The Readiness of the European Union to Embrace the Fourth Industrial Revolution

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Knowledge has become a crucial factor of production in the developed economies and, as humans are the carriers and utilisers of knowledge, skilled human resource is gaining similarly large relevance. These advancements are elements of the substantial changes that characterise the fourth industrial revolution – a phenomenon worth studying in detail. The European Union has been explicitly concerned about the shift to the knowledge economy since the Lisbon Summit of 2000. More than one and a half decades later the eu's readiness to embrace the knowledge-driven fourth industrial revolution can be examined. We undertake that by creating an index based on various related data.

Key words: 4th industrial revolution, knowledge-based economy, human capital, European Union

Introduction

Change has always been an immanent feature of the economy. However, in our times, changes occur at a pace faster than ever, and are even accelerating. Also, many of the changes are disruptive. Similarly, knowledge has in fact been a factor in doing business forever. According to Dosi (2012), 'economic theory is intrinsically about knowledge-based economies' (p. 167), while Saviotti (2012) claims that we can only identify the roots of today's knowledge-based society 'in the second half of the nineteenth century with the advent of the modern university system and with the institutionalization of industrial R&D' (p. 211). Even so, knowledge has usually not been studied directly in economic theory but along connecting phenomena such as innovation (Saviotti 2012). In contemporary economics, Lundvall (1992) stated as early as in the beginning of the nineties that, in the economy as a whole, knowledge was the most important resource, and learning the most important process.

So, in our times, the role of knowledge is widening more than ever before, its importance is growing larger than before, and its creation, management and sharing is gradually but decisively transforming. This transformation is where the substantial roles of change and knowledge meet, both in economic theory, and in every-day business life. How have we gotten to this point, and where is Europe in this process now? The first industrial revolution took place in Europe though it originates in England, not from continental Europe. Since the second industrial revolution, though, the role of the main initiator has been taken over by the United States of America (USA). However, even in the USA technological advancement is posing huge challenges to maintaining employment levels (Martus 2015). The question how Europe, the European Union (EU) is (or is not) prepared to embrace or even master the changes occurring in the framework of the fourth industrial revolution can be asked. Our study addresses this question in the first place.

In order to be able to find answers to our own query, in our study we first take an overview of the phenomena often referred to by the umbrella expression of 'the fourth industrial revolution'. In our analysis, we pay special attention to two areas crucial for businesses to succeed in this new era: knowledge and human capital. We are interested in seeing how their nature and relevance as inputs to business success have altered with technological advancement, and how they can be developed and maintained by firms to remain competitive in this dynamic environment.

Afterwards, we change focus, from theory to analysis. In particular, we turn our attention to the economy of the EU as the specific subject of our investigation, i.e. how European integration as a whole is (or is not) reacting to the changes underway, and how the EU member states are performing in the areas identified as inevitable in the successful adoption to these changes.

As regards the EU member states, we also conduct a statistical analysis in order to depict a fact-based, sufficiently detailed picture of the current state of affairs in relation to the main fields of our investigation. At last, based on our analyses, we make some cautious predictions regarding the prospects for the economy of the EU in the foreseeable future.

The Fourth Industrial Revolution

The *fourth industrial revolution* (also referred as *industrial revolution 4.0* or, in Germany in particular, *Industry 4.0*) is currently the subject of debate in the economic literature as academics are trying to make reasonable projections for the future. On one hand, some argue that the fourth industrial revolution and future innovations in general do not imply such a growth potential what we have experienced in the past, for example with the generation of power (Gordon 2014). On the contrary, other theorists claim that the impacts of the fourth industrial revolution and the on-going digitalisation on innovation and growth will be ever stronger (Brynjolfsson and McAfee 2014).

The World Economic Forum (WEF) organised its 2016 Annual Meeting in Davos around the topic of the fourth industrial revolution. The director of the WEF, Schwab (2016) released his book dedicated to the topic precisely for the meeting. He takes a thorough overview of the ongoing and predicted changes in how we work, live, and do business, starting with the main affirmation that 'changes are historic in terms of their size, speed and scope' (Schwab 2016). At the same time, we have to discover that technology is not an exogenous factor in the lives of individuals and businesses; quite the contrary, it is a tool to embrace, an opportunity to grab. In particular, the fourth industrial revolution is characterised by: widespread and broadly accessible internet; smaller, cheaper and more powerful sensors; artificial intelligence; and machine learning. The drivers of the change are physical (autonomous vehicles, 3D printing, advanced robots, new materials), digital (internet of things, relationship between things, and people connected by technologies and platforms), and biological (genetic sequencing and genetic engineering, synthetic biology and biological editing).

At present, technological transformation is changing practically every aspects of economic and social life, including basic mechanisms like demand formation, capital accumulation, or employment generation (Dosi 2012). And also *market structures,* with the appearance of two- or multi-sided markets, and platform economics. Two-sided markets are the ones where there are two or more, clearly distinguishable groups of users whose demands are interdependent and therefore either or both groups produce positive externalities. At present, many industries operate as two-sided markets. In this setting, it is a platform that ensures room for interaction among the different groups, making it easier for them. Platforms play a distinctive role in reducing transaction costs.

Two-sided markets were first analysed by Rochet and Tirole (2003). Upon their classification, economic theory distinguishes four different types of *platforms* (Evans 2011, 5–9): those of exchange, the media, transaction systems, and software platforms. Nevertheless, regulation of platforms is far from advanced and is only sluggishly following markets. Regulators are still lacking new robust models so they are constrained to using traditional methods in the course of their investigations, which raises the risk of false conclusions. In particular, traditional approximations of demand tend to underestimate the size of the relevant market and thus overestimate market distorting effects.

Under the fourth industrial revolution, firms change substantially as well. They are 'no longer viewed merely as machines of transactional efficiency, bureaucratic order of labour exploitation. They are seen as repositories of competences, knowledge and creativity, as sites of invention, innovation and learning' (Amin and Cohendet 2012, 403). In fact, firms appear as a cognitive platform for interacting communities. Importantly, corporate culture is part of the common knowledge.

We are also witnessing large communities of businesses organising themselves into complete *business ecosystems*. These are 'dynamic and co-evolving communities of diverse actors who create and capture new value through both collaboration and competition' (Canning and Kelly 2015, 4). Such businesses are shaping their own business landscape, act as collective wayfinders. They share resources and they work cooperatively and competitively at the same time. Their adaptive and transformative capabilities are exceptional and, in fact, immanent. In such business ecosystems, value creation no more occurs linearly, along a value chain, but in a network structure called the value web. Ecosystems realise synergies, which makes them attractive for individual firms, be they small or large.

Knowledge and Human Capital in the Fourth Industrial Revolution

In relation to the fourth industrial revolution, there are some specific characteristics of knowledge as an asset or factor of production that are worth discussing. Firstly, knowledge has many faces. And knowledge has been approached many ways in economic theory. In the pragmatist theory of knowledge, it arises from the method of inquiry that rests on creative hypotheses and experiences. Moreover, acquiring knowledge is not an individual process but it is taking place in a collective dimension; therefore, institutions, and especially their quality, play a role (Dutraive 2012).

Amin and Cohendet (2012) identifie the so-called *knowing communities* which are triggered by the fast expansion and growing complexity of the knowledge base and the organisational challenges posed by the need to acquire and utilise knowledge within strict time limitations. In such an environment, knowing communities act as pools of various competences that can be deployed in highly flexible manners. They can be formed within traditional organisations or across old structures. Knowing communities have no clear boundaries but are kept together by individual passion on behalf of its members and commitment to the common goal. Nevertheless, economic aspects appear among the motivations of the participants. In such cooperating communities, the frequency of interactions considerably reduces opportunistic behaviour. Belonging to the community is experienced in the jointly undertaken process of validation and interpretation of the common knowledge.

Kasper, Streit and Boettke (2012) also emphasise that knowledge (and skills) are spreading in the various communities of humans, 'despite the fact that each and everyone has a limited capacity, limited resources and limited time to acquire and evaluate new information and to compound it to knowledge' (p. 46). They interpret knowledge in an exceptionally wide sense, including knowledge on where and what to buy, what new products to try out, rivals, close substitutes, product variations, production processes, organisation, communication and selling methods, possible exchange partners, etc. They also discuss the costs of the knowledge management processes and, even if not naming them as such, are mentioning platform-type actors (calling them middlemen and their activities intermediation) who urge to contribute to the reduction of those costs for their business partners. In their view, in the knowledge economy, the main functions of competition are: to find and test useful knowledge, to disperse that knowledge, and to control errors. Those suppliers win the competition that are successful in lowering their and their consumers' transaction costs, rather than production costs.

Dosi (2012) also claims that knowledge is a rather wide concept, it includes, for example, 'tacit and rather automatic skills like operating a particular machine or correctly driving a car' (pp. 171–2) and its accumulation may happen both through informal mechanism of learning by doing and also in much more formalised processes. According to Saviotti (2012), a way to grab the concept of knowledge in the economic theory framework is to accept its two properties: that knowledge is a co-creational structure, and a retrieval or interpretative structure. This way we are properly equipped to analyse the processes of knowledge creation and utilisation, even enabling ourselves to map the knowledge base of firms.

In the *knowledge-based economy,* many new aspects have to be considered by applied economic theory. If an economy is primarily knowledge based, its self-sustainable growth is rather likely (Dosi 2012). The web economy is a specific manifestation of the knowledge-based economy. The web economy can in fact be divided into four major platforms: e-commerce, online publishing, social networks, and online advertising. In comparison to regular markets, here new features appear and influence the market: the critical mass (of suppliers and/or users) is more relevant, fees are calculated in a more complex way (in fact, some user groups may eventually enjoy some products or services free of charge) than in traditional linear markets, and there is a so-called 'invisible engine' (Evans 2011) operating in these markets, catalysing trade.

In the knowledge-based view of the firm, rationality is bounded, knowledge has tacit elements and is distributed within and across firms. Transaction costs are functions of (economically relevant) knowledge, and so is value creation and value appropriation. *Knowledge assets* are eventually owned and controlled by individual agents who are becoming increasingly important to the firm. In this theoretical context, the major strategic objective of creating and maintaining competitive advantage are pursued through targeting the optimisation of these transaction costs (Foss 2005). Besides scaling economies there can be substantial learning economies and not only in relation to knowledge on the market (Church and Ware 2000) but also regarding knowledge as an asset of good in itself.

Information, knowledge, or software are not only inputs but also outputs of production (i.e. they are goods). In the context of the knowledge economy, the concept of *club goods* is interpretable (Elsner, Torsten, and Schwardt 2014), referring to the in-between status between private and public goods, i.e. when a certain group of agents have access to them. Within this group, *network goods* are the ones of which the owners construct a network – in such cases, network externalities also arise. As for knowledge itself, it can be a private or a public good but, in most of the cases, it is somewhere in-between. In this respect, we can identify two parallel tendencies: on one hand, there are strong incentives to provide access to knowledge, even if it is codified knowledge. At the same time, in part connected to the above tendency, there is also a strong push to protect intellectual property (Lundvall 1992).

In this environment, the main question is who bears the costs of development and in what way, and how the income realised on investments is distributed. Besides the usual issues of industrial organisation (pricing, effects of scale, tying, planned obsolescence etc.) new ones come up, including compatibility and interoperability, pirating, or open source as a business model (Elsner, Torsten, and Schwardt 2014). For economic modelling, even if network science methodology is applied, the two-sided markets where there are two (or more) multiple, distinct, and separable groups of actors (see above), bring further new challenges, especially as there presumably exist *network externalities* within the groups, and for the whole of the network as well.

Relevant literature identifies two models of *knowledge creation* (Lundvall 1992): in the STI model, there is a science – technology – innovation sequence occurring. In the other approach, the so-called DUI mode, it is the steps of doing – using – interaction that are taken. In Lundvall's (2012) view, 'while the output of the DUI mode may be a tangible new product with embodied technical knowledge – such as a numerically controlled machine tool – the outcome of the STI process may be disembodied knowledge that can be widely distributed. But the more codified form also makes it easier to protect this kind of knowledge through intellectual property rights in the form of patents or licenses' (p. 307).

The term *knowledge society* is not unknown in academic literature either, as it has already been described and expanded during the previous decades by notable scholars in the field, like Drucker, Mansell or Stehr (UNESCO 2005). Developing a knowledge society gained its momentum at the end of the last millennium as the information technology started to develop at such pace that the world has never experienced before. Focus turned on new industries like cybernetics, biotechnology, nanotechnology etc., areas which require an advanced level of knowledge. Soon economies recognized that having a highly skilled labour force is a necessary precondition of the establishment of a knowledge-based society. The main driver of developing the level of high-skilled labour force is sharing knowledge among members of the society. Higher education institutions and private sector enterprises are those, who can contribute the most to fostering innovation and the transition into a knowledge-based economy. Knowledge is a complex phenomenon that is influenced by education, technological development, and innovation as well.

Taking into consideration the pro and contra arguments, we can be sure that the current trends and changes will have a major impact on the *future of jobs and skills* required on the labour market, especially as it is also going through a transformation (Acemoglu and Autor 2010). For example, the boundaries of routine and non-routine tasks are pushed further by technology (Autor and Dorn 2013; Goos, Manning, and Salomons 2009). The non-routine tasks at the lower and the higher ends of the skill scale are the ones that are not likely to be automated. This may lead to the further polarization of the labour market since knowledge workers are already in more favourable positions. In fact, currently the highest potential for productivity and growth is located in the knowledge sector (European Commission 2015).

Furthermore, employment has a strong connection with *educational attainment.* As Esping-Andersen claimed, back in 2002, 'accelerating the pace towards a knowledge-intensive economy implies heavy investments in education, training and cognitive abilities. Those with low human and social capital will inevitably fall behind and find themselves marginalised in the job and career structure. It is accordingly tantamount that educational investment be as broad-based as possible' (Esping-Andersen 2002, 79). Lindley (2002) was observing that, already at that time, 'knowledge workers and the socially excluded seem destined to live in different worlds' (p. 95) and that the best tool to fight social exclusion was education. For this reason, we claim that *education* is of key importance when we talk about knowledge, skills and human capital.

The formation of future human capital is taking place today so education systems also have to adapt to current changes in order to be able to deliver the knowledge and skills required in the future. First, instead of the silo type approach in education, there is a need to develop individuals with cross-functional skills encompassing both technical and social analysing skills (World Economic Forum 2016). The skills required may vary across industries; however, the complex problem-solving ability is of growing importance in every sector. Second, the issue of skill mismatches has already been identified in the European Union (European Commission 2016) but still it is generally associated with the present state of skill gaps. In our point of view, what raises more concern is that the skills acquired or being taught today are not matching the skills demanded in the future.

Technology is at the same time the trigger and the enabler of transformation in education. The new skills and competences required in the labour market of the future can be developed by integrating technology into education. Besides the basic digital skills, students have to acquire programming and advanced computing skills, learn how to use big data and how to utilise online learning platforms for sharing knowledge (OECD 2016).

However, the *human capital* present in the labour market today should also be maintained. Businesses and their managements have a great responsibility in upskilling and reskilling the current labour force by encouraging life-long learning and providing on-the-job training. Maintaining human capital should be a priority for businesses if they wish to survive under the fourth industrial revolution. Moreover, investment in skills and human capital is also associated with higher levels of competitiveness (Pelle and Laczi 2015).

The European Economy at the Verge of the Fourth Industrial Revolution

The European Council agreed in March 2000 in Lisbon that: 'The European Union is confronted with a quantum shift resulting from globalisation and the challenges of a new knowledge-driven economy. These changes are affecting every aspect of people's lives and require a radical transformation of the European economy. The Union must shape these changes in a manner consistent with its values and concepts of society and also with a view to the forthcoming enlargement.' (European Council 2000) Accordingly, the strategic goal was set for the 2000–2010 period, name that the EU should 'become the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion.' (European Council 2000) Already at the time of the Lisbon presidency of the EU in the first half of year 2000, the main question was how knowledge was going to shape Europe's future and experts agreed that Europe was on the crossroads whether to maintain a leading position in the global economy or losing relevance (Rodrigues 2002).

The strategic goal of the Lisbon strategy was reaffirmed and renewed with the adoption of the Europe 2020 strategy in March 2010 (European Council 2010). According to the Europe 2020 strategy, the EU should realise smart, sustainable and inclusive growth (these are the priorities) in the second decade of the 21st century. To this end, measurable targets were set in the fields of the three priorities. In May 2015, the European Commission published the Digital Single Market strategy and set out 16 initiatives to make it happen.[1] Among these, we can find provisions on fostering the digital business environment, making e-commerce easier, modernising copyright law, analysing online platforms, and ensuring digital privacy and cyber security.

To see how prepared the European Union is for the arrival of the fourth industrial revolution, we examined some indicators that show R&D and innovation-related performance, and the availability of skilled human capital.[2] First, taking Eurostat data for gross national research and development expenditures (GERD) from the year 2014, we can see that German GERD is far beyond the other EU Member States (a total of 82,866 million EUR). However, taking size differences into account, GERD expenditures as a total cannot be compared directly. Instead we took the GERD per capita values for the year 2014 as the last available data. In this respect, the three Northern member states are the best performers, then come five out of the six founding member states, Italy being an exception. Western countries, and also Austria and Slovenia, are in the mid-range as well. The major Southern Eurozone countries (Spain, Portugal and Italy) seem to perform slightly better than Eastern new member states but are still lagging behind their Western neighbours.

This indicates a clear distinction to be drawn between the Western member states and those countries that joined the EEC/EU later, the majority of them being referred to as new member states. In 2014, Denmark spent 1,413 EUR per inhabitant on research and development, this being the highest among the 28 member states. Denmark is followed by fellow Northern countries Sweden and Finland, then Austria, Luxembourg, and Germany as well, also spending more than 1,000 EUR per capita on R&D. The worst performers are Romania, Bulgaria and Croatia, with a difference between them and the best performers being more than 1200 EUR per capita.

Fostering innovation and encouraging research and development has been a priority of the EU since the Lisbon strategy. Connected to the Europe 2020 strategy, a flagship initiative called Innovation Union has been launched. As part of the five main targets of the strategy, an overall goal of R&D spending to reach 3% of EU GDP was set (European Commission 2016). If successful, this initiative and the Digital Single Market agenda together are to make the desired goal of the EU becoming the most competitive economy of the world finally reached. R&D and innovation, often referred to as R&D&I, contribute to the functioning of a well-established knowledge-based society which in the long run could benefit not only European businesses, but governments as well, and would improve living conditions and provide further opportunities: more jobs or better social services for citizens.

But still, halfway through the Europe 2020 programme, the desired goals have not been realised yet, and regional differences mentioned above persist, making the core and the periphery diverge further away from each other. Western Member States seem to be able to reach the 3% goal in R&D expenditures, and Northern countries like Sweden, Finland and Norway have Falready surpassed it. Still, new member states and the Southern Eurozone countries show generally lower performance and, in their cases, the national target is adjusted lower as well, taken into account their circumstances and current state of affairs. The fact that even the headline indicator was set lower for the majority of the countries in the periphery indicates that these countries might not be able to catch up with the fast technological development, not even in the future.

The number of patent applications to the European Patent Office (EPO) shows one aspect of the innovative performance of a country. The latest available data for the number of patent applications per million inhabitants is from 2013. On average, 113.27 patent applications were submitted to the EPO per million inhabitants; however, the divide between the core and the periphery is, again, vast. While Sweden, as the best performer, had 301.97 patent applications per million inhabitants, the latest joining member states, Croatia, Bulgaria and Romania all have less than 5 per million citizens. New member states, with Slovenia being an exception again, generally submitted less than 30 patent applications per million inhabitants to the EPO in 2013.

The number of R&D personnel in full-time equivalent is not a good indicator to be compared directly either but the rate of R&D personnel as a percentage of the active population makes data comparable and also shows how much effort a country puts into developing a steady base of human capital to improve its research and development performance. The same pattern as explained above can be noticed in this case as well: the ratio of R&D personnel measured in full-time equivalent as a percentage of the active population in 2014 is the highest among Western and Northern countries, with Denmark having 2.02%, followed by Finland, Luxembourg, Sweden, and the old member states. Slovenia ranking 7th among them with 1.46% is again the exception from the new member states that have generally lower rates, most of them below 1%.

Another challenge Europe is facing is the transformation towards the knowledge-based economy. As universities and higher education institutions drive innovation in Europe, one target within the education-related initiatives of the Europe 2020 strategy is that, by

2020, more than 40% of the population aged 30–4 should have a tertiary education degree. It is a promising fact that, by 2014, the majority of the Member States were above 30%, and more than half of them already reached the 40% goal and have been working to reach higher goals (Eurostat 2015). In this case, the previous pattern of core and periphery diverging cannot be observed: from the old member states, Italy is the one that has the lowest rate with 23.9% and is also the last from all the EU member states. However, Germany is also among those performing the lowest rates, far below the EU28 average (37.9%) while, from the new member, states Lithuania and Cyprus, both having a level above 50%, manifest that, for tertiary education attainment, Eastern countries are able to perform just as well as their Western and Northern neighbours.

Almost all the mentioned indicators show that the core and the periphery of the EU are far from reaching the same development level towards building a well-functioning knowledge-based economy. In fact, this divergence remains an urgent problem that the EU has not been able to tackle so far. There are some exceptions, namely Slovenia and the Baltic states, that have succeeded in realising convergence towards Western European levels: Estonia has introduced e-Residency, a transnational digital identity[3] to unleash the country's full business potential while Slovenia has carried out serious ICT investments and has made huge efforts to turn the vision of the knowledge economy into reality (Bučar 2006; 2011). However, regional differences in the majority of the region continue to persist and, in fact, the gap between the core and the periphery has deepened even more in the aftermath of the financial crisis, now merging the group of the Southern Eurozone countries and the Eastern new member states into one group: the periphery (Pelle 2015).

Data Analysis

In order to discover EU member states' readiness for the fourth industrial revolution, we introduced a new index based on Eurostat data, called *Industry 4.0 Readiness,* and also carried out a cluster analysis to reveal territorial differences among the member states. In creating the new index, we followed the methodology the World Economic Forum uses to generate new indices based on the calculation of secondary indices (World Economic Forum 2013). The calculation is carried out according to the following formula:

$$\frac{\textit{country value} - \textit{sample minimum}}{\textit{sample maximum} - \textit{sample minimum}}. \qquad (1)$$

TABLE 1 Indicators Used to Create Industry 4.0 Readiness Index

Name of indicator	Unit of measurement
(a) Total intramural R&D expenditure (GERD)	Euro per inhabitant
(b) Gross domestic expenditure on R&D (GERD)	Percentage of GDP
(c) Community trade mark (CTM) applications	Per million inhabitant
(d) Community design (CD) applications	Per million inhabitant
(e) Total R&D personnel and researchers	Percentage of active population – numerator in full-time equivalent (FTE)
(f) Tertiary educational attainment	Percentage of age group 30–4
(g) ICT specialists	Percentage of total employment
(h) Digital single market – promoting e-commerce for businesses, enterprises selling online	Percentage of enterprises

We used 2014 data from the Eurostat database (as latest available), and chose indicators that are closely related to the innovative performance and development of the countries. We were keen on finding indicators to represent all fields introduced in this study; however, for one indicator, the number of patent application to the EPO, no 2014 data were available so we had to omit that dimension from our analysis. Our *Industry 4.0 Readiness* index thus consists of 8 indicators (tables 1 and 2).

While forming our new index, first, we calculated secondary indices based on the above introduced formula and then, as a result, created values that lie between 0 and 1 for all indicators (this comes from the very nature of the applied formula) where 0 represents the country with the lowest value in that sample and 1 being the best performer. As the next step, we took the simple average of the values and created the final *Industry 4.0 Readiness* index (table 3). Unfortunately, in the case of Croatia, data were not available for the ratio of enterprises selling abroad so we could not set up the index for Croatia. For the other 27 countries, after having the index calculated, we sorted them from highest to lowest in order to show which country is the best prepared for the upcoming challenges of the fourth industrial revolution (furthest right column of table 3). We also made a visual representation of the data (figure 1). The outcome of our analysis confirmed our prior expectations of Northern and Western countries being better prepared for the upcoming technological and innovation challenges.

To further underpin our assumptions of the territorial differences in this respect, we carried out a cluster analysis. From the above used

TABLE 2 Components of Industry 4.0 Readiness Indicator and EU Member States' Performance along These, 2014

Country	Raw indicators							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
EU28	558.4	2.03	163.03	30.92	1.14	37.9	3.66	17
Sweden	1411.3	3.16	269.88	59.82	1.61	49.9	6.00	25
Luxembourg	1117.4	1.24	2279.50	191.02	1.94	52.7	5.09	7
Denmark	1413.0	3.08	269.23	77.48	2.02	44.9	3.86	26
Finland	1194.6	3.17	191.33	58.15	1.95	45.3	6.66	15
Belgium	881.3	2.46	185.47	34.09	1.38	43.8	4.39	23
Austria	1155.9	2.99	342.19	58.89	1.54	40.0	3.77	13
Ireland	623.5	1.55	223.86	22.15	1.16	52.2	4.62	27
Germany	1026	2.84	231.10	43.48	1.43	31.4	3.68	23
Netherlands	776.9	1.97	236.31	49.79	1.38	44.8	4.96	13
United Kingdom	595.9	1.72	183.09	27.90	1.19	47.7	4.87	20
Slovenia	431.9	2.39	168.84	50.46	1.46	41.0	4.78	14
France	730.7	2.26	113.71	27.04	1.47	43.7	3.47	12
Czech Republic	294.0	2.00	85.80	24.45	1.22	28.2	4.12	27
Estonia	217.3	1.46	231.03	23.56	0.86	43.2	4.95	12
Spain	273.6	1.20	188.51	19.69	0.87	42.3	3.09	17
Malta	158.3	0.85	898.01	56.42	0.82	26.5	4.58	16
Lithuania	125.6	1.02	76.78	12.57	0.76	53.3	1.94	18
Hungary	144.7	1.38	53.35	7.09	0.84	34.1	4.85	10
Cyprus	96.4	0.47	490.68	27.97	0.29	52.5	2.37	10
Portugal	213.8	1.29	122.75	18.89	0.90	31.3	2.47	14
Poland	101.6	0.94	84.78	34.27	0.60	42.1	3.05	10
Slovakia	123.6	0.89	61.30	10.89	0.65	26.9	4.10	12
Italy	341.7	1.29	152.17	33.63	0.97	23.9	2.51	5
Greece	135.6	0.83	72.36	4.22	0.90	37.2	1.31	9
Latvia	81.3	0.68	79.94	14.99	0.58	39.9	2.03	7
Bulgaria	46.3	0.80	92.47	14.91	0.57	30.9	1.88	6
Romania	28.8	0.38	29.18	3.01	0.34	25.0	2.65	7
Croatia	80.0	0.79	30.14	4.24	0.53	32.2	2.85	n.a.

NOTES For names of indicators and units of measurement see table 1 above.

8 indicators, we had to leave Community Trademark and Community Design applications out of the examination as the outlier values of Luxembourg and Malta distorted the cluster creation process. Accordingly, we created our clusters considering the remaining 6 main indicators. As a result of our analysis, we succeeded in setting up 4 clusters that all have their distinctive features (tables 4 and 5).

The first cluster represents the most innovative and developed

TABLE 3 Industry 4.0 Readiness indicator, EU Member States, 2014

Country	Secondary indicators								Industry 4.0 Readiness	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	Score	Rank
Sweden	0.998772	0.996416	0.106962	0.302165	0.763006	0.884354	0.876636	0.909091	0.72968	1
Luxembourg	0.786447	0.308244	1.000000	1.000000	0.953757	0.979592	0.706542	0.090909	0.72819	2
Denmark	1.000000	0.967742	0.106673	0.396096	1.000000	0.714286	0.476636	0.954545	0.70200	3
Finland	0.842219	1.000000	0.072056	0.293282	0.959538	0.727891	1.000000	0.454545	0.66869	4
Belgium	0.615879	0.745520	0.069452	0.165310	0.630058	0.676871	0.575701	0.818182	0.53712	5
Austria	0.814261	0.935484	0.139095	0.297218	0.722543	0.547619	0.459813	0.363636	0.53496	6
Ireland	0.429634	0.419355	0.086512	0.101803	0.502890	0.962585	0.618692	1.000000	0.51518	7
Germany	0.720416	0.881720	0.089729	0.215255	0.658960	0.255102	0.442991	0.818182	0.51029	8
Netherlands	0.540457	0.569892	0.092044	0.248817	0.630058	0.710884	0.682243	0.363636	0.47975	9
United Kingdom	0.409695	0.480287	0.068394	0.132387	0.520231	0.809524	0.665421	0.681818	0.47097	10
Slovenia	0.291215	0.720430	0.062062	0.252380	0.676301	0.581633	0.648598	0.409091	0.45521	11
France	0.507080	0.673835	0.037563	0.127812	0.682081	0.673469	0.403738	0.318182	0.42797	12
Czech Republic	0.191591	0.580645	0.025161	0.114036	0.537572	0.146259	0.525234	1.000000	0.39006	13
Estonia	0.136180	0.387097	0.089698	0.109303	0.329480	0.656463	0.680374	0.318182	0.33835	14
Spain	0.176853	0.293907	0.070803	0.088719	0.335260	0.625850	0.332710	0.545455	0.30869	15
Malta	0.093556	0.168459	0.386090	0.284081	0.306358	0.088435	0.611215	0.500000	0.30477	16
Lithuania	0.069932	0.229391	0.021152	0.050848	0.271676	1.000000	0.117757	0.590909	0.29396	17
Hungary	0.083731	0.358423	0.010741	0.021701	0.317919	0.346939	0.661682	0.227273	0.25355	18
Cyprus	0.048837	0.032258	0.205081	0.132759	0.000000	0.972789	0.198131	0.227273	0.22714	19
Portugal	0.133651	0.326165	0.041581	0.084464	0.352601	0.251701	0.216822	0.409091	0.22701	20
Poland	0.052594	0.200717	0.024707	0.166268	0.179191	0.619048	0.325234	0.227273	0.22438	21
Slovakia	0.068487	0.182796	0.014273	0.041913	0.208092	0.102041	0.521495	0.318182	0.18216	22
Italy	0.226051	0.326165	0.054654	0.162864	0.393064	0.000000	0.224299	0.000000	0.17339	23
Greece	0.077156	0.161290	0.019188	0.006436	0.352601	0.452381	0.000000	0.181818	0.15636	24
Latvia	0.037928	0.107527	0.022557	0.063720	0.167630	0.544218	0.134579	0.090909	0.14613	25
Bulgaria	0.012643	0.150538	0.028125	0.063295	0.161850	0.238095	0.106542	0.045455	0.10082	26
Romania	0.000000	0.000000	0.000000	0.000000	0.028902	0.037415	0.250467	0.090909	0.05096	27
Croatia	0.036989	0.146953	0.000427	0.006542	0.138728	0.282313	0.287850	n.a.	n.a.	n.a.

NOTES For names of indicators and units of measurement see table 1 above.

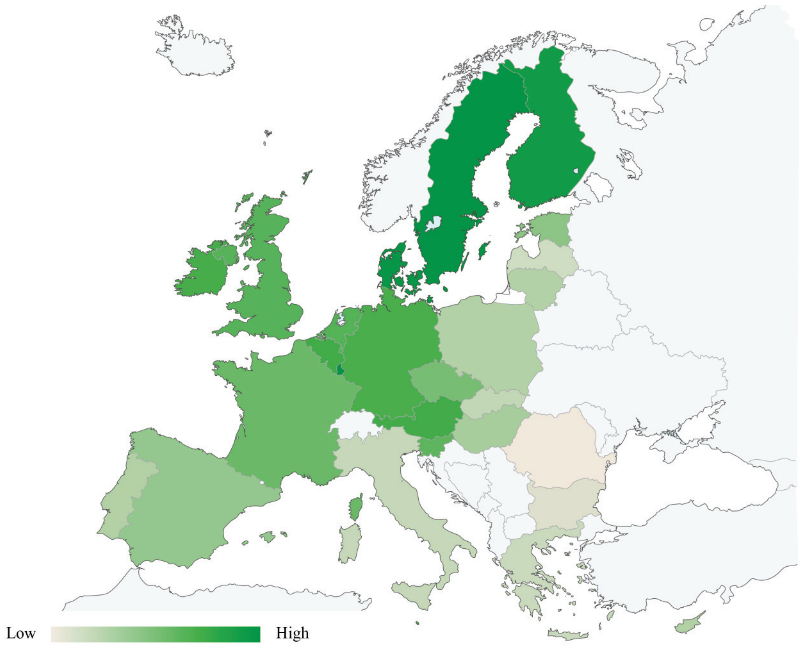

FIGURE 1 Industry 4.0 Readiness, EU Member States, 2014 (OpenHeatMap based on authors' calculations)

TABLE 4 Cluster Division

Cluster	Member States
1st	Belgium, Denmark, Germany, Austria, Finland, Sweden
2nd	Bulgaria, Estonia, Croatia, Italy, Hungary, Malta, Romania, Slovakia
3rd	Czech Republic, Ireland, France, Luxembourg, Netherlands, Slovenia, United Kingdom
4th	Greece, Spain, Cyprus, Latvia, Lithuania, Poland, Portugal

countries, with outstanding values in all indicators. In 2014, member states in this cluster spent on average 1180.35 Euros per inhabitant on research and development, total R&D expenditures being at average 2.95% of GDP. The ratios of R&D personnel and ICT specialists are also the highest in this group, indicating that these countries are on the best way towards a well-established and well-functioning knowledge-based economy and society. The rate of online trading enterprises was 20.83% on average, again the highest among the clusters.

The second and the fourth clusters show similar characteristics, primarily by performing the lowest values. Nevertheless, the two

TABLE 5 Cluster Characteristics

Characteristics	Cluster			
	1st	2nd	3rd	4th
Total intramural R&D expenditure (GERD), euro per inhabitant	1180.3500	142.5875	652.9000	146.8429
Gross domestic expenditure on R&D (GERD), percentage of GDP	2.9500	0.9800	1.8757	0.9186
Total R&D personnel and researchers as percentage of active population – numerator in full-time equivalent (FTE)	1.6550	0.6975	1.4029	0.7000
Tertiary educational attainment, percentage of age group 30–4	42.5500	30.3375	44.3286	42.6571
ICT specialists, percentage of total employment	4.7267	3.5463	4.5586	2.3229
Digital Single Market – promoting e-commerce for businesses, enterprises selling online, percentage of enterprises	20.8333	8.5000	17.1429	12.1429

clusters face different challenges: while both of them have similarly low gross domestic R&D expenditures, in the second cluster, tertiary educational attainment on average is about 12 percentage points lower than in the fourth cluster, the rate of enterprises trading online and the rate of R&D personnel are also the lowest, indicating that they are lacking high skilled human capital. Countries with the lowest *Industry 4.0 Readiness* values belong to the second cluster. At the same time, members of the fourth cluster struggle with the lack of ICT specialists but, at the same time, they perform better regarding tertiary education attainment, the group average even exceeding the best performing group's mean tertiary education attainment value. Thus, we can say that countries in the fourth cluster are at least showing commitment towards development. (Answering the question in what way Greece and Spain have arrived in this cluster is outside the scope of this study but, at first site, their current position may be the result of diminishing readiness, instead of development.)

The third cluster represents Western Europe and, as we can see, Slovenia and the Czech Republic also belong to this group. This cluster can be considered as a follower of the first cluster, with just slightly lower mean values, except for tertiary educational attainment, which is the highest among all clusters. Member states in this cluster can be considered as having a sufficient supply of highly skilled labour, yet do not paying as much attention to investing in research and development as their Northern neighbours.

To conclude the data analysis, we confirm our assumptions of the existence of territorial differences. However, instead of a core and a periphery, we could compose four distinct clusters: the North, the West, the East, and the South. The North and the West show similarities but differ slightly in the intensity in research and development expenditures while the East and the South also share common features but differ in the availability of highly skilled labour force.

Conclusions

We are living in a time of substantial changes. Knowledge, technology and new business models are shaping our present and future. Adaptability, preparedness, and responsiveness are key ingredients to success, not only at the level of individuals and businesses, but also for countries or economic blocs as the European Union itself.

According to our analysis, the EU as a whole is performing acceptably well to meet the challenges posed by the fourth industrial revolution. However, if we go to the level of individual member states, we can identify vast differences among them in this respect. Our *Industry 4.0 Readiness* indicator and our cluster analysis have also highlighted these differences. According to the latter, the EU is divided into four distinctive groups of countries: a North (being the most prepared for the changes), a West, a South, and an East. The tendencies are not showing in the direction of convergence or homogeneity, implying that policy action would be needed to scale up the periphery in order to avoid even more serious fault-lines within the EU.

Notes

1 See http://europa.eu/rapid/press-release_IP-15-4919_en.htm
2 All data in this section can be found at http://ec.europa.eu/eurostat/web/europe-2020-indicators/europe-2020-strategy/headline-indicators-scoreboard and at http://ec.europa.eu/eurostat/web/science-technology-innovation/data/main-tables
3 See https://e-estonia.com/e-residents/about/

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