culot, Orzes, et al., 2020; Hofmann & Rüsch, 2017; Kim, 2018; Reischauer, 2018; Sung, 2018; Weber & Schaper-Rinkel, 2017; Woodhead, Stephenson, & Morrey, 2018)
Information Transparency	BD_Any	Enterprises analyzing big data from any data source	(Bai et al., 2020;; Frank et al., 2019; Hofmann & Rüsch, 2017; Li, 2018; Olsen & Tomlin, 2020; Pacchini et al., 2019; Rehse et al., 2016)
	BD_Geo	Analyze big data from geolocation of portable devices	
	BD_Own	Analyze own big data from enterprise's smart devices or sensors	
Technologies	Website	Website has online ordering, reservation or booking and at least one of: webacc, webctm, webot, or webper	(Büchi et al., 2020; Hasija et al., 2020; Rehse et al., 2016)
	3DPrint	Use 3D printing	(Frank et al., 2019; Mariani & Borghi, 2019; Olsen & Tomlin, 2020; Pacchini et al., 2019)
	Robots	Use industrial or service robots	(Frank et al., 2019; Li, 2018; Mariani & Borghi, 2019; Olsen & Tomlin, 2020; Pacchini et al., 2019; Rehse et al., 2016; Tussyadiah, 2020)

from the Eurostat database on Information and Communication Technologies in enterprises (Eurostat, 2020), corresponding to 10 variables across 28 countries plus the European Union average and eight economic activities, or industries, according to the statistical classification of economic activities in the European Community (NACE, Rev.2) (Eurostat, 2008). Afterwards, three factors were identified, and a principal components analysis was performed. Cluster analysis identified five homogeneous clusters of countries and industries in the fifth and final step. All the analyses were performed using Python and SAS®. Figure 1 depicts a scheme of the research process.

4. Methodology and results

The following subsections provide a step-by-step explanation of the methodological approach and present each step's results.

4.1. Industries

The choice of industries to be included in the analysis reflects the respective relevance in the EU economy and the potential impacts of Industry 4.0 on the industries' development and structural business models. The main Industry 4.0-related themes were identified for each industry based on relevant Industry 4.0 literature. Because of their specific nature, agriculture, forestry and phishing and mining and quarrying were not considered, as well as Sections K to U from the NACE Rev. 2 classification, which includes, among others, financial and insurance activities, real estate, education, health and recreation. The industries under analysis are shown in Table 1. For each, the corresponding Industry 4.0 relationship is identified based on relevant literature.

4.2. Variables characterizing Industry 4.0

The Eurostat database provides information on technologies associated with Industry 4.0 implementation but not directly linked to it. One of those technologies is related to the interconnectivity between machines, devices, sensors, and people through the use of IoT (Hermann et al., 2016). Connectivity and integration allow for autonomous and decentralized decision-making (Hofmann & Rüsch, 2017) within each firm and between the firm and its partners (Kagermann et al., 2013). Consequently, the variable *the maximum contracted download speed of the fastest fixed internet connection is at least 100 Mb/s* (MCDS_100) was chosen to represent the increased need for interconnectivity. Additionally, ERP software is useful to ensure real-time information sharing and, consequently, production adjustment as needed (Hofmann & Rüsch, 2017). Thus, the business's ability for autonomous monitoring and controlling of the physical world to ensure information transparency and decentralized decisions (Hermann et al., 2016) can be measured with the variable *Enterprises that have ERP software packages to share information between different functional areas* (ERP).

Most websites permit personalized options for the products and services they offer, which allows for user engagement from customers as they perceive the utility of the services being offered and feel motivated to collaborate with the company (Hasija et al., 2020). The variable *Website has online ordering, reservation or booking and at least one of webacc, webctm, webot, or webper* (Website) measures if the firm's website provides a description of goods or services, price lists (webacc), if it provides the customization of goods or services (webctm), whether it allows for tracking orders (webot) or if it personalizes content for regular visitors (webper). The website was chosen to capture a company's flexibility to adjust its production capacity through mass customization and personalization (Büchi et al., 2020) based on previously collected customers' real-time information (Rehse et al., 2016)

The crucial role of policymakers in the process of adopting Industry 4.0 technologies (Culot, Orzes, et al., 2020; Kim, 2018; Oesterreich & Teuteberg, 2016; Sung, 2018) and the significant relationship between stakeholders and the government in all matters related to Industry 4.0 (Büchi et al., 2020), stresses the importance of collaboration between the parts involved in the process. Hofmann & Rüsch (2017) also address the role of collaboration between business partners across the supply chain. Annosi, Brunetta, Monti, & Nati (2019) concluded that the implementation of Industry 4.0 technologies by Italian SMEs has a positive relationship not only with the companies' managerial capabilities and the technologies' perceived usefulness but also with the external supporting business services. Therefore, another variable was

Table 3
Data for the aggregate of the EU Countries.

Industry	MCDS_100	HighCC	CollabPartn	Website	BD_Any	BD_Geo	BD_Own	ERP	3DPrint	Robots
Hospitality	0.15	0.11	0.14	0.35	0.10	0.03	0.02	0.16	0.01	0.02
Construction	0.17	0.10	0.09	0.03	0.11	0.08	0.02	0.21	0.02	0.03
Utilities	0.24	0.13	0.11	0.12	0.20	0.13	0.10	0.41	0.02	0.03
ICT	0.55	0.45	0.32	0.22	0.27	0.10	0.09	0.49	0.05	0.02
Manufacturing	0.18	0.10	0.10	0.12	0.09	0.04	0.04	0.46	0.09	0.18
Retail	0.16	0.10	0.13	0.32	0.12	0.04	0.03	0.29	0.02	0.04
Logistics	0.18	0.11	0.09	0.13	0.19	0.16	0.04	0.26	0.01	0.03
Wholesale	0.26	0.15	0.16	0.26	0.12	0.05	0.04	0.55	0.04	0.05

Table 4
Factor loadings and variance explained

Variable	Description	I40 Infrastructure	Big Data Maturity	I40 Applications
CollabPartn	Collaborate with business partners (e.g., suppliers, etc.) or other organizations (e.g., public authorities, non-governmental organizations, etc.)	**0.81**	0.24	0.08
HighCC	Buy high CC services (accounting software applications, CRM software, computing power)	**0.78**	0.38	0.19
Website	Website has online ordering, reservation or booking and at least one of: webacc, webctm, webot, or webper	**0.74**	-0.22	-0.14
MCDS_100	The maximum contracted download speed of the fastest fixed internet connection is at least 100 Mb/s	**0.71**	0.37	0.29
BD_Geo	Analyze big data from geolocation of portable devices	-0.14	**0.91**	-0.13
BD_Any	Enterprises analyzing big data from any data source	0.41	**0.85**	0.05
BD_Own	Analyze own big data from enterprise's smart devices or sensors	0.33	**0.78**	0.20
3DPrint	Use 3D printing	0.19	0.03	**0.88**
Robots	Use industrial or service robots	-0.22	-0.15	**0.87**
ERP	Enterprises that have ERP software packages to share information between different functional areas	0.33	0.32	**0.67**
Variance Explained		2.80	2.68	2.18
Variance Explained (%)		42%	19%	15%
Total Variance Explained (%)		42%	62%	77%

added to the list: *Collaborate with business partners (e.g., suppliers, etc.) or other organizations (e.g., public authorities, non-governmental organizations, etc.)* (CollabPartn).

Of the specific technologies that describe Industry 4.0, Cloud Computing and software as service technology (SaaS), in particular, are important tools for sharing real-time information with customers. SaaS is believed to increase the company's perceived value and customers' trust when purchasing (Ghouri & Mani, 2019). The concept of a smart factory also benefits from using CC, as it integrates the industry and its information with the process of manufacturing digitalization (Li, 2018). On the other hand, technologies such as sensors, actuators, and AI, combined with CC, contribute to environmental sustainability by providing greater efficiency in materials usage, reduced use of toxic materials, and lower impact on effluents and wastes (Bai et al., 2020). For these reasons, a company needs to *Buy high CC services (accounting software applications, CRM software, computing power)* (HighCC) to process and store real-time information.

Additive manufacturing allows for the distribution of low-volume production of highly customized products, which in turn permits the reduction of upfront production costs and material waste (Olsen & Tomlin, 2020; Pacchini et al., 2019). This aspect was measured with the variable *Use of 3D printing* (3DPrint). On the other hand, the collaboration between industrial robots and human operators in manufacturing processes has intensified as it increases productivity (Li, 2018) in high-volume repetitive operations (Olsen & Tomlin, 2020). The use of service robots has also seen an upsurge in Hospitality, as there are already hotels that use a combination of robots and AI to minimize their human personnel and still give customers a pleasant experience (Tussyadiah, 2020). Consequently, the *Use of industrial or service robots* (Robots) was chosen to measure the level of integration of robots in different industries' businesses.

Finally, using BDA, along with CC, AR, and robots, among others, enables the transition to Service 4.0 by allowing for greater flexibility, greater speed, higher productivity, and better process quality (Rehse et al., 2016). The application of BDA can be empowered if companies can organize and maintain data in secure digital systems, which require a specific infrastructure (Pacchini et al., 2019). Therefore, to measure the implementation level of BDA solutions, the variable *Enterprises analyzing big data from any data source* (BD_Any) were selected. However, to narrow down the use of BDA, two other variables were identified: *Analyze big data from geolocation of portable devices* (BD_Geo) and *Analyze own big data from enterprise's smart devices or sensors* (BD_Own). Table 2 summarizes the ten variables selected for the analysis.

4.3. Data collection and exploratory analysis

Of the ten variables selected, four were available for the year 2019. These include MCDS_100, CollabPartn, Website, and ERP. The other six were available only for the year 2018. The unit of measure is the percentage of enterprises in each industry. Considering the period chosen, 28 countries, including the United Kingdom, were analyzed as the country was still part of the EU in 2018/2019. The aggregate of the EU Countries – "European Union - 28 countries" – was also included in the analysis as a means of comparison, which is the weighted average of all European countries per industry. The null values were filled using the KNN imputer, with k=3, from Sklearn (Python). This method uses the mean value of the closest neighbours after comparing each pair of countries in the dimensions (variables) included in our study. Table 3 presents the data from the aggregate of the EU28 countries that serves as an excerpt from the final data set. By examining Table 3, it is possible to acknowledge the dispersion in the implementation of each variable in

Table 5
Factor scores per industry.

Industry acronym	I40 Infrastructure	Big Data Maturity	I40 Applications
Hospitality	0.55	-1.02	-0.97
Construction	-0.75	-0.24	-0.42
Utilities	-0.64	1.33	-0.05
ICT	1.56	1.05	0.18
Manufacturing	-0.63	-0.51	1.92
Retail	0.28	-0.64	-0.38
Logistics	-0.69	0.77	-0.67
Wholesale	0.40	-0.33	0.28

Table 6
Factor scores per country.

Country	I40 Infrastructure	Big Data Maturity	I40 Applications
Austria	-0.08	-1.00	0.39
Belgium	0.08	0.52	0.19
Bulgaria	-0.65	-0.41	-0.51
Croatia	-0.27	-0.13	-0.15
Cyprus	-0.01	-0.48	-0.46
Czech Rep.	-0.32	-0.40	0.35
Denmark	1.34	-0.37	0.74
EU28	-0.24	0.06	0.06
Estonia	0.23	-0.23	-0.41
Finland	1.31	0.64	0.87
France	-0.68	0.72	0.19
Germany	-0.49	0.33	-0.02
Greece	-0.79	0.25	-0.46
Hungary	-0.20	-0.67	-0.66
Ireland	0.42	0.55	-0.35
Italy	-0.67	-0.35	0.02
Latvia	-0.44	-0.50	-0.08
Lithuania	0.51	0.30	0.12
Luxembourg	-0.29	0.81	0.26
Malta	0.74	0.33	0.07
Netherlands	1.04	0.75	0.28
Poland	-0.47	-0.21	-0.21
Portugal	-0.20	0.48	0.20
Romania	-0.44	0.02	-0.61
Slovakia	-0.13	-0.49	-0.31
Slovenia	-0.21	0.29	0.04
Spain	-0.29	0.11	0.51
Sweden	1.29	-0.58	0.38
United Kingdom	0.29	-0.11	0.03

the different industries. For example, High CC services are used more intensely in ICT, as 45% of enterprises identified the technology's presence. All other industries have implementation values of High CC ranging between 10% and 15%.

4.4. Principal Components Factor Analysis

Principal components factor analysis was chosen for the present study to identify relationships between variables. With this technique, a set of (original) variables is reduced to a smaller number of dimensions (i.e., factors) that explain the maximum portion of the total variance of the initial set of variables. The first step in applying a factor analysis is to examine the correlation between the initial variables (Hair et al., 1995) (Table A1). If many primary variables have a high correlation between themselves, they are measuring the same event and may be associated with the same factor (Decoster & Hall, 1998). The next phase was to perform the factor analysis, with which it was possible to observe the so-called factors. Three criteria were considered to define the "ideal" number of factors to extract: the Kaiser's criterion, which states that every factor with an eigenvalue greater than one (as the original variables were standardized) should be considered; the Scree Plot, which considers the difference in explained variance from each factor; and the Pearson's criterion, which states that every factor should be retained until 80% of the variance is accounted for (Hair et al., 1995; Sharma, 1996)

The three criteria we used to decide how many factors to retain led us to conclude that three was the "ideal" number (see Table A2 and Figure A1in Appendix). These three factors combined explain 77% of the total variance. The first factor is highly correlated with the variables associated with interconnectivity, virtualization, collaboration, and one technology that connects the business to its consumers. Hence, we named it **Industry 4.0 Infrastructure**, as it reflects Industry 4.0's characteristics closely related to the fundamental business operation. The second factor was labelled **Big Data Maturity**, as it incorporates all three variables related to BDA from any data source, own devices or sensors, or geolocation of portable devices. Finally, the third factor comprises ERP systems, 3D printing, and industrial or service robots, which incorporate each of the three stages of Industry 4.0 implementation (Frank et al., 2019). While ERP systems help the vertical integration of the supply chain in the earliest stage of Industry 4.0 implementation, the use of robots facilitates the automation of processes in the second phase. In the third stage, the flexibilization of processes due to the use of AM promotes the customization and personalization of products (Frank et al., 2019). For these reasons, the third factor was named **Industry 4.0 Applications**. Table 4 presents the factor loadings and variance explained.

We computed the average factor scores per industry to analyze how each industry, at the European level, behaves in each dimension. It is interesting to note that ICT, Utilities, and Manufacturing are industries performing better in terms of **I40 Infrastructure**, **BD Maturity**, and **I40 Applications** implementation, respectively. ICT also performs better than the average in all three dimensions. On the other hand, Hospitality has the lowest scores for both **BD Maturity** and **I40 Applications** implementation, while Construction lags further in **I40 Infrastructure**. Construction is also the only industry performing below the average in all three dimensions. Table 5 presents the factor scores per industry.

We examined factor scores at the country level to examine differences across European member states. It is noticeable that Denmark, Finland, the Netherlands, and Sweden have had a higher implementation rate than the EU average regarding **I40 Infrastructure**. Denmark and Finland are also performing quite well regarding I40 Applications of these four. The use of BDA in business has been more prevalent in Finland, France, Luxembourg, and the Netherlands. At the other end of the spectrum, Bulgaria, Hungary, Latvia, Poland, and Slovakia have implementation levels lower than the average for all three dimensions. Austria is performing far behind its EU counterparts in terms of **Big Data Maturity**, while France, Greece, and Italy fall behind on **I40 Infrastructure**. Table 6 includes the factor scores per country.

The combination between each European country and industry is depicted in Figures A2, A3 and A4 of the Appendix for the sake of readability.

4.5. Cluster Analysis

In the next step of the analysis, combinations of European countries and industries were aggregated into homogeneous groups (i.e., clusters) using the three dimensions found in the previous section (i.e., **I40 Infrastructure, Big Data Maturity,** and **I40 Applications**). In this regard, we combined hierarchical and non-hierarchical methods, as this approach tends to yield better results (Sharma, 1996)

The hierarchical analysis was conducted using five algorithms – Single, Complete, Ward, Centroid, and Average – that were run on the factor scores to assess the "ideal" number of clusters that should be retained. The best algorithm was evaluated based on the clusters' respective R-squares. Ward's method was considered the best (Figure A5, Appendix section), explaining 66% of the total variance with five clusters. In other words, the amount of information retained using five clusters instead of the whole dataset is two-thirds. The dendrogram was also assessed, confirming the five-cluster option (see Figure A6in the Appendix).

Table 7
Clusters and descriptive statistics.

Cluster	Frequency	I40 Infrastructure	Big Data Maturity	I40 Applications
Infrastructure Focused	60	**0.56**	-0.85	-0.57
Average -> Laggards	92	-0.50	-0.32	-0.14
Infrastructure Leaders	37	**1.57**	0.85	0.30
Big Data Leaders	38	-0.92	**1.49**	-0.39
Applications Leaders	19	-0.58	-0.43	**2.67**

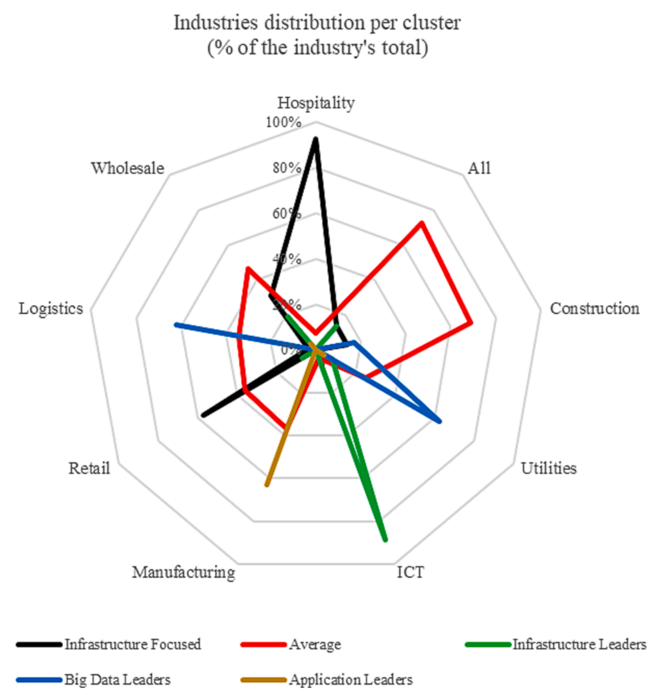

Figure 2. Industries distribution per cluster

The next step was to run a non-hierarchical method - k-means - using the centroids of the five clusters previously generated by Ward's method as initial seeds. This method was chosen because it tends to return better results (Sharma, 1996). In simple terms, k-means was used to improve what was already a good solution (Ward's hierarchical algorithm). This option is also beneficial as it minimizes one of the k-means weaknesses – the initialization of the seeds. This option was ultimately proven correct, as the R-Squared improved by 3pp. Table 7 presents the results for each cluster, all of which are characterized by at least one dimension in which the country-industry pairings have been performing better than their counterparts. Consequently, it is possible to define each cluster by the implementation level of each dimension's technologies.

In this way, the first cluster was named *Infrastructure Focused,* as it is composed of country-industry pairings that already have a good I40 Infrastructure but are still lacking in the other two dimensions. On the other hand, pairs in the second cluster are behind their counterparts in all three dimensions. Because its values are all close to zero, this cluster was named *Average*. The third cluster includes the *Infrastructure Leaders*, who have been performing the best in terms of I40 Infrastructure while also being better than the average in the other two dimensions. Pairings in the fourth cluster were ahead in the implementation level of BD solutions and were thus called *Big Data Leaders*. Last, the fifth cluster, *Applications Leaders*, includes those investing more in relative terms in implementing I40 Applications.

After characterizing each cluster based on their factors' score, the different industries and countries were analyzed considering their distribution per cluster. Figure 2 presents the industries' distribution per cluster.

Hospitality is a rather homogeneous industry, with 25 out of 27 countries belonging to the Infrastructure Focused cluster, which reflects a better preparedness in terms of I40 Infrastructure compared to the other two dimensions. ICT closely follows, with 24 out of 27 countries belonging to the *Infrastructure Leaders* cluster and, thus, having performed better than their counterparts in all three dimensions. Utilities and Logistics are implementing more BDA solutions in their businesses, while Manufacturing is outperforming all others in terms of I40 Applications. Most of the Construction industry is performing below but close to the average in all three dimensions, thus belonging to the *Average* cluster in its majority.

Similarly, Figure 3 represents the countries' distribution per cluster. At first glance, none of the countries seems to be homogeneous, meaning that their industries are evenly distributed throughout the five clusters. Nevertheless, Bulgaria, the Czech Republic, Greece, Hungary, Latvia, Poland, Romania, and Slovakia have most of their industries in the *Average* cluster. Denmark, Finland, and the Netherlands have the highest portion of their industries belonging to the *Infrastructure Leaders* cluster, indicating a better preparedness to embrace Industry 4.0.

As is noticeable by the analysis of Figures 2. and 3, there is a stronger relationship between the five clusters and the industries than between the clusters and the countries. In fact, 55% of the industries fall primarily within a specific cluster despite the country, compared with 29% of countries mainly falling within a specific cluster despite the industry. Detailed information per sector and country can be found in the Appendix. The highest portions describing each industry always account for more than 50% of the total, with only one exception – Wholesale – for which the highest portion only contributes 46%. Hence, seven out of eight industries (88%) are better defined by a specific cluster, which corroborates the notion that the industries are somewhat homogeneous. On the other hand, only eight out of 28 countries (29%) have the majority of their industries belonging to a specific cluster (in this case, the *Average* cluster), which reflects the idea that the industries within each country are more dispersed throughout the clusters and, thus, have contributed more to its formation. Consequently, there are more apparent discrepancies between industries than between countries.

5. Discussion

5.1. Discussion of Findings

The present work represents a step forward in understanding the reality of Industry 4.0 implementation across Europe from a country and industry perspective.

5.1.1. Industry 4.0 characterizing dimensions across EU countries and industries

Through a principal components factor analysis based on extensive and recent Eurostat data, it was possible to conceptualize Industry 4.0 across three non-overlapping dimensions, each one representing a specific characterizing element. The first dimension, **Industry 4.0 Infrastructure**, measures the interconnectivity, virtualization, collaboration, and website use as a communication and transactions platform. These are basic conditions required so that Industry 4.0 technologies can be applied effectively – the infrastructure – and are necessary for the existence of the other two dimensions. As a platform that makes interconnectivity possible between suppliers and customers, a website with transactional capabilities enhances customer interaction and allows for customization and personalization options (Büchi et al., 2020). The existence of collaborative practices with external partners reflects the ability of the firm to integrate external knowledge, a necessary condition

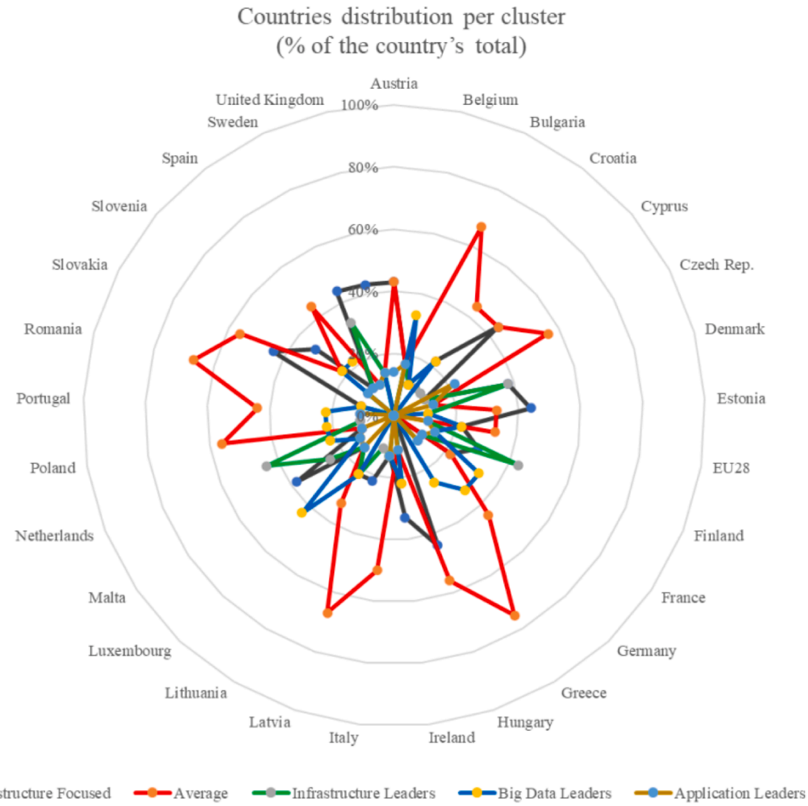

Figure 3. Countries distribution per cluster

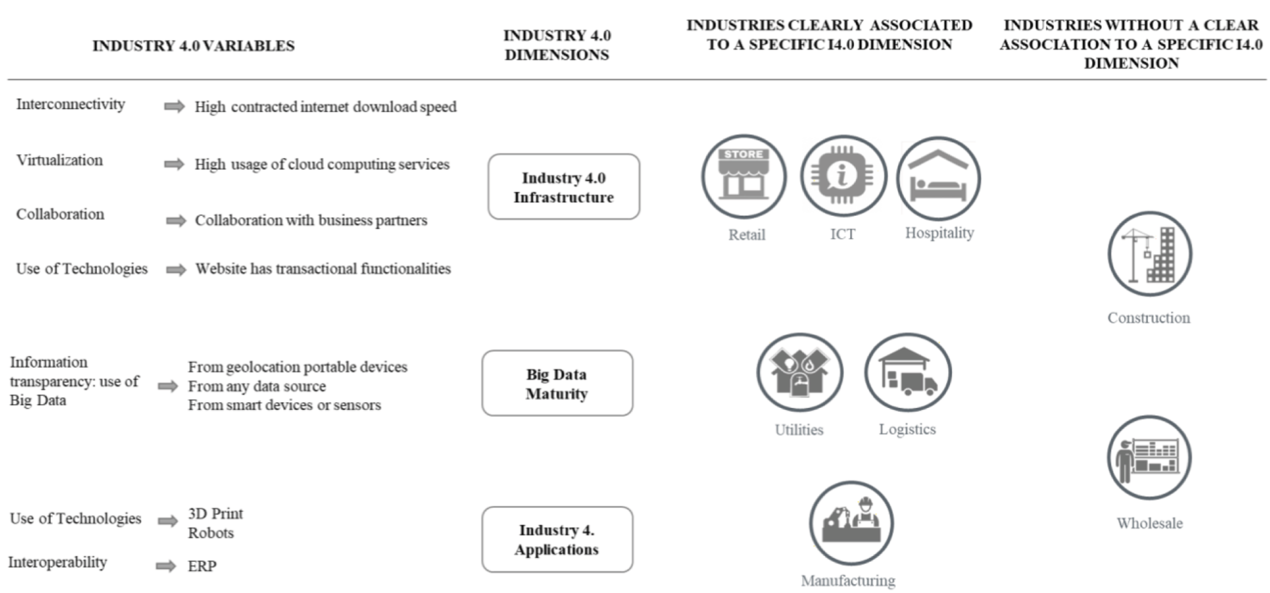

Figure 4. Industry 4.0 identified dimensions and associated industries

for efficient horizontal and/or vertical integration (Liboni et al., 2019). It also relies on interconnectivity, the ability to transfer data and information across business units (Hermann et al., 2016) and suppliers and customers (Hasija et al., 2020). The devices and interactions generate data that can be accessed in the cloud, facilitating the collaboration between a company and its partners throughout the supply chain (Hofmann & Rüsch, 2017; Oesterreich & Teuteberg, 2016). The second dimension, **Big Data Maturity**, reflects the ability to analyze data – either from any source or specifically from devices - and generate information to improve decision-making and the overall quality of the processes (Rehse et al., 2016). The third dimension, **Industry 4.0 Applications**, represents the element in Industry 4.0 characterization that includes specific technologies from all Industry 4.0 implementation stages: ERP systems can integrate internal processes and the supply chain, robots automate processes and 3D printing that can contribute to customization and increased flexibility (Frank et al., 2019).

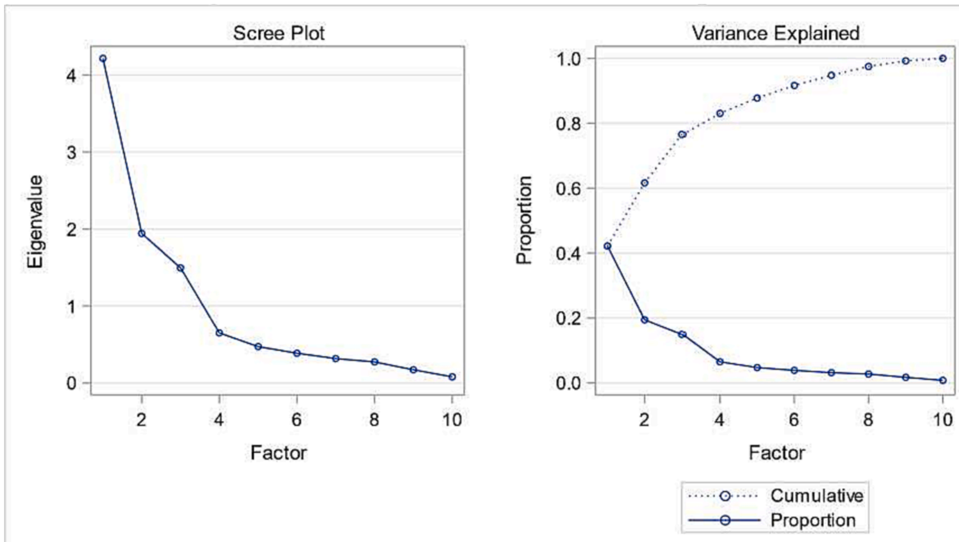

Figure A1. Scree Plot and variance explained

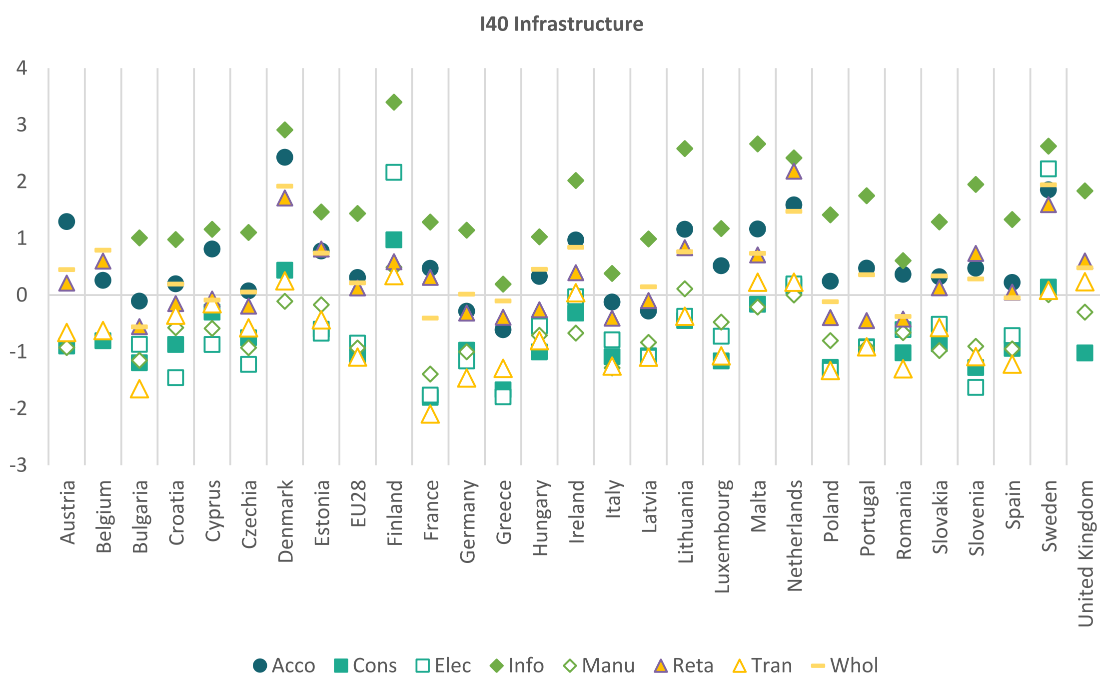

Figure A2. I40 Infrastructure factor scores distribution per country

Industry 4.0 dimensions show many differences across European industries. It comes as no surprise that Manufacturing has been investing in **I40 Applications** more than any other industry, as these are mostly elements of production processes. The growth of e-commerce platforms is leading Logistics to an increased necessity to collect data and further analyze it to optimize inventory and routes, which is consistent with the view of some authors (Hofmann & Rüsch, 2017; Zhu et al., 2018). Likewise, Utilities have benefited from using BDA solutions, as it allows for optimized power generation and planning, thereby improving the allocation of resources and production efficiency (Zhou et al., 2016). ICT, an industry whose services rely almost exclusively on technologies, has been above average in all three dimensions. The main difference between Retail and Wholesale is reflected in the implementation level of **I40 Applications**, as the latter has invested more in it than the former. This facet is consistent with the extension of the Industry 4.0 concept to the supply chain. As for Construction, it remains a conservative industry, falling below average in all dimensions, which denotes failing to capture the benefits of Industry 4.0 technologies (Dallasega et al., 2018; Oesterreich & Teuteberg, 2016). However, Hospitality has the lowest implementation levels of **Big Data Maturity** and **Industry 4.0 Applications**, even though it shows the second-highest level in **Industry 4.0 Infrastructure**. Figure 4. depicts a schematic distribution of industries across the identified Industry 4.0 dimensions.

5.1.2. *Countries and industries under the Industry 4.0 paradigm*

The five clusters show interesting relations between countries and industries. The *Infrastructure Focused* cluster benefits from the Machine to Machine (M2M) and Machine People (M2P) interconnectivity and the collaboration among partners and customer integration into the supply chain through websites. The cluster mainly comprises Hospitality and Retail, which involve businesses that deal closely with customers and suppliers. ICT represents more than half of the *Infrastructure Leaders*

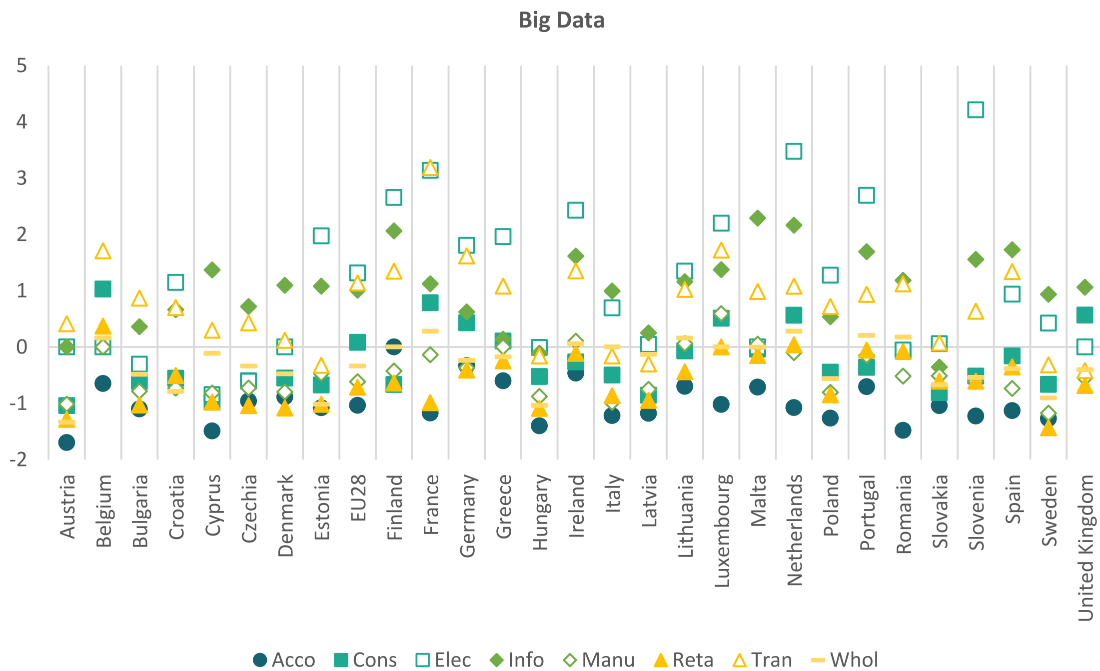

Figure A3. Big Data Factor Scores

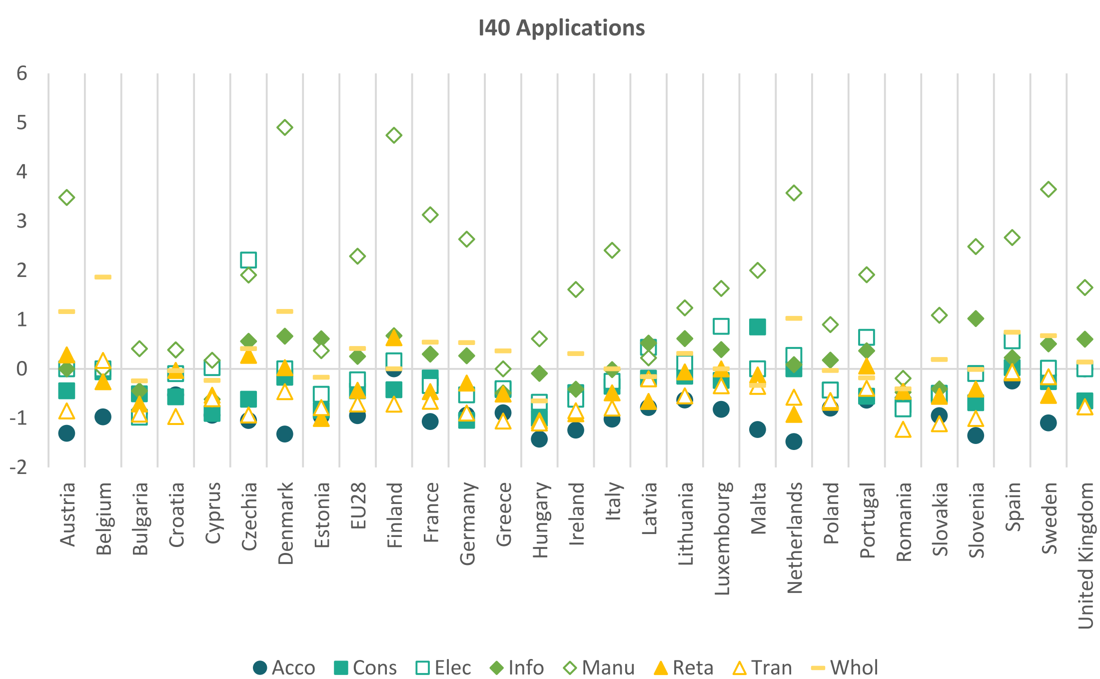

Figure A4. I40 Applications Factor Scores

cluster, which is above average in all dimensions. The *Big Data Leaders* are mainly composed of Utilities and Logistics, which benefit from BDA to optimize waste management and routes and inventory. Manufacturing is at the core of the *Applications Leaders*, as the technologies that characterize it are part of the production processes.

On a country level, there are different patterns in how EU countries implement Industry 4.0. Bulgaria, the Czech Republic, Greece, Hungary, Latvia, Poland, Romania and Slovakia have more than 50% under *Average*. Denmark, Finland, the Netherlands, and Sweden have been adapting well to the 4th IR as they have been investing not only in **I40 Infrastructure** but also in its applications. In terms of **Big Data Maturity**, Finland and the Netherlands have been taking the lead together with France and Luxembourg. The EU28 presents a higher percentage under *Average* (33%), followed by *Infrastructure Focused* and *Big Data Leaders* (22%).

5.1.3. The country/industry dichotomy

The fact that the relationship between clusters and industries is higher than the relationship between countries and industries points to a greater homogeneity among industries than among countries. Manufacturing relies on I40 Applications and Utilities and Logistics on Big Data Maturity, while ICT is in front in all dimensions, for example. These results intuitively seem to reflect each industry's structural activity for delivering either goods or services. Moreover, while the

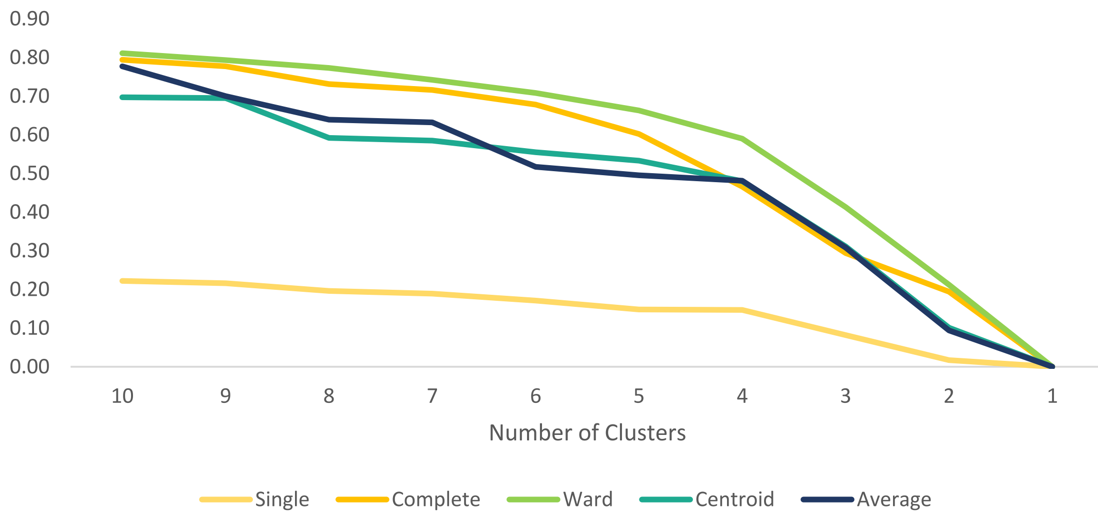

Figure A5. R-square Plot

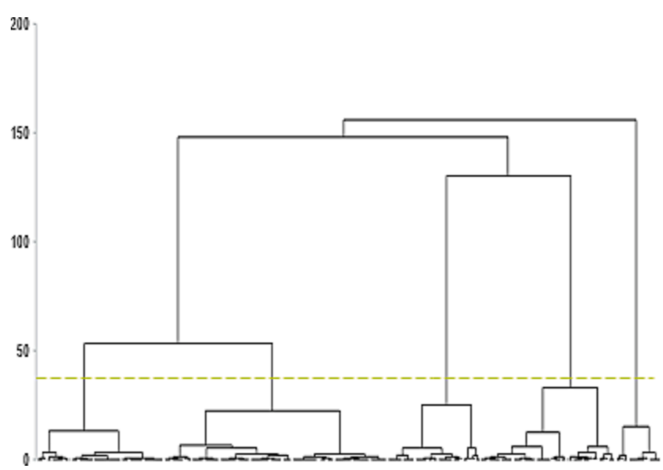

Figure A6. Dendrogram for Ward's method

explanations for the disparities among countries fall behind the scope of the present study, it seems inevitable that the structure of the economy of each country and its relative concentration in specific industries, as is the case, for example, of Germany with manufacturing, and Portugal with tourism, should determine the relative presence of each dimension.

5.2. Implications and limitations

The present study contributes to the theoretical field of knowledge on Industry 4.0 in several ways. First, it brings new evidence on the status of Industry 4.0 across the EU countries and several industries. By performing two analyses simultaneously, it was possible to understand how these different entities have embraced Industry 4.0 and their relative stance. The study also brings insights into which of the two groups – industries or countries – have had a greater impact on the existing discrepancies and similarities. Secondly, it shows that other industries beyond manufacturing are also implementing Industry 4.0 principles, thereby confirming the overlap of the term with the 4th IR, as proposed by Mariani & Borghi (2019), and admitting the possibility of referring to the implementation of Industry 4.0 to non-manufacturing. In the third place, the dimensions extracted from the factor analysis deepen the conceptualization of Industry 4.0 along with the conditions for its implementation and manifestations, contributing to the characterization of the phenomenon. In the fourth place, by including data from different industries within the same country, we noticed how misleading a simple aggregate analysis, or including just one industry, can be, which is the norm in the literature. In other words, we demonstrate that while a country might be well positioned in one industry, it might also perform

Table A2
Eigenvalues per factor and variance explained.

	Eigenvalue	Difference	Proportion	Cumulative
1	**4.22**	2.27	**0.42**	**0.42**
2	**1.94**	0.45	**0.19**	**0.62**
3	**1.49**	0.84	**0.15**	**0.77**
4	0.65	0.18	0.07	0.83
5	0.47	0.09	0.05	0.88
6	0.39	0.07	0.04	0.92
7	0.32	0.04	0.03	0.95
8	0.27	0.10	0.03	0.98
9	0.17	0.09	0.02	0.99
10	0.08		0.01	1.00

Table A1
Correlation Matrix.

	MCDS_100	HighCC	CollabPartn	Website	BD_Any	BD_Geo	BD_Own	ERP	3DPrint	Robots
MCDS_100	**1.00**									
HighCC	0.78	**1.00**								
CollabPartn	0.62	0.69	**1.00**							
Website	0.27	0.33	0.38	**1.00**						
BD_Any	0.54	0.62	0.52	0.21	**1.00**					
BD_Geo	0.20	0.18	0.10	-0.18	0.72	**1.00**				
BD_Own	0.50	0.56	0.43	0.11	0.81	0.53	**1.00**			
ERP	0.52	0.41	0.39	0.10	0.38	0.18	0.44	**1.00**		
3DPrint	0.31	0.32	0.23	0.05	0.20	-0.09	0.25	0.55	**1.00**	
Robots	0.04	-0.06	-0.14	-0.16	-0.14	-0.18	0.01	0.35	0.64	**1.00**

poorly in others. Only by using data at different levels within the same country is it possible to expose the incomplete picture provided by an analysis performed at the country level or only one industry (e.g., manufacturing), which is the standard practice in the literature. Finally, perhaps the most important finding of our study is that Industry 4.0 pervasiveness is much more driven by an organization's economic activity than by the country where that organization is located.

Contrary to the digital divide, where the country of origin plays a much stronger role than the individual's characteristics (Cruz-Jesus et al., 2012), the Industry 4.0 divide depends much more on the industry characteristics than the environment it operates. Therefore, the adoption and implementation of Industry 4.0 technologies are less constrained by the specificities of the country of origin. It should be noted that 88% of industries across the EU countries fall mostly within one cluster, a value substantially higher than the 29% of EU countries that have their industries all in one cluster. Hence, we find that the EU is far from homogeneous in Industry 4.0 and that this phenomenon is rather complex as it comprises three distinct dimensions. In other words, there is a meaningful Industry 4.0 divide across the EU. Therefore, European policymakers need to be aware that different countries and industries present their own strengths and weaknesses in the three dimensions of Industry 4.0 we found. With our results, Industry 4.0 stakeholders can draw tailor-made incentive policies for the specific country/industry combinations.

Despite the comprehensiveness of our study, some limitations must be acknowledged. Hence, this study pertains to the years 2018 and 2019, reflecting different realities separated by one year. Considering that the study examines only a specific period, it is at risk of soon becoming outdated, as the concept of Industry 4.0 has been changing rapidly. Therefore, future works should try to use longitudinal data and more lengthy time windows. Moreover, the variables chosen for analysis have a broader scope, as they were first collected to evaluate the adoption of ICT in enterprises and, thus, do not have the specific purpose of understanding the Industry 4.0 development in the EU. The comparison between industries and countries might also have been affected by the lack of some data replaced by an approximate value. Secondly, although the study strives to dive deeper into each country's industries to understand what is creating discrepancies within the EU, it does not tackle country-specific characteristics such as employment or education levels, which might influence Industry 4.0 implementation.

6. Conclusions and research directions

The present study seeks to bring insights into how European industries are adapting to the 4th IR through the lenses of Industry 4.0. A factor analysis based on the use of Industry 4.0 technologies by several industries and countries has derived three dimensions: Industry 4.0 Infrastructure, Big Data Maturity, and Industry 4.0 Applications. As expected, the relative presence of these dimensions relates to the structure of each industry's business models and each country's economic activities. In the second stage, it was possible to understand how the different EU countries and their respective industries have placed themselves compared to one another. It then became more evident that the clusters were more closely related to the industries than the countries, suggesting a higher homogeneity among industries than among countries. Thus, the study takes a step further in framing Industry 4.0, confirming its application to other industries beyond manufacturing and reflecting on how EU industries are adapting to the 4th IR.

From the findings of the study enumerated above, we identify two relevant research directions:

What are the elements driving the Industry 4.0 divide among industries? A more exhaustive investigation might identify how each industry is adapting to the Industry 4.0 paradigm. In recent years, servitization, the integration of supply chains and the development of business ecosystems have been changing business models and, in many cases, blurring the frontiers between industries. A more profound knowledge of the drivers of the Industry 4.0 divide among industries might help to understand the trends driving competitiveness at the firm and industry levels. Furthermore, the disruption in global supply chains as a consequence of the COVID-19 pandemic calls for a better understanding of how companies and industries can build resilience by developing the Industry 4.0 dimensions.

What are the elements driving the Industry 4.0 divide among countries? In an age where competitiveness is strongly associated with technological development, understanding the reasons that explain the relative presence of Industry 4.0 dimensions within countries may help to calibrate the design of innovation policies directed explicitly to industries. Policies at the country level may consider regions or activity clusters that overpass national frontiers, eventually involving international cooperation. Future research may add country-specific internal variables that might influence the level of Industry 4.0 investment. These may include the concentration level of specific industries within each country, firms' sizes, and education level. From that, researchers can derive conclusions on the best practices to enhance Industry 4.0 investment across industries and countries, achieving an even more integrated EU.

Disclosure statement

No competing interests from any of the authors.

CRediT authorship contribution statement

Isabel Castelo-Branco: Conceptualization, Methodology. **Maria Amaro-Henriques:** Data curation, Methodology. **Frederico Cruz-Jesus:** Methodology, Validation, Supervision. **Tiago Oliveira:** Validation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is public information, collected from Eurostat database

Acknowledgement

None.

Appendix

Figs. A1-A6, Tables A1 and A2.

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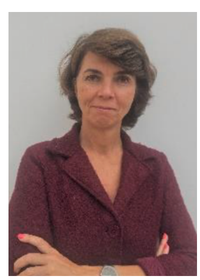

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