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THE ROLE OF ICT IN SMART SPECIALIZATION OF EU REGIONS

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Abstract. The aim of the paper is to answer the overriding question what is the role of ICT in implementation of smart specialization (SS) in EU regions (NUTS2 level)? This role can be dual and ICT is considered in this study both as an invention which has led to the emergence of new sector, and from the perspective of general purpose technology (GPT) properties where ICT plays the role of input in innovation process. There are used following methods and techniques: desk research, descriptive statistical analysis, the correlation measure and Hellwig's method of taxonomic analysis. The main findings indicate that in practice SS in ICT is not focused on development ICT as invention and is not based on readiness to usage of ICT as GPT. However, the abilities of regions to take advantage of ICT as a driver of innovation (as GPT) are materially related to specialization in the ICT sector (development ICT as invention). The findings bring some improvements by evidence-based policy making. The research contribute to the better understanding of the innovation determinants during digital transformation and especially the base of specialization in ICT as GPT under SS assumptions.

Keywords: ICT, smart specialization, general purpose technologies, EU regions, sectoral specialization, innovation, taxonomic analysis.

JEL Classification: R12, F15, O33, O52.

Introduction

In times of pervasive technological revolution and transformation to a new model of digital economy, the prioritization of ICT and usage of its full potential is apparent. The EU has also recognized that ICT, and more generally digitalization, is a key driver of improvements in productivity, further economic growth and job creation, and member states should therefore more broadly reap the benefits of these technologies (Van Welsum et al., 2013). It was also found that the main cause of the low and deteriorating competitiveness of the EU, especially against the US, has been the failure to effectively adopt and exploit ICT (Van Ark, 2014).

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After certain difficulties in reaching the goals of subsequent strategies, the EU proposed new unusual idea of smart specialization (SS) which has become a tool of policy. The existence of regional Research and Innovation Strategies for Smart Specialization (RIS3) is a prerequisite for receiving funding from the European Cohesion policy. The focus on ICT emerges from its special role in digital transformation underpinning development and due to its properties as GPT which underlies the idea of SS.

SS itself is interpreted as quite different in relation to traditional (industrial or sectoral) specialization, and is aimed at selection of kinds of activities, which have ex ante competitive advantage and are based on available resources as well as eliminating bottlenecks by filling in missing assets or capabilities (Foray et al., 2009). Radosevic et al. (2017), who consider SS from the innovation and industrial policy aspect, labelled it "new industrial innovation policy" as a blend of sector-based industrial policy and horizontal innovation policy. Foray (2016) placed RIS3 as a one of the new industrial policies in the field of sector-non-neutral innovation policy.

The logic behind concept of SS is connected with GPT properties of ICT (Foray et al., 2009). These technologies have led to the emergence of a new economic sector producing ICT and to the transformation of traditional sectors by implementation of ICT (i.e. adoption, adaptation and application). So, ICT can be considered as output and input of innovation and production processes. However, ICT as a source of innovation and production factor should be complemented by others, mainly human capital.

The process of innovation based on the GPT properties offers a wide range of possibilities resulting from ICT utilisation or "co-invention by applications". So, the SS could be a tool for high developed regions as well as lagging behind ones. Taking into account sectoral and regional dimension of SS and the critical role of ICT in the development process, it can be expected that all EU regions could choose ICT as SS. However not all regions selected ICT as a priority in their RIS3.

Given that SS is a huge experiment in the creation and implementation of innovation and development policies during the digital transformation process occurring in the whole economies, the general research question is: what is the role of ICT in SS implementation in EU regions? ICT is considered here both as an invention, i.e. output of the research, development and innovation process (Edquist & Henrekson, 2006; Karlsson et al., 2010; Rajaraman, 2018; United Nations Conference on Trade and Development [UNCTAD], 2018) which has led to the emergence of new sector (called ICT sector), and as a GPT, i.e. knowledge which works as an input in innovation process, what is called "co-invention of application" in RIS3 (Bresnahan, 2002; Rosenberg & Trajtenberg, 2004; Liao et al., 2016). To find the answer to the main question, it has been broken down into three detailed questions:

RQ1: Is SS in ICT different from traditional sectoral specialization?

RQ2: Is SS in ICT based on readiness to usage of ICT as GPT?

RQ3: Is the readiness to application of ICT as GPT related to traditional sectoral specialization in ICT?

The study is carried out at the NUTS2 regional classification level and recognizes ICT as the aim of RIS3 prioritization and the area of smart and industry specialization. The regional NUTS2 level is the principal and most appropriate tool for analysis of RIS3 formulation and performance in the EU. This is also due to the fact that EU structural funds are mostly targeted at this level of NUTS regions.

The relations between SS and traditional sectoral specialization, and potentially dual role of ICT in the SS during digital transformation is the field of study where the research gap has been identified. This paper fills in the existing gap and brings a contribution to understanding the base of specialization in ICT as GPT under SS assumptions. According to the best knowledge of authors, aforementioned issue has not been considered at regional level yet. The research is focused on the foundations of the SS concept being applied in practice, and at the same time the pursuit of a better understanding of the contribution of RIS to improvement of innovation in the EU.

The paper is structured as follows. First, it gives the theoretical foundation of the concept of SS in ICT from the perspective of GPT properties and examines the capability of regions to effectively utilize ICT as an input in innovation process. In the Section 2 the methodology is elaborated. The diversified research methods are applied: Hellwig's method of taxonomic measure (multivariate comparative analysis) to construct composite indicator of the readiness to application of ICT as GPT and to group of EU regions by their similarity; statistical correlation technique to test the relationship between readiness to application of ICT and specialization in the ICT sector, as measured by the Balassa index of revealed comparative advantage (RCA). The empirical research is undertaken in the Section 3. Finally, discussion, conclusions and policy recommendation are formulated.

1. ICT as a priority in the smart specialization strategy – the literature review

Although SS became a keyword of European policy, its theoretical foundations are scarce. Different approaches to SS in the academic literature have been analysed by Lopes et al. (2019). The difficulties in interpretation of SS emerged from its complexity and the fact that the author(s) of the SS concept did not embed it within any theory. SS is considered in the literature in the context of very diverse fields, including economic geography, development studies, science policy as well as industrial, innovation, sectoral, technology, and regional policies (McCann & Ortega-Argilés, 2015; Radosevic et al., 2017). The numerous studies has focused on SS and has elaborated the assumptions, the essence and expected results, although questions about many aspects of RIS3 are still being asked (e.g. Karo & Kattel, 2015; Rodríguez-Pose & Wilkie, 2015; Hassink & Gong, 2019; Foray, 2019; Benner, 2020). Capello and Kroll (2016) indicate some initial weaknesses in the practical implementation of SS strategy and possibilities for overcoming them. However these revisions change the background of SS to some extent. The drawbacks as well as positive experiences with the SS strategy designation are also described by Kroll et al. (2014). Lundström and Mäenpää (2017) indicate the complexities and challenges of the SS process at a regional level, building on the wicked games theory. Moreover, Gianelle et al. (2020) point to the circumvention of the selective rationale of SS in practice. The aforementioned discussion shows that the fundamentals of SS, its formulation and results of its implementation are still under recognition.

A neglected area in studies on SS is the very background of the concept based on GPT properties, and its meaning for current innovation systems. It should be stressed that GPT are inputs in many or even all sectors and are labelled as an "enabling technologies" with the potential for inducing innovation across the whole economy. The theoretical models of GPT (Bresnahan & Trajtenberg, 1995; Lipsey et al., 2005; Bresnahan, 2010) show that the application of GPT-related innovation has an exponential effect and a dynamic feedback mechanism that triggers investment in R&D throughout the economy, while also having general transformative effects. However, GPT are partially regarded as a "public good" due to their vast scope of application. Therefore, there are not enough incentives for the private sector to invest in this field.

The nature of ICT as GPT and their role in innovation, combined with the SS concept, give rise to the question about the desired shape of policy directed at "smart growth". Some researchers indicate that efficient knowledge exchange is positively connected with geographical proximity (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Braczyk et al., 2004; Corradini et al., 2021) and with relatedness among technological domains (Crespo et al., 2017). Balland et al. (2019) prove that innovation policy based on the SS concept should encourage all regions to develop related technologies that are more complex than already existing ones. This requires a stronger and more active policy focused on education, research and strategic investment. This could be mission-oriented R&D (Mazzucato, 2018) and a human capital (Corò & Volpe, 2020) policy rather than a mix of sectoral-horizontal policies, that is SS strategy.

Moreover, Boschma (2009) elaborates many requirements for innovative development, which besides knowledge creation and knowledge spillovers, includes the critical mass of organizations and their interactions (Gaspar & Glaeser, 1998). This is a rather systemic approach which makes reference to path dependence, potential and bottleneck issues. Other research (Cortinovis & Oort, 2015) suggests that favouritism for a certain variety, as under RIS3, has discriminatory effects, and a better option for regional development is overall promotion of R&D and entrepreneurship.

ICT does not always promote regional convergence as less populated, peripheral and poorer regions have problems related to insufficient demand, resulting in delays in the implementation of new services. These regions are also characterized by poor social and economic networks. The negative effects of the insufficient use of ICT, the divergence process, are therefore observable instead of the commonly recognized convergence process (de Castro & Jensen-Butler, 2003). ICT affects inequalities as its later implementation in peripheral regions results in social and spatial inequalities (Jakobi, 2012; Barzotto et al., 2020).

According to GPT properties, ICT are radical technological innovations with general applicability (pervasiveness), technological dynamism and innovative complementarities (input for further/subsequent innovation) (Rosenberg & Trajtenberg, 2004) Taking into account the nature of ICT, their usage as GPT requires specific conditions and depends on absorptive capacity. The determinants of adoption and widespread diffusion of ICT are multiple. Thus, the role and effects of ICT depend not only on development and specialization in ICT sector, but also on regions' readiness to usage of ICT as a driver of innovation (in the RIS3 called "co-invention of applications").

2. Research design, methods and data

In the introduction, the main research question and three detailed questions were formulated. During the research process an attempt has been made to find the answers to these questions, which will lead to a better understanding of the role of ICT in SS implementation in EU regions.

In the first step, the regions which have selected ICT as a priority of their RIS3 were identified. To do this, the EYE@RIS3 tool on the Smart Specialisation Platform (Smart specialization platform, 2020) was employed. The "ICT" keyword is used as a search filter and entered in the "Title/Description of Priority" selection box.

With regards to the first research question (RQ1: Is SS in ICT different from traditional sectoral specialization?), the study was based on smart specialization assumptions, which indicate that prioritizing in the smart specialization strategy (S3) is not necessarily based on industry specialization in the sector in question. So, the hypothesis was formulated (H1) that SS in ICT is not related to ICT sector specialization in practice. This means that SS in ICT is not commonly targeted towards development of ICT inventions.

To determine a region's industry specialization in the ICT sector, the Balassa index of revealed comparative advantage (RCA) was used (Hinloopen & Van Marrewijk, 2001). It is calculated here as the ratio of the share of employment in the ICT sector in a given region to the same share for the EU28 as a whole. An RCA index value above 1 means that a region is specializing in the ICT sector (has a revealed comparative advantage), while a value below 1 denotes that the ICT sector in a given region is weak (its size in terms of employment is smaller than the EU28 average) and reveals a comparative disadvantage.

The definition of the ICT sector refers to the one introduced by the OECD (2007, p. 15). This uses a general principle to identify ICT industries, which states that "*the production (goods and services) of a candidate industry must primarily be intended to fulfil or enable the function of information processing and communication by electronic means, including transmission and display*". It indicates particular industries (based on ISIC Rev. 4) from the manufacturing, trade and service sectors. However, this harmonized definition is relatively broad, and if the ICT sector is to be studied in more detail, a narrower meaning is often used. This research is carried out at the NUTS2 level and depends on the Eurostat regional statistic database, which does not have the necessary disaggregated data to take account of all ICT economic activities included in the aforementioned comprehensive definition. Therefore, the operational definition of the ICT sector adopted for this study uses the information and communication section (J) according to NACE Rev. 2 classification as an approximation for the whole sector. This limitation should not influence the assessment because industries belonging to this section together account for 81% of the total value added of the whole ICT sector in the EU28, and 78% of its employment (Mas et al., 2017, p. 105).

RQ1 is tested using descriptive statistics tools in the next section.

According to RQ2 (Is SS in ICT in EU regions based on readiness to use ICT as GPT?), the hypothesis was formulated (H2) that regions which selected ICT as SS strive to take advantage of ICT for "co-invention of applications", therefore have similar characteristics as regards readiness to application of ICT as GPT. To test this, Hellwig's method of taxonomic analysis (Hellwig, 1968, 1972) has been used. This method is a kind of multivariate comparative analysis (MCA) and assumes that the examined complex phenomenon can be described by specific features (characteristics) which are either dependent or interdependent (Balicki, 2009; Mierzwa, 2017). Hellwig's method includes the construction of composite indicator, linear ordering according to the value of this synthetic measure and enables classification (grouping) of objects by their similarity (distance from the template object). Taxonomic method is used in many areas and especially in economics to measure socio-economic development, competitiveness and other complex phenomena (Balcerzak, 2016) which is the readiness to application of ICT as GPT across EU regions. This aggregate is not directly measurable and is described by multiple characteristics.

To construct a composite indicator of the readiness to apply ICT as GPT, a set of 22 detailed diagnostic variables has been chosen. They are described and their rationale is explained in Table 1. The selection of these variables is adjusted and divided into 7 main groups of determinants of application of invention, especially GPT.

Table 1. Determinants of ICT as GPT adoption and their operationalization (variables) at regional level (source: authors)

Symbol	Description (definition, years and source)	Rationale
I. Complementary investment		
X_1	Intramural R&D expenditures in business sector as percentage of GDP, 2013, 2017 (Eurostat)	The complementary investment is needed to realizing the benefits of ICT as GPT (Basu & Fernald, 2007)
X_2	Non-R&D innovation expenditures in SMEs as percentage of their total turnover, EU28 = 100, 2014, 2016 (RIS database)	
X_3	Gross fixed capital formation in all NACE activities as percentage of GDP, 2014, 2017 (Eurostat)	
II. Human capital		
X_4	Persons with tertiary education as percentage of active population, 2014, 2018 (Eurostat)	A fertile ground for co-invention of application (ICT adoption and use at firm level) is provided by skilled labor market, specialized human capital and continuous learning processes (Bresnahan, 2002; Arvanitis, 2005; Falk, 2005)
X_5	Scientists and engineers as percentage of active population, 2014, 2018 (Eurostat)	
X_6	Lifelong learning – participation of adults in education and training as percentage of population aged 25–64, 2014, 2018 (Eurostat)	
X_7	Young people neither in employment nor in formal, non-formal education or training as percentage of population aged 15–24 (NEET rate) – dis-stimulant 2014, 2018 (Eurostat)	
III. Cooperation networks and linkages		
X_8	Innovative SMEs collaborating with others (firms that have had any cooperation agreements on innovation activities with other enterprises or institutions) as percentage of SMEs, UE28 = 100, 2014, 2016 (RIS database)	Transformation of invention to innovation through application of ICT (using off-the-shelf GPT developed elsewhere) is determined by cooperation networks and linkages which ease flow of knowledge between public institutions and firms, and between firms (Phelps et al., 2012)
X_9	Number of public-private co-authored research publications per million population (excludes medical and health sector), UE28 = 100, 2013, 2017 (RIS database)	

End of Table 1

Symbol	Description (definition, years and source)	Rationale
X_{10}	Persons commuting to work in another region as percentage of employed aged 15–64, 2014, 2018 (Eurostat)	
IV. Proximity and diversity		
X_{11}	Population density, persons per square kilometer, 2014, 2018 (Eurostat)	Capabilities to utilize knowledge spillovers are dependent on spatial, cognitive, social or relational proximity (Boschma, 2005; Basile et al., 2012), however the capacity to combining existing knowledge is easier in a region where the population is diversified (Bernhard et al., 2020)
X_{12}	Individuals who used the internet, participating in social networks (creating user profile, posting messages or other contributions to facebook, twitter, etc.) as percentage of individuals, 2014, 2018 (Eurostat)	
X_{13}	Foreigners as percentage of population aged 15–64, 2014, 2018 (Eurostat)	
V. Entrepreneurship and innovation activities		
X_{14}	Self-employed persons as percentage of active population aged 15–64, 2014, 2018 (Eurostat)	ICT as GPT utilization (capacity to translate knowledge into innovation) is explained by the presence of entrepreneurship where entrepreneurs are interpreted as the innovative adopters of new knowledge, especially related to non-technological innovations (Braunerhjelm et al., 2010; Hollenstein, 2004)
X_{15}	SMEs introducing marketing or organizational innovations as percentage of SMEs, UE28 = 100, 2014, 2016 (RIS database)	
X_{16}	Individuals who used the internet for selling goods or services as percentage of individuals, 2014, 2018 (Eurostat)	
VI. Knowledge base		
X_{17}	Gross value added per hour worked by person in the 15–64 age group in all NACE activities (in euro), 2014, 2018 (Eurostat)	Innovation is a complex process based on knowledge recombination or integration and some knowledge stock is needed for application of new ideas (Furman et al., 2002)
X_{18}	Employment in high-technology sectors (high-technology manufacturing and knowledge-intensive high-technology services) as percentage of total employment, 2014, 2018 (Eurostat)	
VII. Demand		
X_{19}	Households with broadband access as percentage of households, 2014, 2018 (Eurostat)	One of main determinants of innovation adoption and/or diffusion and, thus, the innovation is demand (Hall & Khan, 2003; Peine & Herrmann, 2012; Edler, 2016)
X_{20}	Individuals who used the internet daily as percentage of individuals, 2014, 2018 (Eurostat)	
X_{21}	Individuals who used the internet for internet banking as percentage of individuals, 2014, 2018 (Eurostat)	
X_{22}	Individuals who never used the internet as percentage of individuals– dis-stimulant, 2014, 2018 (Eurostat)	

Variables such as R&D expenditure in the public sector, SMEs innovating in-house or patent applications are intentionally not used, as they capture innovation activity and knowledge creation in the traditional meaning, and are not suitable for measuring "co-invention of application".

The last research question (RQ3) about the relationship between the readiness to application of ICT as GPT and traditional sectoral specialization in the ICT sector (RCA) is tested using the Spearman's rank correlation statistical method. As a hypothesis (H3), it is assumed that the usage of ICT as GPT in SS implementation is related to specialization in the ICT sector.

The statistical data used in the research is mainly derived from Eurostat, but for some variables the Regional Innovation Scoreboard (RIS) database was also used (European Commission, 2017, 2019a). The missing data has been imputed using RIS methodology (European Commission, 2019b).

The analysis is carried on in dynamic approach to cover temporal changes of examined objects. Two years were selected for this analysis: 2014 – when the implementation of 2014–2020 EU cohesion policy started, and the condition for obtaining EU cohesion funds was elaboration of an SS strategy; and 2018 or the latest available year indicated in the Table 1.

3. Analysis and findings

3.1. NUTS2 regions' SS in ICT and their industry specialization in the ICT sector

In the first step, a search conducted with the EYE@RIS3 tool of EU regions with policies prioritizing ICT as SS under RIS3 resulted in 126 different regions. However the SS could have been adopted for regions at different NUTS level, not only for the NUTS2 level regions. Thus, in our selection of the sample of NUTS2 level regions with SS in ICT, the following assumption is made: if the SS in ICT is adopted only for the NUTS1 region, then all NUTS2 level units included in this NUTS1 region are considered for the analysis; if the SS in ICT applies to NUTS3 level units, whole NUTS2 regions are included if most of their NUTS3 units adopted S3. Moreover, the number of EU regions in our study at NUTS2 level (based on the NUTS 2016 classification) was reduced by countries that consist of only one NUTS2 region (when NUTS1 level corresponds to NUTS2 level). Regions with no data for RCA analysis were also removed. As a result, the overall sample for RCA analysis included 235 regions, which is 84% of the NUTS2 regions' population, giving a total of 108 regions with SS in ICT (38%).

The NUTS2 regions which prioritize ICT under S3 are not as a group specialized in the ICT sector as their average RCA index is below 1 (Table 2). However, this value increased slightly from 2014 to 2018. These regions represented about two fifths (41%) of the ICT sector measured by employment, and 45% of the whole EU28 economy in 2014. Changes over examined period indicate that NUTS2 regions with SS in ICT are, on average, no more dynamic than other regions as their share in ICT sector employment raised slightly, but in all economic activity decreased.

Table 2. RCA index for the group of NUTS2 regions with SS in ICT and their share in the UE28 economy and the ICT sector (2014–2018) (source: authors)

Indexes/Years	2014	2015	2016	2017	2018
RCA index	0.91	0.91	0.92	0.92	0.93
Share in ICT sector employment (%, EU28 = 100)	41.2	40.9	41.1	41.5	41.8
Share in all economic activities (all NACE) employment (%, EU28 = 100)	45.1	45.0	45.0	45.3	44.8

The overall pattern of RCA distribution for the NACE2 group with SS in ICT in relation to the rest of the regions includes boxplots (Figure 1). The regions most specialized in the ICT sector in 2014 did not choose ICT as SS. Greater variability can be observed in RCA for non-SS in ICT regions. However, the differences between regions non-SS and SS in ICT in extremes and outliers fell from 2014 to 2018. The spread of RCA for both groups has a negative skew. However, in the interquartile range (25–75%), the group of SS in ICT is also asymmetric.

To verify the relation between smart and sectoral specialization in ICT across EU regions, the NUTS2 regions were split into four categories, for which the statistics are described in Table 3.

To present the changes of the RCA value over time, a scatterplot for the RCA variable in 2014 and 2018 has been used and drawn a straight line as a diagonal across the square (Figure 2). The points placed above the diagonal are those which increased their RCA value over the period in question, while those under the line diminished their specialization in the ICT sector.

Analysis of the points distribution on the scatterplot lead us to observe that the changes of RCA value are bidirectional in both groups of regions. Only some NUTS2 regions with SS in ICT have raised their sectoral specialization in ICT, whereas others

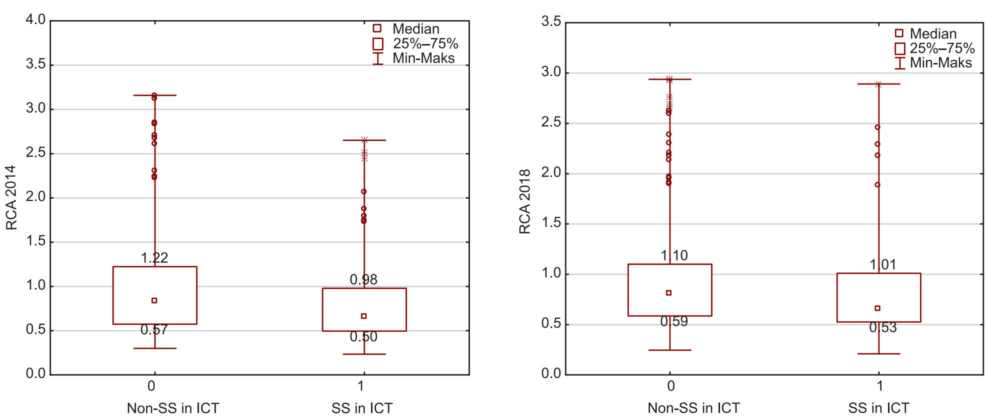

Figure 1. Dispersion measurements for RCA by non-SS in ICT and SS in ICT groups – NUTS2 regions (2014, 2018) (source: authors)

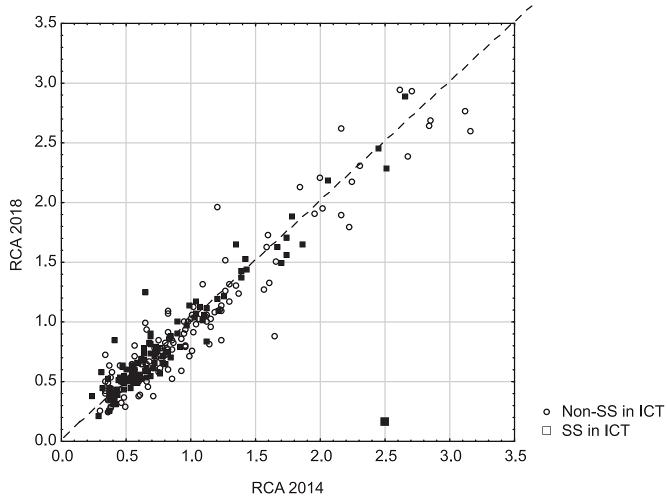

Figure 2. Changes in RCA value by non-SS in ICT and SS in ICT groups – NUTS2 regions (2014, 2018) (source: authors)

have not or have even decreased it. A similar situation can be seen for NUTS2 regions with non-SS in ICT.

The findings of the RCA analysis finally support the hypothesis that in practice SS in ICT is not related to ICT sector specialization.

3.2. Characteristics of NUTS2 regions with SS in ICT in terms of readiness to application of ICT as GPT

In this part of the research an attempt has been made to find the answers to research questions RQ2 and RQ3.

The analysis of readiness to application of ICT as GPT covered 197 NUTS2 regions. The following regions were excluded from the study at this stage: all regions in France and the Netherlands and some regions in other countries for which it was not possible to collect data for the selected variables. As a result of the process of data verification, the group of NUTS2 regions with SS in ICT in this analysis includes 93 regions.

The procedure proposed by Hellwig (1968) has been applied, which allows the synthetic measure of the level of readiness to use ICT as GPT for 2014 and 2018 to be determined. The subsequent steps in this multivariate comparative analysis are as follows:

- the set of variables was verified in terms of the discrimination ability of variables and thus the coefficient of variation was analysed (the variables for which the value was below 10% or above 100% were eliminated); also the degree of the correlation between the variables in this group was taken into consideration (Panek, 2009, pp. 18–23). The aforementioned formal procedure of variables selection was applied. Thus, from the initial set of variables (22 variables) the following 8 variables were excluded: X_5, X_{10}, X_{11}, X_{13}, X_{16}, X_{20}, X_{21}, X_{22} due to the high coefficient of variation or the high correlation with other variables. Thus the number of variables were reduced to 14 representing each of the category which describes the readiness of usage ICT as GPT;

- the final set of variables were classified to either stimulants or dis-stimulants (the dis-stimulant was converted into the stimulant), which then were normalized;
- the synthetic indicator for the reference object (pattern) was constructed and its values is in the range <0,1>. The better performance of the examined region is, the higher the value of the synthetic measure and the distance from the reference object is lower;
- the last step – grouping regions into classes. Each of the class is characterized by the similar structure in terms of their readiness to usage ICT as GPT. In our case the four groups of regions were distinguished. This method enables us to determined regions in relation to their position to the reference object and to identify their weaknesses related to their readiness to usage ICT as GPT.

Application of the Hellwig's method enabled us to classify the NUTS2 regions in terms of their readiness to usage ICT as GPT, resulting in 4 groups of regions being formed, characterized by: high readiness (group I), medium, low and the lowest readiness accordingly. In 2014, the first group covered regions characterized by high readiness (group I): these 36 NUTS2 regions, which constituted 18.3% of the total analyzed regions in our study. The group I included 14 regions with SS in ICT (39% of the total number of regions in this group). The second group of regions characterized by medium readiness numbered 63 regions – 32% of the total number of analysed regions – and is the most numerous group, including 26 NUTS2 regions with SS in ICT (41.3% of the total analysed regions within this group). The groups with low and the lowest readiness (III and IV) included 60 and 38 regions respectively, altogether regions included in these two groups constituted about 50% of all analysed regions. However, about 40% of regions (out of total regions in each group) classified either to the group of high readiness (group I) or to the medium readiness (group II) had prepared SS strategies (Table 3). While, more than 50% of regions classified to group III or IV prepared such strategies.

Table 3. Groups of regions in terms of readiness to application of ICT as GPT and number of regions prioritising ICT by group (2014) (source: authors)

Group	Interval of synthetic variable for the type of group	Number of regions in each group	Percentage of regions in each group	Number of regions with SS in ICT	Percentage of regions with SS in ICT in total SS	Percentage of regions with SS in ICT in each group
Group I	$d_i > 0.3091$	36	18.27	14	15.05	38.89
Group II	$0.2318 < d_i \leq 0.3091$	63	31.98	26	27.96	41.27
Group III	$0.1546 < d_i \leq 0.2318$	60	30.46	33	35.48	55.00
Group IV	$d_i \leq 0.1546$	38	19.29	20	21.51	52.63
		197	100.00	93	100.0	

Table 4. Groups of regions in terms of readiness to application of ICT as GPT and number of regions prioritising ICT by group (2018) (source: authors)

Group	Interval of synthetic variable for the type of group	Number of regions in each group	Percentage of regions in each group	Number of regions with SS in ICT	Percentage of regions with SS in ICT in total SS	Percentage of regions with SS in ICT in each group
Group I	di > 0.3087	37	18.78	15	16.13	40.54
Group II	0.2316 < di ≤0.3087	61	30.96	26	27.96	42.62
Group III	0.1544 < di ≤ 0.2316	67	34.01	34	36.56	50.75
Group IV	di ≤0.1544	32	16.24	18	19.35	56.25
		197	100	93	100.00	

In 2018, group I included almost the same number of regions as in 2014 and included 15 regions with SS in ICT, and this share of the total number of regions in the group remained the same 40.5%. The number of regions in the group II decreased in relation to 2014. It can be seen that the number of regions characterized by low readiness (group III) increased to 67, however the share of regions with SS in ICT in this group (in total SS) remained almost the same. It should be underlined that the number of regions in group IV decreased in 2018 in comparison to 2014 from 38 to 32, but the number of regions with SS in ICT also has been reduced. Therefore, out of the total sample of regions, the share of regions characterized by the lowest readiness and with SS in ICT increased from 52.6% to 56.3%.

To conclude, the spread of NUTS2 regions with SS in ICT by their synthetic measure of readiness to application of ICT as GPT is broad and includes all classified groups (I-IV). In the period 2014–2018 the number of regions with high readiness remained stable. Compared to 2014, in 2018 one can observe that the number of regions in group III classified as regions with low readiness increased, as did the number of regions with SS in ICT in this group, albeit slightly. However, in 2018 the number of regions classified to group 4 with very low readiness to use ICT as GPT decreased compared to 2014, but the share of regions with SS in ICT increased to more than 56% (Table 4). Therefore, one could suggest that in the analyzed four-year period, the selection of SS in ICT by regions does not have a real impact on improving their readiness to application of ICT. This is particularly noticeable in group IV, which includes regions characterized by the lowest readiness. It is also observed that the number of regions characterized by low readiness in group III increased, which could be the result of regions losing readiness, or that some regions characterized by the lowest readiness (group IV) improved their situation and moved to the higher group. The Spearman's rank correlation coefficient of the two rankings show high correlation 0.979. Finally, hypothesis H2, that SS in ICT is based on "co-invention of applications" in practice, has been refuted.

For the last question, the relationship was tested between the readiness to apply ICT as GPT (assessed on the basis of the taxonomic method of linear ordering according to the value of synthetic measure) and specialization in the ICT sector (RCA index). The calculation of the Spearman coefficient produced a result which shows that there is a strong positive monotonic relationship (R = 0.694) between the readiness to apply ICT as GPT and specialization in the ICT sector. Performance of a significance test revealed that the association between these factors is statistically significant to a level of at least 5%. Therefore, hypothesis H3, that the readiness to apply ICT as GPT is materially related to specialization in the ICT sector, can be confirmed.

4. Discussion

Regions SS in ICT display huge differences and are statistically less able to take advantage of ICT as GPT than others. So, the implementation of S3 at regional level in EU is not enough consistent with its assumption to use ICT as a driver of regional innovation by "co-invention of applications". Moreover, dynamic analysis revealed no significant differences within analyzed four years period. Substantial reinforcement in the sectoral specialization and readiness to application of ICT as GPT have not been observed. These findings can be explained to some extent by the gap that exists between having a strategy and its effective implementation. This tends to confirm the results of the analysis conducted by Kleibrink et al. (2015), who showed that prioritization under SS strategy alone did not bring the expected effects, but this was only achieved when appropriate investment was made. Verification of this would involve in-depth research based on EU funding data, which is not fully relevant to the NUTS2 level at which this analysis was carried out. However, the results obtained could be explained similarly to the ICT (Solow's productivity) paradox, where many factors are considered to be influential on the productive and innovative effects of ICT, among which special importance are held by investments in resources complementary to ICT (mainly human capital), as well as the longer time period required for the full effects of investments to become evident (Kijek & Kijek, 2019).

The limited usage of ICT in its role as a driver of innovation by 'co-invention of applications' at regional level could also be explained by findings of correlations analysis. Therefore, one can agree with SS concept that development of human capacity (as key factor for innovation) is not to be associated with a strategy of simple industrial specialization, but concerns application of ICT, which in practice means knowledge spillover, although specialization in ICT industries is still of importance. These confirm the conclusion drawn by Boschma (2009, p. 14) who stated that "*knowledge will spill over more intensively when regions are endowed with related industries that share a common knowledge base*".

In relation to ICT it is reasonable to consider application of a dynamic GPT-related mechanism triggering innovation and investments in R&D. This would require the redirection of the research and innovation policy towards the European level policy aimed at investing in:

- promotion of ICT due to its GPT properties (including public spending on R&D), ultimately resulting in flourishing of private R&D investment,
- human capital and entrepreneurship development as a pre-condition for "co-invention of applications".

This approach is also confirmed by the case elaborated by Todeva (2015). In this analysis, the development of technology clusters is not connected with RIS3, however government funding for university research is important for creating location advantages. Similarly, the solid local base (resources, quality of life etc.) is also needed to retain the innovative start-ups (Fan et al., 2019).

Conclusions

This study aimed to specify the role of ICT in SS implementation in EU regions. Some foundations of the application of the SS concept in practice were verified, as well as its effects during the 2014–2018 period. This contributes to a deeper recognition of SS embedded in regional innovation policies by verification of empirical implementation of SS strategy in reference to ICT. This may also bring improvements to European policies through the application of evidence-based policy making.

To begin with, it would be emphasized that although ICT is GPT and as such is the core of innovation, productivity growth of virtually all kinds of economic activity and base of digital transformation, the majority of EU regions did not choose ICT as a priority in their RIS3.

Analysis at the level of NUTS2 regions confirmed that SS in practice is different from sectoral specialization as regards the field of ICT. This means that ICT in SS is not commonly accounted for as invention which is developed and focused on. It was also proved that SS in ICT is not based on readiness to usage of ICT as GPT in practice. The obtained results show that the readiness to application of ICT as GPT are materially related to specialization in the ICT sector. Thus, it is not only activities aimed at the process of ICT diffusion that play a key role in innovation development at regional level, but equally crucial is enhancement of the ICT production sector. There might be a single solution to these two issues, one which is probably associated with the same factors that enable ICT production and diffusion, the most important of which is human capital (i.e. skills, entrepreneurship).

However, the findings obtained are tentative and should be confirmed by more in-depth research. The existence of reciprocal relationship between development of the ICT sector and exploitation of ICT as GPT in the whole economy may be suspected. One of the next steps should be to investigate this interdependence in other regions and different backgrounds.

This research also has some limitations. The main is related to data availability. The period for analysis 2014–2018 is relatively short and it is assumed that structural changes have not been captured in full. Another limitation is the adopted industry specialization measurement which is based on the employment-related data only. Some distortions in the results can be caused by the diversities in the size and nature of NUTS2 regions. Among them are regions covering only a large city with its surroundings. In drawing conclusions, one should bear in mind the narrower scope of the ICT sector, which focuses mostly on the information and communication services section.

Implementation of S3 and its implications still pose some challenges in practice at the regional level. It is recommended that European regions should focus both on ICT sector development, while at the same time encouraging all other industries to make use of the output from this sector.

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