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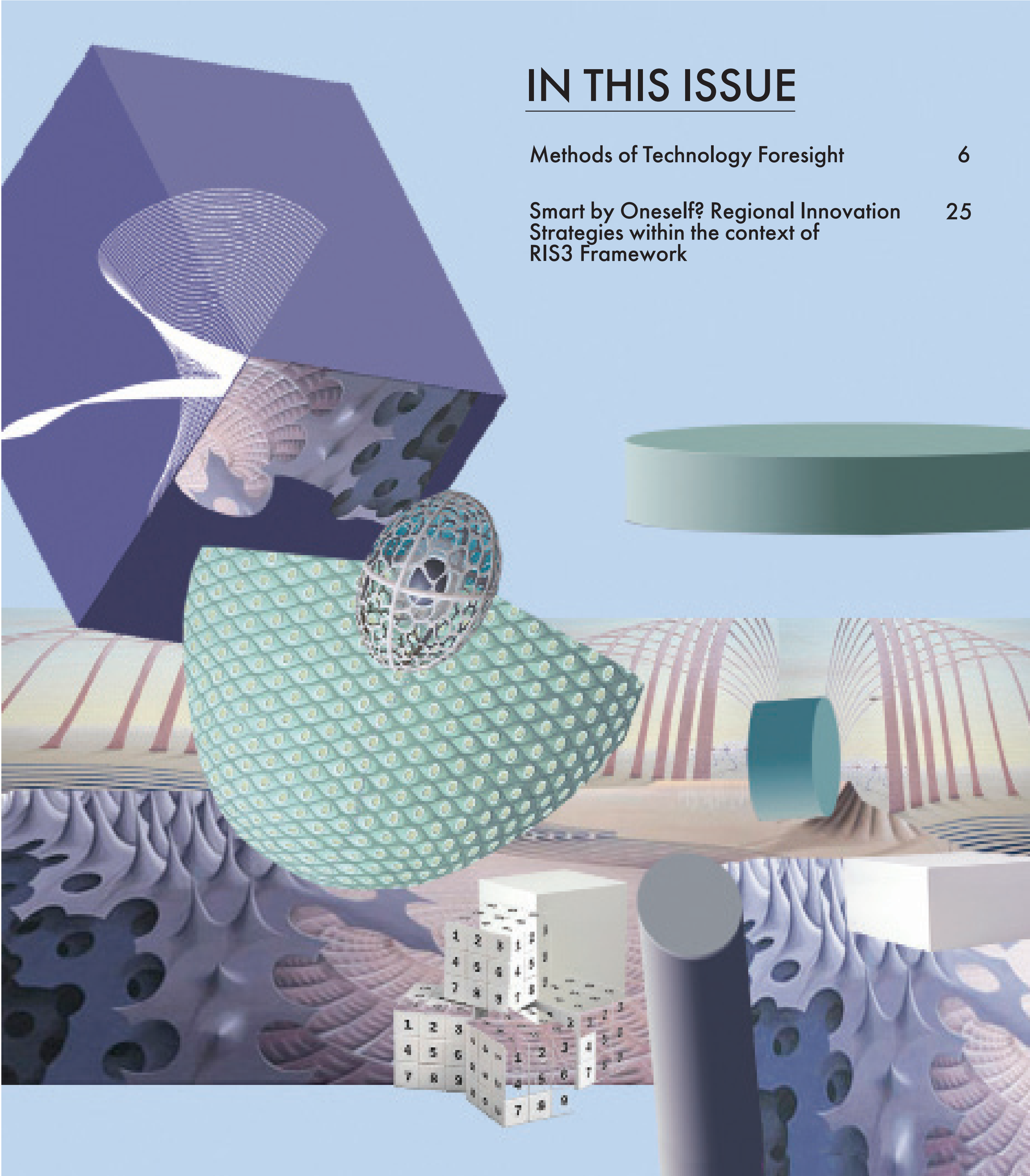


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Foresight and STI Governance is an international interdisciplinary peer-reviewed open-access journal. It publishes original research articles, offering new theoretical insights and practice-oriented knowledge in important areas of strategic planning and the creation of science, technology, and innovation (STI) policy, and it examines possible and alternative futures in all human endeavors in order to make such insights available to the right person at the right time to ensure the right decision.

The journal acts as a scientific forum, contributing to the interaction between researchers, policy makers, and other actors involved in innovation processes. It encompasses all facets of STI policy and the creation of technological, managerial, product, and social innovations. *Foresight and STI Governance* welcomes works from scholars based in all parts of the world.

Topics covered include:

- Foresight methodologies and best practices;
- Long-term socioeconomic priorities for strategic planning and policy making;
- Innovative strategies at the national, regional, sectoral, and corporate levels;
- The development of National Innovation Systems;
- The exploration of the innovation lifecycle from idea to market;
- Technological trends, breakthroughs, and grand challenges;
- Technological change and its implications for economy, policy-making, and society;
- Corporate innovation management;
- Human capital in STI;

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The target audience of the journal comprises research scholars, university professors, post-graduates, policy-makers, business people, the expert community, undergraduates, and others who are interested in S&T and innovation analyses, foresight studies, and policy issues.

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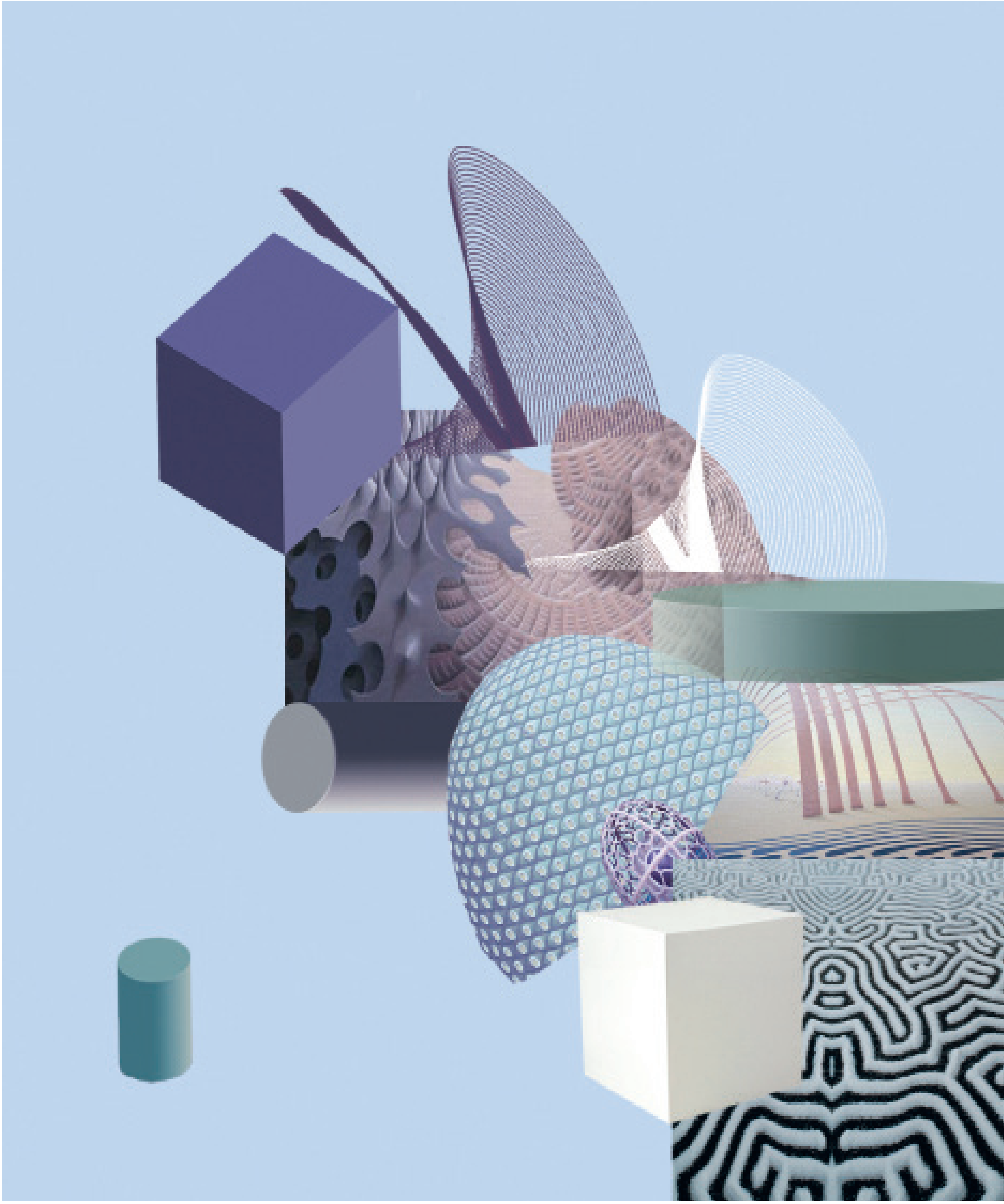

Technology Foresight: A Bibliometric Analysis to Identify Leading and Emerging Methods

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Abstract

Foresight studies provide essential information used by the government, industry and academia for technology planning and knowledge expansion. They are complicated, resource-intensive, and quite expensive. The approach, methods, and techniques must be carefully identified and selected. Despite the global importance of foresight activities, there are no frameworks to help one develop and plan a proper foresight study. This paper begins to close this gap by analyzing and comparing different schools of thought and updating the literature with the most current tools and methods. Data mining techniques are used to identify articles through an extensive literature review. Social Network Analysis (SNA) techniques are used to identify and analyze leading journals, articles, and researchers. A framework is developed here to provide a guide to help in the selection of methods and tools for different approaches.

Keywords: technology foresight; strategic foresight; adaptive foresight; Social Network Analysis (SNA); bibliometric tools; data mining; text mining.

Article type: research paper

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Technology foresight is a process that systematically looks into the future to examine areas of research and emerging technologies [*Grupp, Linstone,* 1999]. The results of this process provide inputs for policy setting and strategic planning [*Alsan, Oner,* 2003; *Major et al.,* 2001]. Foresight studies are increasingly important as policy makers grapple with complex socio-technical challenges in major industries, such as information and communication technology (ICT) [*Rohrbeck,* 2010], energy, food [*Chavez,* 2013], healthcare [*Masum et al.,* 2010], and transportation [*Alkemade, Suurs,* 2012]. They are often expensive and time-consuming. However, conducting effective and efficient technology foresight studies remains a challenge. Technologies, as well as the methods, techniques, and tools used to examine them, are evolving rapidly. Thus, the process previously used may no longer deliver the best results. Different approaches, tools, and methods add to the complexity. Despite the global importance of foresight activities, the literature lacks consensus about the approach, methods, tools, and techniques required to conduct foresight activities [*Blind et al.,* 1999]. This paper synthesizes technology foresight research and introduces a framework that can be used by policy makers as a guide for designing and conducting a proper foresight study.

The literature shows that many studies have been conducted for a variety of purposes. The European Network for Monitoring Technology Foresight (EFMN) recognizes 73 different foresight activities in Europe, 120 in South America, 109 in North America, 89 in Asia, and 15 in regions of Australia and Oceania [European Commission, 2009]. Among these, 67 international projects have been financed by the OECD (Organization for Economic Co-operation and Development), FAO (Food and Agriculture Organization of the United Nations), UNESCO (United Nations Educational, Scientific, and Cultural Organization), UNIDO (United Nations Industrial Development Organization), and World Bank. While most of these studies have been conducted to provide inputs into policy setting, other reasons include strategic planning, decision support for priority setting, infrastructure decisions [*Ecken et al.,* 2011], or the pursuit of knowledge [*Yokoo, Okuwada,* 2013].

Two literature reviews were conducted to examine the importance, methods, and techniques used and challenges found when conducting technology foresight studies. First, "foresight" was used as a keyword to search three major indices (Science Citation Index Expanded, Social Sciences Citation Index and Humanities Citation Index) between the years 1980-2013 to select journal articles. Figure 1 represents a trend of increased popularity since the early 1990s. A content review of the abstracts supports the EFMN data and provides evidence that studies are increasingly being undertaken for broader purposes.

An integrated bibliometric approach with a two-step social network analysis process was developed to systematically uncover the dynamics and contextual relationships. Specifically, Step 1 informed Step 2 and the results out of Step 2 were integrated into the interpretation of the literature. Further content analysis was used to develop and then apply a framework to discuss the results and finalize the paper.

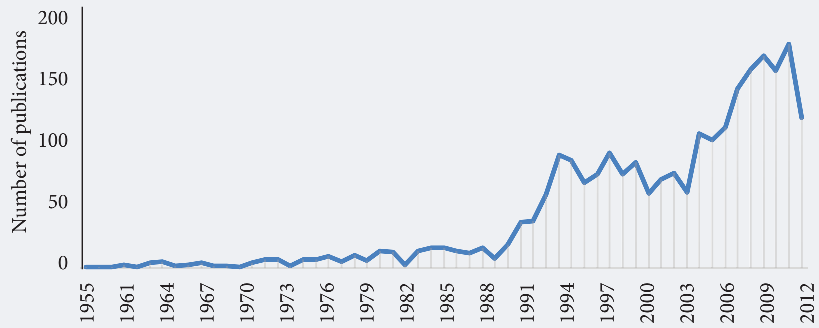
Today, not only is it imperative to be knowledgeable about current methods and trends, it is also important to select the techniques that best support the purpose of the study. However, the evolution of foresight methodology is diverse, resulting in confusion about selecting the proper approach and techniques for a given time period [*Choi, Park,* 2009]. Thus, a more systematic and robust review of the literature was conducted to describe the methodological landscape of foresight used and studied around the world. A three-phase framework was developed. Five criteria were used to map methods into the framework resulting in a decision-support model for selecting methods required to conduct a proper foresight study.

Background

As World War II came to a close, policy leaders began to recognize the importance of science and technology as inputs for foresight studies. The energy crisis, of the 1970s and 1980s, required foresight studies to consider further inputs such as the political, geopolitical, and enconomic environment. Irvine and Martin [*Martin,* 2010] began to consistently use and apply technology foresight terminology in studies for "futures" work funded by the Office of Technology Assessment (OTA) [*Miles,* 2010]. Martin defined foresight as a "process involved in systematically attempting to look into the longer-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits" [*Martin, Johnston,* 1999]. Other researchers [*Bezold,* 2010] expanded upon this definition in an attempt to gain definitional consensus in the field.

Many nations undertake periodic foresight activities for national policy setting [*Georghiou et al.,* 2014]. Grupp and Linstone noted the importance of foresight as a national policy tool to "wire-up" and strengthen national innovation programs [*Grupp, Linstone,* 1999]. Cuhls [*Cuhls,* 2003] emphasized that foresight is a process rather than a set of tools, stressing the importance of communication. This led researchers to the concept of multiple futures. In Germany, *Futur* was typically recognized as a continuous process characterized by features such as multiple perspectives and an orientation towards society's needs at the national level [*Ibid.*]. In parallel, researchers in France clarified similar concepts using the term *la prospective* [*Coates et al.,* 2010]. In the UK, foresight panels explored how market drivers would shift as the aging population became more techno-friendly and demanded a higher quality life [DTI, 2000].

Figure 1. **Foresight Keyword Search Results**



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The 1990s and 2000s introduced even more complexity and resulted in more political, socital, psychological, and cultural factors to be considered when gathering foresight study inputs. Data was included to consider the citizens' perspective about the environment and technology. Today, systematic efforts are used to collect data that will provide a holistic picture required to examine the future interactions of science, technology, society, and the economy to promote and exploit social, economic, and environmental benefits [*Cachia et al.*, 2007].

Policymakers are interested in measuring the impact of these studies because they are expensive and time consuming. The European Foresight Network states that "a participative approach to creating shared long-term visions to inform short-term decision-making processes" [*Calof, Smith,* 2012, p. 5] as their primary purpose for funding a foresight study. This shift in purpose spurred interest by connecting science and technology to societal problems. Martin and Johnson found that technology foresight provided: 1) an approach for science and technology policy decision making, 2) offered a way to integrate research opportunities and link science and technology to wealth creation, and 3) stimulated communication between necessary stakeholders for translational research [*Martin, Johnston,* 1999].

National planners and corporate strategists are both concerned about the examination of multiple futures as well as a plan for how to reach a desired future. Foresight activities are spanning countries as global companies and public-private partnerships have increased the use of foresight activities [*Durand,* 2003]. The Foresight Vehicle Initiative, a sub-group of the UK Foresight Programme, was launched in 1997 as a collaborative effort between the government, industry, and academia in the UK to examine possible futures of the transportation industry [*Phaal,* 2002]. The domain is broad, foresight studies are complex, and technology is driving improvement in the tools and methods.

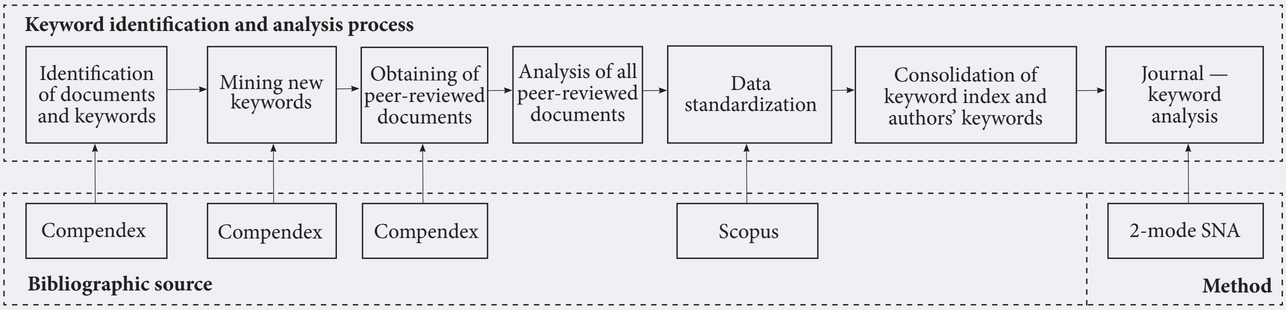
Methodology

Bibliometrics and Social Network Analysis (SNA) techniques were used to develop a two-mode network. Bibliometric techniques are often used to obtain inputs for developing public policy, science programs, and technological foresight activities [*Godin,* 1998]. Bibliometrics are used to analyze elements such as citations, authors, and semantic items of all forms of written communication regardless of discipline or research field. Mining bibliometric patent citation data and conducting SNA has been used in foresight activities to analyze technology development trends [*Choi, Park,* 2009]. Graphically presenting the bibliographic data in the form of network maps is a powerful technique for knowledge transfer facilitating group discussion [*Chen, Kien Pham,* 2014]. Affiliated networks using SNA techniques were first used to analyze patent and citation data from the USPTO [*Chien, Weng,* 2012]. Incorporating keywords into the maps adds value in new technology creation activities [*Lee et al.*, 2009]. Thus, SNA opens the opportunity for analyzing studies about technology and their relationships [*Cachia et al.*, 2007]. This study follows the affiliated network approach by using a three-phase research approach to build a two-mode network.

One hundred ninety-six articles were selected by mining the Compendex database, from 1995 to 2015 inclusively, using the keyword "foresight". A content analysis of the literature was conducted to review the origin, purpose, and scope. Then, Social Network Analysis (SNA) was conducted to quantitatively and qualitatively analyze and investigate the social structures between journals and keywords. The framework in Figure 2 shows the three-phase approach: 1) Keyword identification via text mining, 2) Mode one analysis, 3) Mode two analysis.

The process of text mining was used to identify key concepts that were meaningful and representative of the topic. The analysis followed an affiliation network relationship between actors based on their participation in events. These types of networks are composed of sets of actors and subsets of events. A two-mode network allows for an analysis of the relationships among actors from two perspectives

Figure 2. **The Analysis Framework**



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or two different single-mode events [*Chien, Weng,* 2012]. Thus, SNA was used to identify key concepts, leading journals, and popular methods in technology foresight.

Early researchers described a successful foresight process in terms of three simple phases: inputs, foresight activities, and outputs [*Horton,* 1999]. The three-stage framework, pre-foresight, foresight, and post-foresight was first documented by Irvine and Martin [*Irvine, Martin,* 1984]. In this context, inputs are the collection, collation, and summarization of data. Activities and skills are used in the foresight phase to produce outputs such as tools, workshops, and reports. Amsteus uses the classifications of the present situation, plan, and goal [*Amsteus,* 2011a]. Still other researchers have developed frameworks to fit particular case studies [*Brandes,* 2009] or to provide general frameworks by industry area [*Boretos,* 2011]. Smith and Saritas illustrated mapping foresight methods into yet another framework where Phase 1 would contain understanding, Phase 2 would consist of Synthesis, Analysis, and Transformation and Phase 3 would consist of actions [*Smith, Saritas,* 2011].

For this paper, the groups and keywords were synthesized and mapped into a three-phase, six-step foresight framework.

Phase 1: INITIATE

1) **D**efine, develop, and document the purpose
2) **E**xpected outputs, outcomes, and impact
3) **S**tructure and approach

Phase 2: EXECUTE

4) **I**nvite the right experts
5) **G**ather data
6) **N**ew methods/Innovative Analysis Techniques

Phase 3: CLOSE and COMMUNICATE

Results

The two-mode network links key concepts to journals showing a singularly directed flow. Figure 3 graphically represents how the network relates 15 journals and 1,299 key concepts. Note that three isolated journals are not considered in this analysis because they are not connected to any key concept. Figure 3 illustrates the groupings of sub-networks around important journals. When the key concepts were associated with two or more journals at the same time they were treated as common elements and are denoted by bridges linking the journals to the topics. In-degree centrality quantifies key concepts, which are graphically represented by the size of the label. The dominant journal, *Technological Forecasting and Social Change*, has the largest label in Figure 3 and the highest value in Table 2 because it publishes the greatest number of articles examining foresight concepts and covers the maximum array of such concepts.

Tables 1 and 2 rank the key concepts and journals. In Table 1, the centrality measures are normalized values for the two-mode network. Degree, eigenvector, closeness, and betweenness-centrality measure concepts for the positive strength of the relationship. A betweenness-centrality threshold of 0.003 was used to truncate the outliers with little interconnection between journals.

Table 2 applies the same method to quantify the importance of the journals and then ranks them using the betweenness-centrality measure.

Figure 4 shows how journals use key concepts to connect in order to form sub-networks. Table 3 shows the most cited articles on technology foresight.

Table 1. **Network Centrality Measure for Key Concepts**

No.	Key Concepts	Degree	Eigenvector	Closeness	Betweenness
1	Decision Making	0.600	0.039	0.936	0.034
2	Innovation	0.533	0.039	0.922	0.019
3	Foresight	0.400	0.038	0.904	0.018
4	Research	0.467	0.039	0.903	0.017
5	Competition	0.333	0.034	0.828	0.015
6	Societies and Institutions	0.400	0.036	0.859	0.011
7	Sustainable Development	0.333	0.037	0.882	0.011
8	Decision Makers	0.200	0.032	0.807	0.010
9	Investments	0.267	0.034	0.850	0.010
10	Social Network	0.200	0.034	0.821	0.010
11	Technology Foresight	0.333	0.037	0.876	0.009
12	Adaptive Foresight	0.133	0.032	0.788	0.008
13	Social Aspects	0.333	0.035	0.847	0.008
14	Strategic Planning	0.333	0.036	0.852	0.008
15	Strategic Foresight	0.267	0.034	0.838	0.007
16	Industry	0.267	0.034	0.821	0.006
17	Nanotechnology	0.267	0.035	0.855	0.006
18	Corporate Strategy	0.267	0.036	0.854	0.005
19	Energy Market	0.133	0.032	0.802	0.005
20	Energy Modeling	0.133	0.032	0.802	0.005
21	Mathematical Models	0.133	0.032	0.802	0.005
22	Optimization	0.133	0.032	0.802	0.005
23	Planning	0.267	0.037	0.861	0.005
24	Strategic Approach	0.267	0.035	0.824	0.005
25	Business Development	0.267	0.035	0.830	0.004
26	Business Model	0.200	0.035	0.824	0.004
27	Delphi Method	0.200	0.035	0.843	0.004
28	Emerging Technologies	0.200	0.034	0.840	0.004
29	Industrial Research	0.200	0.034	0.826	0.004
30	Research and Development Management	0.267	0.035	0.829	0.004
31	Risk Management	0.200	0.035	0.843	0.004
32	Technological Forecasting	0.267	0.035	0.829	0.004
33	Technology	0.267	0.034	0.819	0.004
34	Biotechnology	0.200	0.034	0.818	0.003
35	Business Models	0.200	0.033	0.798	0.003
36	Economic and Social Effects	0.200	0.034	0.817	0.003
37	Evaluation	0.200	0.035	0.831	0.003
38	Forecasting	0.200	0.035	0.831	0.003
39	Impact	0.200	0.035	0.831	0.003
40	Information Technology	0.200	0.034	0.818	0.003
41	Innovation Management	0.200	0.033	0.798	0.003
42	Internet	0.200	0.034	0.817	0.003
43	Knowledge	0.200	0.036	0.850	0.003
44	Learning	0.200	0.036	0.850	0.003
45	Policy Making	0.200	0.036	0.850	0.003
46	Public Policy	0.200	0.034	0.817	0.003
47	Research and Development	0.200	0.036	0.850	0.003
48	Scenario	0.200	0.036	0.850	0.003
49	Scenarios	0.200	0.036	0.850	0.003
50	Technological Development	0.267	0.035	0.823	0.003
51	Technology Forecasting	0.200	0.034	0.818	0.003
52	Technology Policy	0.200	0.035	0.834	0.003
53	Technology Transfer	0.200	0.034	0.817	0.003

Source: compiled by the authors.

Table 2. **Journals' Network Centrality Measures**

No.	Journal	Degree	Eigenvector	Closeness	Betweenness
1	Technological Forecasting and Social Change	0.736	0.994	0.659	0.907
2	Foresight	0.082	0.045	0.354	0.101
3	Futures	0.091	0.071	0.359	0.089
4	Technovation	0.055	0.034	0.350	0.065
5	Research Policy	0.048	0.030	0.348	0.057
6	Energy	0.032	0.009	0.336	0.050
7	Research Technology Management	0.030	0.021	0.342	0.033
8	Journal of Forecasting	0.038	0.033	0.344	0.031
9	International Journal of Technology Management	0.021	0.011	0.330	0.026
10	Energy Policy	0.014	0.007	0.336	0.017
11	International Journal of Research in Marketing	0.011	0.002	0.313	0.017
12	Expert Systems with Applications	0.010	0.004	0.332	0.015
13	Technology Analysis and Strategic Management	0.015	0.013	0.326	0.012
14	Long Range Planning	0.015	0.013	0.331	0.010
15	Journal of Service Research	0.004	0.001	0.287	0.006

Source: compiled by the authors.

Figure 5 focuses on the results from Figure 4 for *Technological Forecasting and Social Change* (TFSC) alone.

The analysis of the two-mode networks has been completed, having found the most important journals and keywords. In the case of "Decision Making" and "Innovation", these keywords are related, as have most of the other keywords, to the journal of Technological Forecasting and Social Change. After applying an ego-network option (e.g. [*DeJordy, Halgin,* 2008]), it can be seen that "Decision Making" and "Innovation" are common nodes between nine of the journals. Figures 6 and 7 shows the ego networks of the main keywords directly associated with technology foresight: "Decision Making", "Technological Foresight", "Adaptive Foresight", and "Strategic Foresight". In Figure 7, knowing that the journal *Technological Forecasting and Social Change* is associated with most of the important keywords, this journal was removed in order to have more clear idea of the ego-networks directly associated with technology foresight.

Figure 3. **SNA Network of Journals and Keywords**

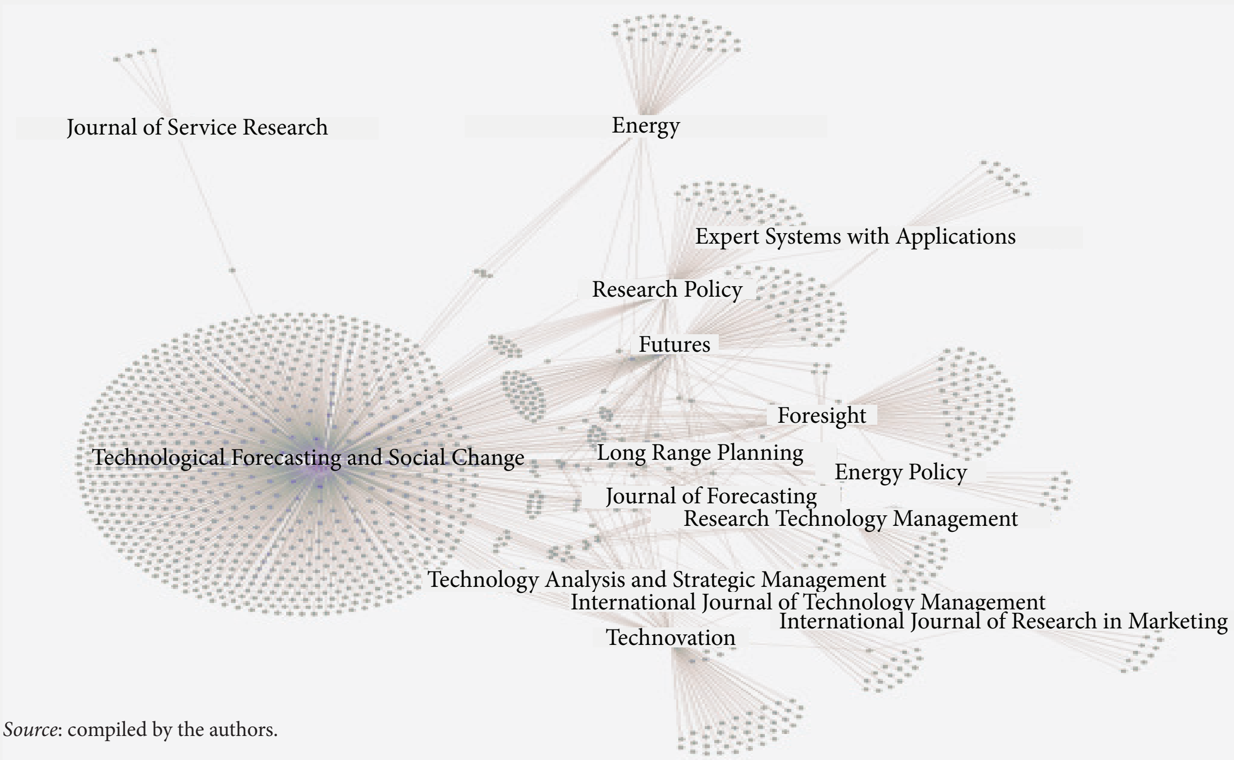

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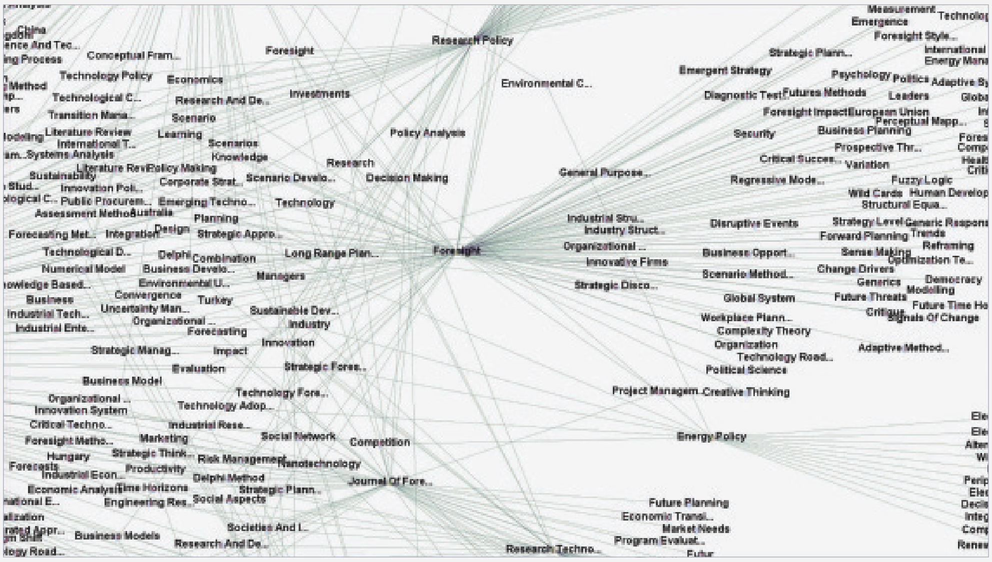
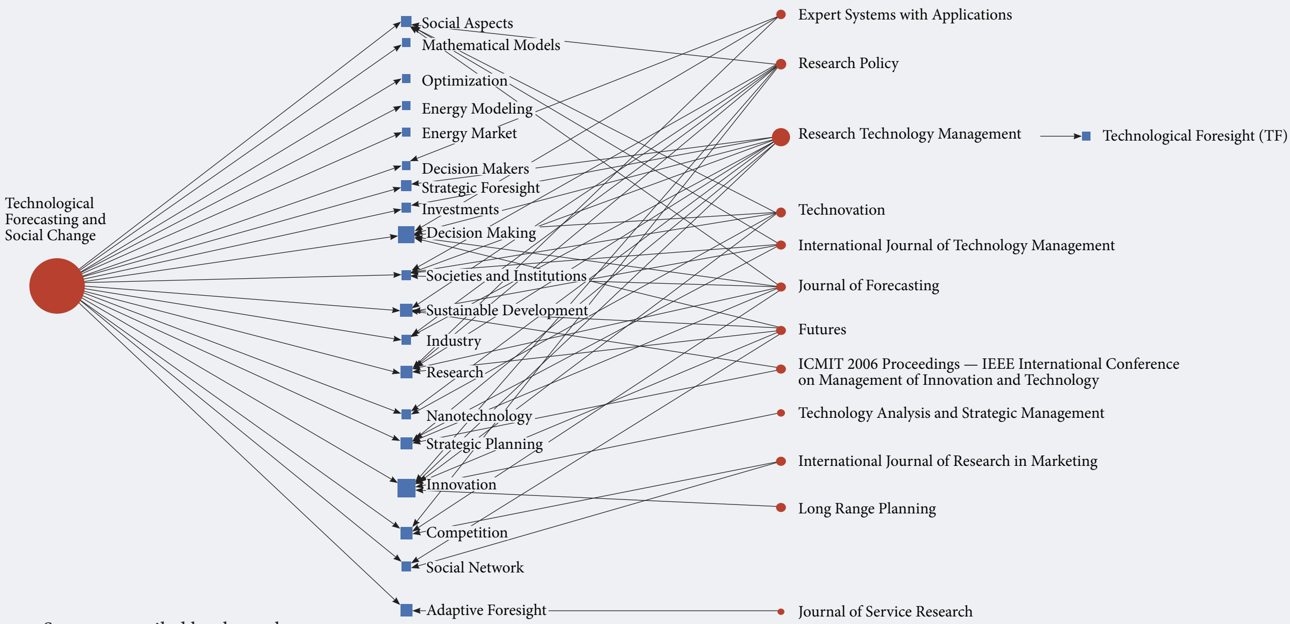
Figure 4. **SNA Sub-Networks of Journals and Keywords**



Source: compiled by the authors.

It can be seen in Figure 7 that the keywords "Technological Foresight' are associated with the journal Foresight with a high betweennees level and are associated with the keyword "Strategic Foresight". "Adaptive Foresight" is associated to two journals. One is the Journal of Service Research, which is not associated with any other important keywords. The keyword "Strategy Foresight" is linked to three important journals, two of them directly associated with technology management with connections to the keyword "Technology Foresight". Following the strategy of analyzing ego-networks directly associated with technology foresight, the ego-network of the journal *Foresight* is shown in Figure 8. The journal *Foresight* links many important keywords including "strategic planning", "decision making", "innovation", and "strategic foresight". All of the keywords linked to the journal *Foresight* are associated simultaneously with a high number of important journals.

Figure 5. **TFSC Connections to Other Journals**



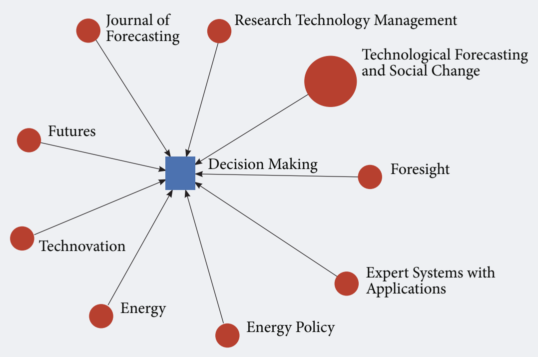
Source: compiled by the authors.

Table 3. **Most Cited Articles on Technology Foresight**

Author(s)	Title	Journal	Citations	Year	Reference
Robert Phaal et al.	Technology roadmapping — A planning framework for evolution and revolution	Technological Forecasting and Social Change	273	2004	[*Phaal et al.*, 2004]
Jules Pretty et al.	Sustainable intensification in African agriculture	International Journal of Agricultural Sustainability	191	2011	[*Pretty et al.*, 2011]
Anthony van Raan	Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises	Scientometrics	180	1996	[*van Raan*, 1996]
Andrew Maynard	Nanotechnology: The next big thing, or much ado about nothing?	Annalysis of Occupational Hygiene	163	2007	[*Maynard*, 2007]
William McDowall and Malcolm Eames	Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: A review of the hydrogen futures literature	Energy Policy	158	2006	[*McDowall, Eames*, 2006]
Jules Pretty et al.	The top 100 questions of importance to the future of global agriculture	International Journal of Agricultural Sustainability	142	2010	[*Pretty et al.*, 2010]
Ben Martin	Foresight in Science and Technology	Technology Analysis & Strategic Management	142	1995	[*Martin*, 1995]
Lena Neij	Cost development of future technologies for power generation — A study based on experience curves and complementary bottom-up assessments	Energy Policy	132	2008	[*Neij*, 2008]
Sirkka Jarvenpaa and Dorothy Leidner	An information company in Mexico: Extending the resource-based view of the firm to a developing country context	Information Systems Research	103	1998	[*Jarvenpaa, Leidner*, 2008]
Theodore Gordon and Adam Pease	RT Delphi: An efficient, "round-less" almost real time Delphi method	Technological Forecasting and Social Change	100	2006	[*Gordon, Pease*, 2006]
Murat Bengisu and Ramzi Nekhili	Forecasting emerging technologies with the aid of science and technology databases	Technological Forecasting and Social Change	99	2006	[*Bengisu, Nekhili*, 2006]

Source: compiled by the authors.

Figure 6. **Ego Network of the Main Keyword "Decision Making"**



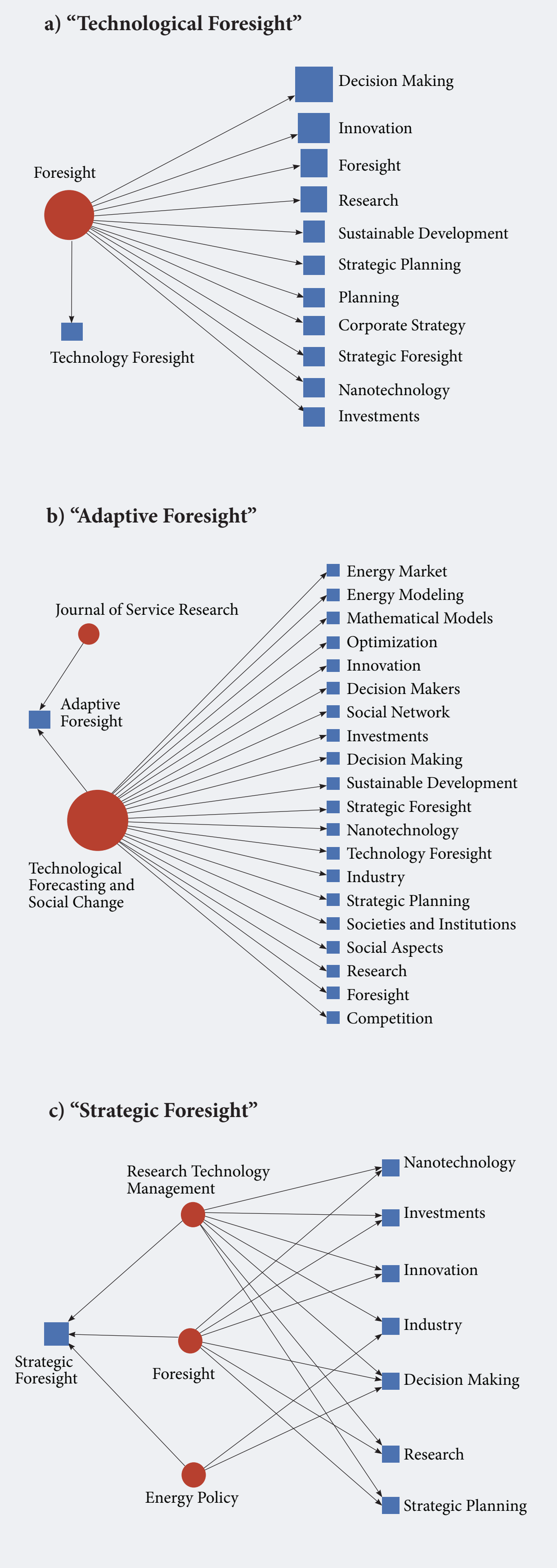
Source: compiled by the authors.

Discussion

Foresight literature is often classified as either descriptive or normative [*Andersen et al.*, 2014]. Descriptive research is concerned with definitional consensus. Early efforts by researchers such as Irvine and Martin [*Martin*, 2010], Coates [*Coates*, 1985], and Miles [*Miles*, 2010] drove some degree of definitional consensus.

New methods and tools expanded the scope and methodologies. For example, Web 2.0 technologies created an opportunity for researchers to explore new methods such as online frameworks, social networks and mass collaboration approaches. This can be seen in a more recent description of foresight "as a social cognition process involving a complex set of methods and interactive process intended to assist policy in becoming more adaptive and forward-oriented in unpredictable environments" [*Mendonça et al.*, 2012]. Web 3.0 readily incorporates machine learning techniques.

Figure 7. **Sorted Ego Networks**



Source: compiled by the authors.

Grouping the concepts identified in Figure 3 shows that the majority of the research attempts to address the purpose, approach, and criteria. Figure 9 shows when the concepts are grouped into the concept of methods (social networks, modeling, optimization, Delphi, and scenarios) they are not as highly ranked as those grouped by purpose (decision making, innovation, research, competition, and sustainable development).

Policy making and public policy rank 44th and 45th, respectively. Decision making and innovation rank 1st and 2nd. Thus, a proper foresight study requires an innovative design approach and a structured process.

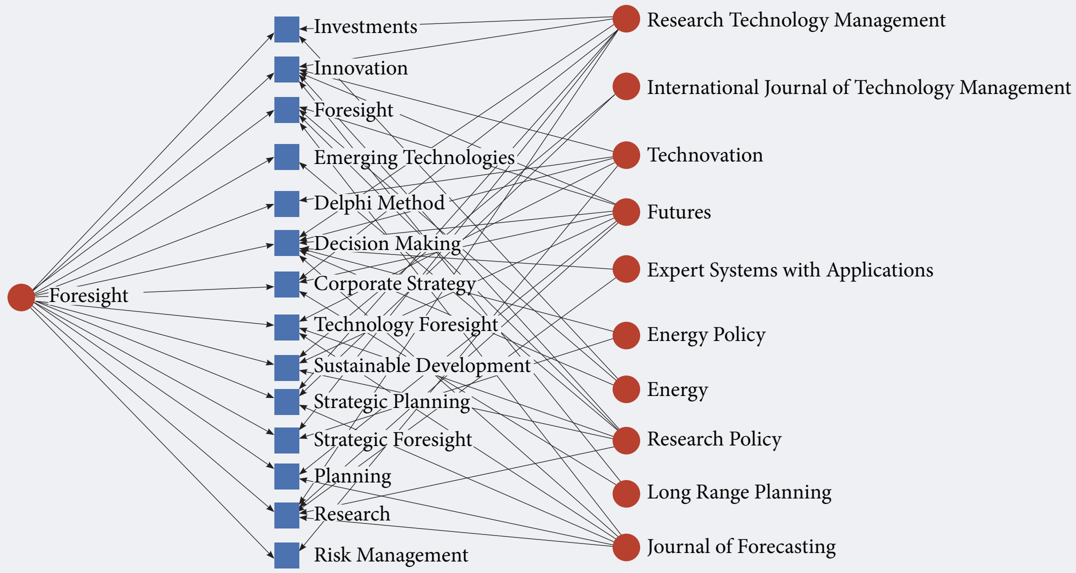
Initiating a Foresight Study

Coates states that "useful futures work can be performed on any scale, with any time dimension, and for any purpose" [*Coates*, 2010, p. 1431]. While the openness of the scope facilitates multi-disciplined use; it can lead to a lack of stakeholder consensus about the problem. This creates challenges. First, socio-technical and environmental problems are inherently complex because they are a national concern that involves cultural value and belief systems [*Geels*, 2004]. There is increasing uncertainty about a future that is approaching more rapidly than ever before. Thus, initiating a foresight study includes developing and documenting a clear purpose, articulating expected outputs, outcomes, impact, and structuring an approach.

Even when the mission is clear, stakeholders from different disciplines come with different perspectives. This is further complicated by an increased emphasis on collaborative research. While some researchers argue that the domain be restricted for a greater impact, others argue that foresight activities should span multiple domains [*Calof, Smith*, 2009]. In general, public entities involve governments and not-for-profit organizations, who seek knowledge expansion. Private and commercial entities, on the other hand, are becoming increasingly concerned about sustainable business. The lack of consensus in the foresight literature and related concepts is not caused by methodologies, but rather by scoping activities. Porter [*Porter*, 2005] argues the importance of understanding motivation. If explorative, foresight activities attempt to identify possible radical futures. However, if normative, the purpose is to identify a singular path towards one possible future. Thus, it is critical to clearly understand the purpose and target audience.

Foresight is important for national technology planning, commercial strategies, and industrial knowledge. Industrial groups, government, and academia conduct studies for knowledge expansion [*Andersen et al.*, 2014; *Gallouj et al.*, 2015]. Many countries engage in national foresight programs to assist them in cultural expansion or policy setting [*Georghiou, Cassingena Harper*, 2013; *Keenan, Popper*, 2008]. Most nations consider foresight activities essential for the health of their knowledge-based economies [*Grupp, Linstone*, 1999]. Companies, increasingly wary of disruption from changing market drivers [*Rohrbeck*, 2012], turn to foresight for options. Corporations use foresight activities for policy creation [*Georghiou, Cassingena Harper*, 2013], corporate sustainability [*Costanzo*, 2004; *Rohrbeck, Gemünden*, 2011; *Destatte*, 2010], or expansion [*Kodama*, 2004; *Ju, Sohn*, 2015]. For example, rapidly evolving nanotechnologies are of particular interest to the ICT and medical fields [*Loveridge, Saritas*, 2009]. Each organization has a unique interest in conducting foresight. Foresight studies

Figure 8. **Ego Network for *Foresight***



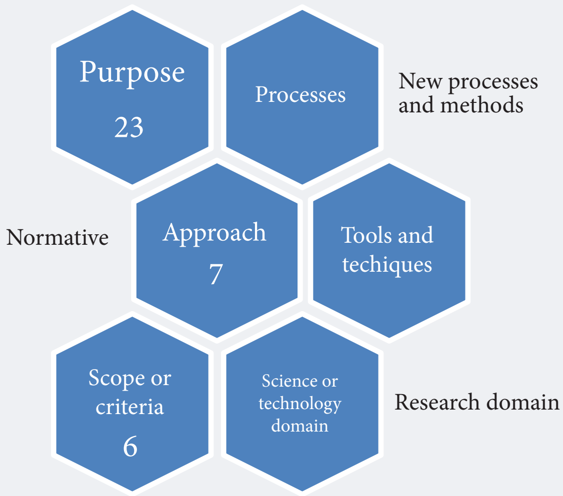
Source: compiled by the authors.

concerned with quality of life problems have a different focus than studies concerned with sustainable business [*Wilburn, Wilburn,* 2011].

Foresight is a process with inputs and outputs. In a properly designed foresight study, clear outputs that meet stakeholder expectations must be defined immediately. What are the outputs of a foresight study? One way to answer this question is to describe which group or process will be using the output from this activity as their input. If the purpose is to help identify changes to technology policy, the output could be in the form of a formal report or briefing. The outcome could be the drafting of a new bill and the impact could be its passage.

There are two main schools of thought about how to best approach technology foresight activities and prediction. The difference in these approaches seem to lie in the question of predicting a future by creating a strategic plan to make that future happen or by envisioning a direction that holds multiple possible futures and starting along a directional path open to adapting said vision of the future. Researchers affiliated with US institutions have related the terms "normative" to a desirable future perspective and "explorative" to a possible future [*Roper et al.*, 2011]. For example, Major et al. [*Major et al.*, 2001] argue

Figure 9. **Foresight Concepts**



Source: compiled by the authors.

that foresight is aligned with strategic planning and management. In France, *la prospective* is discussed in terms of *futuribles* (possible futures) and *futurables* (desirable futures) [*Godet,* 2010]. Habegger argues for the benefit of distinguishing between possible and probable futures for improved policy development [*Habegger,* 2010]. Today, *prospective* has close ties with the concepts of strategic foresight [*Godet,* 2010]. Australia effectively used a strategic foresight approach to develop public policy [*Leigh,* 2003]. Public and private entities have been engaging more frequently in foresight activities that use both approaches [*Habegger,* 2010].

The Adaptive vs. Strategic Approach

The timeline and amount of environmental uncertainty must be established when selecting an approach [*Coates,* 2010]. Strategic foresight is more about identifying a preferable or desired future and creating a plan to achieve it. The adaptive (explorative) approach uses a modular design and a highly iterative foresight process [*Lin et al.,* 2012] to transform the future as it evolves [*Carlson,* 2004]. The more dynamic the environment, the more an adaptive foresight process is needed to combat the greater amount of uncertainty in the continuously shifting environment [*Andriopoulos, Gotsi,* 2006]. In the late 1990s, McMaster introduced the concept of continuous integration into foresight activities while placing an emphasis on the "structure of the future" [*McMaster,* 1996, p. 149]. His argument that emerging technologies disrupted the scale of prediction rendered much of the past information irrelevant. This means that the structure of the future is more important than attempting to discern any linear nature or pattern detailing the shape of its path. Thus, he proposed that the structure of the future is a set of relationships within a complex adaptive system. Van der Meulen et al. discuss the fact that integrating learning through an interactive process provides more value and impact [*van der Meulen et al.,* 2003].

Most of the adaptive foresight literature is focused on exploring new business opportunities in highly uncertain environments [*Heger, Rohrbeck,* 2012; *Rohrbeck et al.,* 2015; *Castorena et al.,* 2013]. This is not surprising because the number of "traditional industries undergoing radical change due to emerging technologies is unprecedented" [*Groen, Walsh,* 2013, p. 187]. In these dynamic environments, firms are finding it increasingly difficult to sustain their competitive advantages or even survive [*Costanzo,* 2004; *Rohrbeck, Bade,* 2012]. This complexity is driving higher levels of uncertainty, requiring decision makers to become more proactive in identifying different industry directions and possible futures. Thus, businesses require more relevant and timely [*Robinson et al.,* 2013] intelligence to successfully respond to triggers [*Rohrbeck,* 2012] and apply strategic-foresight techniques for complex planning tasks such as exploring new business fields [*Alkemade, Suurs,* 2012; *Heger, Rohrbeck,* 2012; *Rohrbeck, Kaab,* 2013].

Statistical evidence shows a positive relationship between foresight and firm performance [*Amsteus,* 2011b]; however, quantitative studies comparing the different approaches are missing. Figure 10 shows how adaptive foresight differs from strategic foresight.

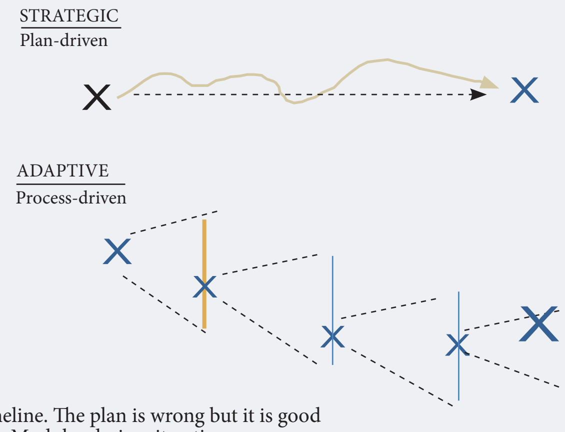
Some researchers [*Rohrbeck, Oliver,* 2013] believe that adaptive foresight may be the better method for emerging companies because the environment is dynamic and there is deep uncertainty [*Hamarat et al.,* 2013]. What these companies need is a set of future visions that can be used in current decision making practices that are adaptable for future-oriented practices [*Brummer et al.,* 2008]. Coates agrees that "there is a need for the development of easily comprehensible, timely, and cheap sources" of technological forecasting for small companies [*Coates et al.,* 2001, p. 15].

The adaptive foresight approach could also be more appropriate for developing countries [*Lin et al.,* 2012] because the expense, time, and other resource requirements are simply out of reach for developing countries that are strapped for cash with limited resources. However, one has to be careful in working with experts in different countries where there is great uncertainty [*Knight,* 1921] as experts will have differing motivations. On the other hand, Havas explored national foresight activities in a small country with a bias towards planning [*Havas,* 2003]. Others have also concluded that size, style, and culture matters [*Keenan, Popper,* 2008]. Cultural expectations and values are often associated with time. As more tools and methods are being introduced into the foresight process and societal problems become more complex, the adaptive approach is gaining popularity in both the public and private sectors.

In the adaptive school of thought, it is also critical to maintain an open foresight attitude to facilitate optimal cognitive learning [*Bootz,* 2010]. This is explained as being open to new or weak signals for the continued analysis of alternate possible paths. Actions will create new data for analysis over time as the firm marches towards a future unspecified point in a general direction. Within this context, learning is a key component because the managers conducting the foresight activities may also have an influence over the firm's actions. Bezold conducted a study to explore the effective use of scenarios and found parallel plausible paths through scenarios leading to the conclusion that a direction could be set for the path while work continues to clarify the vision [*Bezold,* 2010]. Thus, managers operating under these deeply uncertain environments are leaning towards the adaptive school of thought [*Amsteus,* 2011a; *Kwakkel, Pruyt,* 2013] for the purpose of sustainable business.

One must organize and structure the studies around a set of defined criteria. Typical criteria, in addition to the time horizon [*Vecchiato, Roveda,* 2010] and the environmental uncertainty, may include: resource requirements, the domain, and the risk tolerance associated with the output. Researchers know that

Figure 10. **A Comparison Foresight Approaches**



Deep uncertainty, short timeline. The plan is wrong but it is good enough to point a direction. Modular design, iterative process.

Source: compiled by the authors.

no forecasting model captures the entire reality of the current environment and that the output never represents an accurate forecast. In foresight activities there is increased uncertainty as the future timeline is extended. As technology has rapidly advanced, researchers are becoming increasingly concerned about how to improve the foresight process and tailor it to different domains for different purposes [*Heger, Boman,* 2015].

Executing a Foresight Study

Selecting the right experts, designing data collection processes, and leveraging new methods and innovative analysis techniques are required for conducting a proper study. Many stakeholders and panels of experts are needed in order to balance perspectives. One French foresight exercise determined that 100 experts were not adequate and selected 50 more [*Durand,* 2003]. The selection of experts must take a balanced approach by carefully considering perspectives about technologies, industry, and culture.

The methods and tools used in foresight activities are eclectic, flexible, complex, and sophisticated [*Coates,* 2010]. Data collection methods and analysis techniques are rapidly evolving. Methods identified in Table 2 with high rankings include: bibliometrics, SNA, simulation and modeling, mathematical models and algorithms, optimization, Delphi surveys, business forecasting tools and techniques, and scenario analysis. Data collection methods and analysis techniques were grouped into quantitative, qualitative, or hybrid methods for further discussion.

Quantitative methods are numerically based and apply statistical analyses. Many of these tools are commonly found in forecasting activities. Some of these methods include: data-mining, bibliometrics and extrapolation.

Qualitative methods collect contextual data that can be analyzed to provide meaning to events and perceptions. Some of these tools and methods include: backcasting, brainstorming, panels, gaming, interviews, morphological boxes, and surveys. The hybrid methods are primarily focused on quantifying expert judgment. Some of these methods include cross-impact analysis, Delphi, multi-criteria analysis, scenario analysis, and roadmapping.

Delphi is popular as a data collection method because expert panels are "one of the most frequently used methods in foresight" [*Daim et al.,* 2009, p. 32]. When used effectively, the Delphi method creates consensus and clarifies disagreements between experts. The experts remain anonymous in the process and the method is often combined with other methods such as other expert panels, mapping, scenarios, etc. Several researchers provided good discussions about characteristics pertaining to selecting and working with experts [*Loveridge, Saritas,* 2009; *Tichy,* 2004].

Scanning and scouting for strategic intelligence are other methods to collect data. This area is evolving in the literature because monitoring for information can be difficult and some of the signals can be weak [*Ilmola, Kuusi,* 2006], disjointed, or convoluted with inconsistent terminology. Open attitudes are critical in order to avoid introducing bias.

Delphi surveys, scenario analysis, and roadmapping are used to promote creativity based upon the assumptions about the future, the collection of knowledge and experience from experts, and the interaction of experts to find a congruent collective consensus [*Cachia et al.,* 2007]. While foresight activities may use some purely qualitative methods that are narrative based, a proper study requires multiple tools and methods [*Smith, Saritas,* 2011].

Different methods have varying strengths and weaknesses. For example, if the objective is to identify low probability-high impact events, also known as a black swan, forecasting methods could be used based upon what-if scenarios. This also illustrates how the qualitative method of scenario planning is mixed with heavily quantitative forecasting methods. On the other hand, if an organization is concerned about sustainable development or emerging industries, combing the patent databases using bibliometrics could detect patterns in R&D or shifting resources.

Coates [*Coates,* 2010] identifies and describes the use of over seventeen different methods in the description of a properly conducted futures study. Popper [*Popper,* 2008], conducted an extensive research study to investigate how methods are selected and applied by examining 886 different foresight studies from around the globe. The resulting diamond-shaped framework classified thirty-three of the most important methods in terms of interaction, creativity, evidence, and expertise.

A foresight study is a project with a beginning, an end, specific purpose and outcomes requiring multiple processes and activities. A framework is useful to manage complexity. Figure 11 adapts Voros's three-phase framework [*Voros*, 2003] to map methods that help selecting methods to conduct a three-phase study: initiating, executing, and communicating the results. Five dimensions were used to map each method: purpose, time, domain, uncertainty level, and resource availability.

The systematic use of a framework is important. Consider how stakeholders involved in both foresight planning activities and policy development can influence actions [*Bootz,* 2010]. Without an open attitude about knowledge expansion, bias towards a particular path may eliminate other worthy avenues prematurely. Including objectives for both knowledge creation and sustainable business helps one find a balance between knowledge expansion for the sake of knowledge expansion or knowledge expansion for the sake of sustainable business.

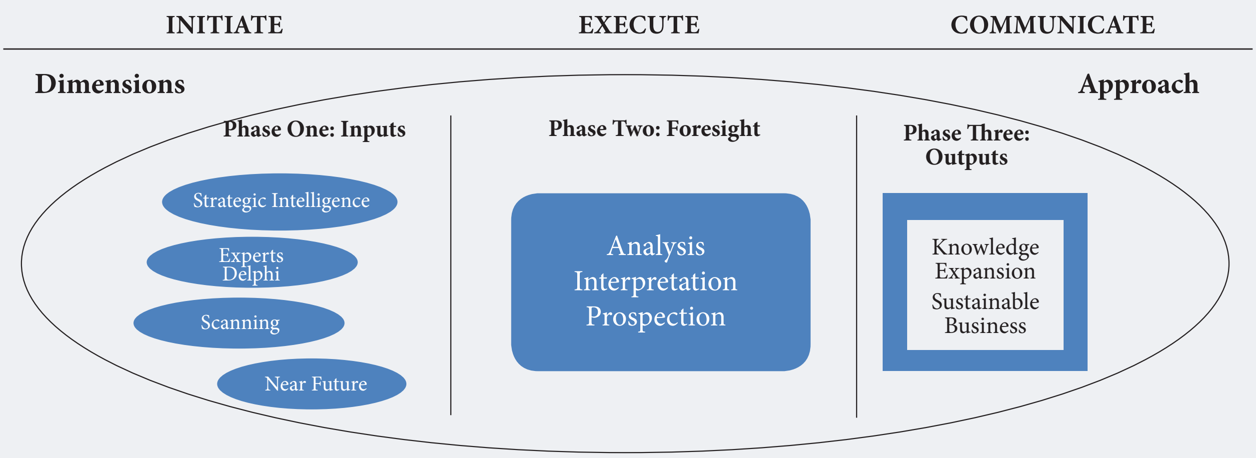
Porter discusses how during a normative study, the preferable future is characterized by ethics, values, and virtues [*Porter et al.,* 2004]. Glenn and Coates [*Glenn, Coates,* 2009] describe normative forecasts as consisting of two essential parts: (1) the statement of a goal or set of goals to be accomplished in a specific time period and (2) a detailed analysis of how to reach the goal or goals. Porter clarifies that normative techniques are more goal-oriented, working towards a firm's mission. Thus, normative techniques tend to move backwards in attempt to control actions aimed at realizing the vision. The construction of normative narratives can create scenarios for out-of-the-box thinking that helps to break conventional thinking patterns [*Andreescu et al.,* 2013]. Examples of purely normative methods are: analytical hierarchy process (HDM), backcasting, multi-criteria decision analyses, participatory techniques, requirements analysis, science fiction analysis, and stakeholder analysis.

Explorative techniques investigate future possibilities depicted by scenarios of shifting forces; using historical chronological data that spans from the past into the future. An exploratory forecasting exercise is undertaken for the purpose of examining where the future may go without any consideration of whether people or society want it to go there or not. Examples of purely exploratory methods are: agent modeling, analogies, bibliometrics, causal models, checklists for impact identification, complex adaptive system modeling, correlation analysis, cost-benefit analysis, cross-impact analysis, demographics, diffusion modeling, economic base modeling, innovation system modeling, institutional analysis, long wave analysis, monitoring, organizational analysis, precursor analysis, sustainability analysis, systems simulation, technological substitution, technology assessment, and trend extrapolation. Some methods are a combination of both normative and exploratory forecasting. These methods include: action analysis, brainstorming, creativity workshops, decision analysis, Delphi, focus groups, interviews, multiple perspectives assessment, risk analysis, roadmapping, scenarios, scenario-simulation, social impact assessment, and TRIZ (theory of the resolution of invention-related tasks).

Time is a key dimension in any foresight activity. Is the possible future to be specified for the near future, next future, or far future? For example, Alsan and Oner's research [*Alsan, Oner,* 2003] defines the time periods as follows: at the normative level — eight to thirty years, the strategic level — four to seven years, and the operative level — one to three years. The time dimension began to be more directly linked to the different approaches and impact levels. For example, Johnston [*Johnston,* 2012] described the impact in terms of instrumental, conceptual, and capacity building. Other time relationships are discussed in terms of output objectives such as knowledge building and business sustainability. Other researchers use only two: future and past where the time in the past is extrapolated into the future using present conditions and criteria. Recently, researchers have been looking to technology foresight rather than forecasting for even shorter time spans for environments where deep uncertainty prevails [*Hamarat et al.,* 2013]. Typically for the same environment, the farther into the future, the more uncertain is the prediction of what the environment will be. However, it is known that different environments carry different unknowns with different uncertainties [*Keenan, Popper,* 2008]. Thus, the domain is another dimension to consider.

High or deep levels of uncertainty can impact the time horizon [*Hamarat et al.,* 2013; *Salo, Gustafsson,* 2003] and method selections. For example, Andreescu et al. [*Andreescu et al.,* 2013] illustrated how the method of scenario analysis was selected for a systems foresight exercise because the domain for the

Figure 11. **Framework for Mapping Methods**



Scanning
Bibliometrics
Crowd Sourcing
Scouting
Expert Networks
Literature Review
Trends/Drivers/Indicators
System Mapping
Panel Workshops
Checklists for Impact

Gaming, Scenario Planning
Wild Card / Weak Signals
Network Analysis
Agent-based Modeling
Dynamic Simulations
Panel Workshops
SWOT Analysis
Multi-Criteria Analysis
Scenario Comparisons
Causal Models
Adaptive Modeling
Trend Extrapolation
Delphi
Scoring/Voting
Benefit/Cost/Risk Analysis
Backcasting
Roadmapping
Emerging Pathways
Correlation Analysis
Long Wave Analysis

Relevance Trees
Roadmaps
Strategic Plans
Logic Charts
Priority Lists
Impact Assessments

Primary Method Key: Black = Strategic (Normative), *Italic =Adaptive (Explorative)*, **Bold = Both**.

Source: compiled by the authors. based on [*Voros*, 2003].

future university education environment in Romania was highly uncertain and little historical data was available [*Andreescu et al.,* 2013]. Others have selected patent data mining over Delphi because Delphi uses expert quantification and is time sensitive [*Hung et al.,* 2013]. Thus, time and uncertainty is highly dependent upon the domain.

Some foresight methods are known to require significant monetary resources and time such as Delphi, scenarios, participatory methods, and technology roadmapping. Thus, these high resource methods, while effective and popular, may simply not be practical due to either monetary or time restrictions. Methods most commonly referenced for small and emerging companies include: backcasting, bibliometrics, diffusion modeling, longwave analysis, monitoring technological substitution, trend extrapolation, and scenario analysis. Companies that use these less resource-intensive methods could also include difficult industries currently experiencing a great amount of uncertainty such as bio-tech, health [*Masum et al.,* 2010], and universities [*Andreescu et al.,* 2013]. Companies operating in this domain require adaptive and robust foresight activities [*Kwakkel, Pruyt,* 2013; *Hamarat et al.,* 2013].

Ruff conducted an extensive research study on how small and medium enterprises (SMEs) conduct strategic foresight [*Ruff,* 2006]. What he found was they are operating in a vastly different resource environment, lacking strategic planning organizations, research and technology divisions, and other support functions. Thus, many of the technology foresight methods are simply not practical for them. He also found their time span was shorter, typically from 1–10 years and the duration of the foresight activity lasted between 3–6 months. Therefore, the major methods for this group would be data-mining and bibliometric techniques, expert interviews, technology monitoring/scanning, quantitative models, and trend research. While several researchers noted a gap in this research, Ruff's study was the only study found in the content analysis of literature that focused on SMEs.

One reason may be that the process requires flexibility in the selection of input criteria and methods to achieve expected outcomes. Input criteria such as market drivers or technical parameters may be highly uncertain. Or, enterprises may be faced with new market drivers and technical constraints where time series data for the desired criteria may simply not be available. In these cases, researchers have found the tools and methods to be lacking [*Barker, Smith,* 1995] and that they require additional research [*Linstone,* 2011]. Some progress has been made with new data mining techniques [*Huang et al.,* 2014] that create smarter ways to capture large amounts of data. These tools are useful to examine and understand the dynamics of the emerging field. Another problem is that the data may be located in pockets and change rapidly, which makes it more difficult to apply these data mining techniques.

Communicate Results

The dissemination of the results to the appropriate audience is important. The foresight process uses multiple methods requiring increasing amounts of communication. One strength in technology roadmapping is that a map is produced as part of the activity. This output can be used as a blueprint facilitating communication that facilitates making a new technology a reality. Whether the outputs are in the form of a written report, document, presentation, or roadmap it is critical that the results are communicated and disseminated.

Conclusions and Directions for Future Research

Rapidly increasing technology, tools, and methods require that facilitators of foresight activities use a framework to initiate, execute, and conclude each study. Methods used to conduct a proper foresight study in the past may no longer be relevant for the problem under consideration today.

The study shows marked improvement in and the usage of bibliometric tools used for data and text mining and patent analysis. Porter's work has significantly contributed to this trend [*Porter,* 2005]. "Computation and simulation are becoming indispensable for managing the complexities of future variables and the enormous range of drivers, factors, and implications" [*Smith, Saritas,* 2011]. Better tools can be used concurrently with one another in order to yield better results. Communication and the importance and breadth of stakeholders continues to be an important discussion point.

The other trend is the move towards iterative processes and sustainable business. Literature increasingly emphasizes the importance of measuring the impact of the study. This can only be done by continuously testing assumptions and predictions against the baseline study. Many researchers have documented a gap in foresight research between theory and practice [*Georghiou, Cassingena Harper,* 2013; *Keenan, Popper,* 2008; *Bootz,* 2010]. One reason may be that the activity may provide a competitive edge, so companies are not willing to share their information. Taken a step further, organizations may be viewing foresight activities as a core competency that provides a competitive advantage. Eriksson and Weber [*Eriksson, Weber,* 2008] discuss this in more detail and others have begun to fill the gap with case studies [*Andersen, Rasmussen,* 2014] and examinations of weak signals [*Battistella, de Toni,* 2011]. The bottom line here is that better evaluation tools are necessary [*van der Meulen et al.,* 2003] before foresight activities can become a part of routine decision making [*Glenn,* 2013]. More research is needed to understand which organizational structure [*Cagnin et al.,* 2013] and measurement system [*Schwartz,* 2008] are needed because currently the results are often vague and difficult to integrate into corporation [*Durand,* 2008]. Rohrbeck and Schwarz call for more research to understand the value generated by foresight methods for the corporation and which practices will best deliver that value [*Heger, Rohrbeck,* 2012; *Rohrbeck, Oliver,* 2013; *Schwartz,* 2008].

Other researchers noted gaps between other fields [*Könnölä et al.,* 2007], suggesting foresight draw from other academic disciplines such as strategic management [*Amsteus,* 2011a], innovation systems [*Alkemade, Suurs,* 2012; *Andersen et al.,* 2014; *Smith, Saritas,* 2011], or cultural differences [*Andersen, Rasmussen,* 2014] and style [*Keenan, Popper,* 2008]. Strategic decision making under conditions of uncertainty is a key concern for technology managers. Despite the importance for sustainable business, the research connecting foresight theory with strategic decision making is sparse [*Vecchiato,* 2012]. Saritas sheds some light on the fragmentation by explaining that foresight is highly context-dependent [*Elena-Pérez et al.,* 2011]. Others consider the connections with other foresight activities critical and emphasize the importance of networking with 'distributive intelligence tools' [*de Lattre-Gasquet et al.,* 2003].

The quantitative analyses provided above can be further improved by trying to normalize the results by using the impact factors of the journals. This would be an interesting test of the relevance of our results.

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Smart by Oneself? An Analysis of Russian Regional Innovation Strategies within the RIS3 Framework

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Abstract

Less than a decade since its official introduction, smart specialization, which guides the selection of priorities for innovative development, has proven to be a far-reaching academic idea and political instrument. In the European Union, smart specialization is mentioned among the *ex ante* conditions for receiving subsidies from European structural and investment funds. Its core principles are considered in innovation strategies in Australia, South Korea, and some countries of Latin America. In Russia, smart specialization is also being introduced in the agenda of policymakers.

The paper seeks to reveal which levels of governance should be involved in the design of a smart specialization strategy and which factors should be the focus of attention when using this approach. The research is based upon an analysis of the innovation strategies of seven Russian regions, conducted with the adapted RIS3 Self-Assessment Wheel.

The results of the study empirically confirm that most principles of smart specialization are considered, at least formally, in the traditional innovation strategies of Russian regions. At the same time, without common rules for the selection, verification, and synchronization of innovative priorities as well as a single analytical database, organizational support, and expertise, even regions considered strong innovators fail to find their smart specialization.

Keywords: smart specialization; regional innovation strategy; regions; Smart Specialization Platform; interregional cooperation.

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Promoting innovation is a national policy priority and a part of the relevant agenda in many countries [European Commission, 2009, 2010; OECD, 2012a]. In recent years, regions commanded increasingly more attention in this context [EU CoR, 2016; *Bellini, Landabaso,* 2007; *Charles et al.,* 2000]. Spatial proximity and local factors play an important role in knowledge creation and in transforming it into innovative products: OECD studies revealed extremely active interaction between innovative actors located within about a 200-kilometer radius from one another [OECD, 2013, p. 13]. However, innovation processes are distinctly region-specific. For example, regions' innovation activity depends upon the profoundly uneven distribution of R&D potential. In particular, two-thirds of the total R&D expenditures in the US are made by just 10 states [NSF, 2007]. Similarly, 58% of patent applications, 30% of R&D expenditures, and 25% of highly skilled professionals are concentrated in 10% of the largest regions in OECD member countries [OECD, 2013a, p. 15]. Innovation activities are exceptionally varied, and R&D leadership is by no means the only source of innovations. Innovations related to social processes, culture, and creative industries as well as the creation and development of new business models are no less important for regional development. The above stresses that each region has its own development path, while universal innovation promotion recipes do not always turn out to be adequate, not by far [*Tödtling, Trippl,* 2005].

Regions' growing interest in innovation was accompanied by the increased application of a systemic approach to its promotion in the R&D sphere (the regional innovation systems concept [*Asheim, Isaksen,* 1997, 2002; *Cooke,* 1992, 2002]; learning regions [*Florida,* 1995; *Morgan,* 1997]; innovative environment [*Camagni,* 1995; *Maillat,* 1997]; innovation networks [*Cooke,* 1999; *Doloreux,* 2004]); and in the political domain (clusters [*Porter,* 1990, 1998], smart cities [*Glaeser, Berry,* 2006; *Hollands,* 2008], and civic universities [*Goddard et al.,* 2013]). Having turned into a strategic planning area at the regional level [*Landabaso et al.,* 1999; *Charles et al.,* 2000; IRE, 2008], most regions in the innovative sphere did not eliminate their various flaws [*Foray et al.,* 2009; Technopolis Group, 2011; *Capello, Kroll,* 2016]. Many regional innovation strategies remain removed from the global economic and technological contexts, in effect boiling down to a simple imitation of successful regions' behavior. The proposed measures are mostly aimed at supporting R&D, not promoting demand or market access. Such documents are often focused on fashionable topics or prestigious projects (e.g., information and communication technologies (ICT), bio- or nanotechnology), even if the region lacks the sufficient number of companies specializing in such areas. On the other hand, traditional industries still have priority over more complex inter-industry and inter-cluster projects.

The above problems are further aggravated by insufficient coordination between different-level agencies, leading to the duplication of support initiatives and the dispersal of limited resources, which ultimately undermines the efficiency of government regulation. At the political level, this issue was first articulated in the European Union (EU), which was concerned with finding a balance between the various decision-making levels. One would have thought that a logical way to eliminate the duplication of competences and fragmentation of support measures would be setting development priorities for each EU region. However, the complexity and diversity of modern technologies, and that of their economic applications [OECD, Eurostat, 2005; *Smith,* 2006; *Warwick,* 2013], make centralizing this sphere an extremely risky proposition. The European Commission funded the development of regional innovation strategies, first of all in unitary nations, i.e., the new member states with no decentralization experience or traditions [*Morgan, Nauwelaers,* 1999]. More than 100 such projects were supported since 1995, but the overall productivity of this effort has turned out to be insufficient due to the low quality of regional strategic governance. An alternative to the approaches that failed to live up to expectations became smart specialization strategies (S3).

Smart specialization is a collection of rules for setting priorities in the scope of an innovative development strategy. The rules are presented in a single EU methodological document titled "Guide to Research and Innovation Strategies for Smart Specialisations" [European Commission, 2012] (further, the Guide). Smart specialization implies a division of responsibilities between management levels: at the (supra) national level, the general conditions for strategy development and implementation are set, along with the verification of priorities and the creation of unified databases for analytical comparison; at the regional level, the actual priority setting for innovative development takes place, together with the development and implementation of strategies and the establishment of relevant coordination structures. On the Smart Specialization Platform website,[1] more than 170 registered regions present their innovation priorities identified using the common European methodology [European Commission, 2016b].

Proposed by the Knowledge for Growth expert group of the European Commission's Directorate-General for Research and Innovation [*Foray et al.,* 2009] only in 2009, the smart specialization concept found very strong demand in the economic policy domain. Its official definition is provided in the European Parliament's Directive of December 17, 2013; according to it, smart specialization strategies are:

[1] Access mode: http://s3platform.jrc.ec.europa.eu/, last accessed on 17.06.2017.

> … the national or regional innovation strategies which set priorities in order to build competitive advantage by developing and matching one's own research and innovation strengths to business needs in order to address emerging opportunities and market developments in a coherent manner, while avoiding the duplication and fragmentation of efforts [European Parliament, 2013].

Having such strategies in place is a precondition for regions' receiving subsidies from the European structural and investment funds (ESIF), whose combined budget for 2014–2020 amounts to 454 billion euros [European Commission, 2016a].

The smart specialization concept has also been adopted outside the EU, and is currently applied by the OECD [OECD, 2012b, 2013b] and the UN [UNECE, 2014, 2015]. Some of the relevant principles are reflected in Australian and South Korean innovative development strategies [OECD, 2013b]. In the scope of the Polos de Competitividad project,[2] Argentina, Brazil, Colombia, Costa Rica, Mexico, Peru, Uruguay, Ecuador, and Chile created a databank comprising 579 industry-specific priorities for 49 regions using smart specialization tools [*Guillonnet et al.,* 2015; *del Castillo et al.,* 2016]. However, the active borrowing of relevant principles and methodologies by various countries puts into doubt the very possibility of designing smart innovation development strategies for specific regions without having an open (supra)national comparison system and standardized requirements to document quality, which so far only exist in the EU. This paper addresses this issue by using the example of seven Russian regions which have adopted their own innovative development strategies. Our objective is to find out which smart specialization characteristics can be considered "natural" ones, i.e., those inherent to high-quality regional strategies including those designed before the relevant methodological recommendations were published and which require special effort outside the scope of strategic regional governance.

Literature Review

The smart specialization concept was originally proposed in a series of studies conducted in 2007–2009 [*Foray, van Ark,* 2007; *Foray et al.,* 2009], which have subsequently engendered more than a hundred publications[3]. As the authors note,

> The smart specialisation phenomenon is by no means new. <…> This simple idea was around for quite some while, and only needed some academic legitimacy [*Foray et al.,* 2011, p. 4–6].

An analysis of papers on the subject allows one to identify the properties distinguishing "smart" strategies from conventional ones. First of all, the former take into account the regional economy's profile [*Barca et al.,* 2012; *McCann, Ortega-Argilés,* 2016]. The application of tacit knowledge and local competences to set development priorities leads to differentiation and the creation of unique market niches for regional investments [*Edmondson et al.,* 2014; OECD, 2013b; *Frenken et al.,* 2007]. Another distinctive feature of smart specialization strategies is their substantiation using an extensive empirical basis [*Kroll et al.,* 2014]: they contain verifiable performance indicators which meet the requirements of numerous expert evaluation studies [*Barca,* 2009]. The single-industry priority setting principle inherent in conventional strategies is being replaced by approaches based on diversification, related variety [*Boschma, Iammarino,* 2009; *McCann, Ortega-Argilés,* 2015], and strong interdisciplinary links [*Foray,* 2013; *Kroll,* 2015]. Smart specialization originates at the junction of industries and their intersection with new emerging S&T areas where the region has a chance to become a leader. This multi-discipline approach provides an answer to global socioeconomic challenges, which require moving beyond the scope of the conventional knowledge areas' nomenclature [*Foray et al.,* 2009]. The inter-industrial nature of smart specialization implies the need to set priorities which merge industrial, technological, and social competences in a new way, for example, this can be done by using ICT to lead an active, healthy lifestyle during one's later years [*Iacobucci, Guzzini,* 2016; *Giannitsis,* 2009].

An important objective of setting innovative development priorities is finding a unique niche for the region on the map of future markets and technologies [*Foray et al.,* 2011; *Hidalgo, Hausmann,* 2009]. Foresight as a smart specialization tool [European Commission, 2012, p. 33] that helps identify global technology trends in the current and potential industries of regional specialization and offers a range of formats for joining various players' efforts and methods for improving communications between them.

Smart specialization studies are frequently based on a broad understanding of innovation as a strictly science-oriented process based on R&D results or as user-initiated social and service innovations, which belong in the medium- and low-tech industries. This understanding can prompt structural changes in the regional economy [*Hughes,* 2012; *Moretti,* 2012; World Bank, 2010; *Edmondson et al.,* 2014; *Kroll,* 2015]. One of the approaches to smart specialization implies matching the region's competences to general-purpose technologies such as, for example, micro- and nano-electronics, photonics, nanotechnology, industrial biotechnology, new materials, advanced production technologies, and ICT [*Larsen,* 2011].

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[2] The project's objective was to find new approaches to economic transformation with an emphasis on innovation and increased cooperation with the EU. The project is sponsored by the EU-LAC foundation established in 2010 by heads of the EU countries and members of the Community of Latin American and Caribbean States. The foundation strives to strengthen cooperation between countries located on both sides of the Atlantic, promote joint projects, and extend the value chains. On October 25, 2016, the foundation received international organization status.

[3] According to Scopus, as of 24.01.2017.

Box 1. The Guggenheim Effect

Apart from the regions that develop or scale general-purpose technologies, there are territories where innovative development is driven not by engineering knowledge per se, but by its amalgamation with the humanities. For example, developing specialized software for finding historical artifacts helped Florence become a major global center of advanced information technologies for archaeological applications. This result would hardly have been possible had the stake been made on developing the ICT industry as a whole. Such a cumulative effect from specific innovations in arts and architecture was named after the branch of the Solomon Guggenheim Museum of Modern Art, which has turned the provincial industrial town of Bilbao into a fashionable tourist center. This effect has transformed depression-struck areas into prosperous global centers through the creation of unusual art objects and is capable of powerfully affecting the local economy. Located in northern Spain, Bilbao was able to successfully deal with the 1970s-1980s recession by implementing its Strategic Reconstruction Plan, the core element of which was building a world-class art gallery.

Source: [*Vicario, Monje*, 2003].

Very few regions have the groundwork R&D results in the above areas. Others should concentrate on applying the available results and products in priority activity areas to increase their efficiency.

Smart specialization researchers stress that developing a high-quality strategy begins with finding the region's place in global value chains, followed by analyzing and benchmarking other similarly structured territories [*Thissen et al.,* 2013; *Kroll,* 2015]. Strategies should be open and must be subjected to external evaluation by "critical friends" — experts from other regions with a similar specialization [European Commission, 2012]. The potential for inter-regional cooperation must be assessed over the course of the strategy's development taking into account the natural interconnection of various regions' smart specializations [*Foray,* 2013; *Iacobucci,* 2014]. Making use of the various formats for inter-regional cooperation is believed to be an important aspect of (supra)national strategic planning, particularly for the allocation of resources and the coordination of innovation promotion initiatives [*Iacobucci, Guzzini,* 2016].

Synchronization, i.e., multiphase management based on smooth communications and a clear division of responsibilities between various levels, is seen as another feature of smart specialization strategies [*McCann, Ortega-Argilés,* 2016; *Kroll et al.,* 2014; *Barca,* 2009]. At the regional level, all stakeholders become involved in priority-setting, strategy development, and implementation. On the (supra) national level, more basic strategizing rules are formulated, along with the requirements for innovative development priorities and their verification. Unified databases for an analytical comparison are also created. Finally, synchronization implies finding a balance between the bottom-up (entrepreneurial search) and top-down (bureaucratic priority setting and strategy development) approaches [*McCann, Ortega-Argilés,* 2014].

Entrepreneurial search — one of the central ideas of the smart specialization concept — frequently leads to the emergence of practical problems [*Estensoro, Larrea,* 2016]. The chances that entrepreneurs will be able to identify promising areas for the region's leadership on their own are quite small [*Iacobucci,* 2014]. The linear growth of specialization areas seems to be a more realistic scenario than efficient priority setting by a wide circle of players [*Boschma,* 2014]. Interaction with the regional community may turn out to be less than efficient if small groups pursuing their own vested interests usurp communications with the public authorities. A possible remedy for that is multilevel coordination [*Coffano, Foray,* 2014; *Capello,* 2014; *Kroll,* 2015; *Estensoro, Larrea,* 2016].

Table 1 summarizes the main characteristics of smart specialization strategies presented in the literature and shows under which conditions and at which management level regional innovation strategies would match these criteria.

Trying to select one key characteristic out of the aforementioned ones leads one to conclude that when applied to regional strategies, the adjective "smart" actually means "unique". However, it is not support measures that are unique (it would be impossible to design specific tools for each particular region), but the development priorities, which channel competences and resources accumulated in the region over the course of entrepreneurial search into new areas of activity [*Hausmann, Roderik,* 2003].

Each area's uniqueness is due to an increased regional division of labor. Without being valuable in itself, this brings benefits even in the absence of an adequate cost difference [*Ricardo*, 1817; *Formaini*, 2004]. Another source of uniqueness is differentiation used as a competitive tool (along with price leadership). The latter threatens long-term prosperity and is unavailable in "expensive" (in terms of production costs) countries, including the EU members. Such nations must compete on the basis of business conditions, human capital, and by making their positions unique among other territories. In this case "unique" means "no cheaper alternatives are available". If regions belong in the same country or union, uniqueness prompts one to look for solutions beneficial to all concerned parties (a win-win strategy). Increased

Table 1. **Characteristics of Smart Specialisation Strategies**

Characteristic	Implementation conditions	Level
Making use of the region's unique competitive advantages	Following recommendations in the Guide to Research and Innovation Strategies for Smart Specialisations [European Commission, 2012]	Regional (internal)
Selecting valid specialization areas		
Setting inter-industrial priorities		
A broad understanding of innovation		
Orienting oneself towards future markets and technologies		
Taking into account other regions' strengths and specialization areas, including foreign ones	Having a top-level structure that sets requirements for the strategies, and ensures their compatibility (an analogue of the EU Smart Specialisation Platform)	(Supra)national (external)
Synchronizing with different management levels		

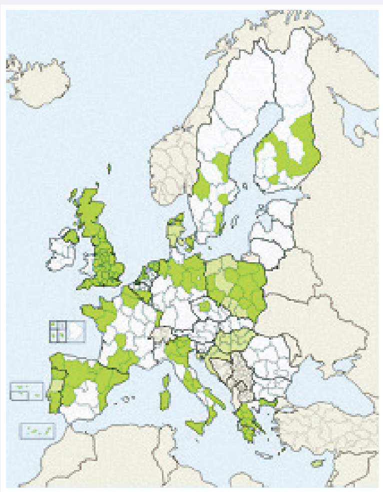
Source: composed by the authors.

diversity also increases the probability of designing new, successful regional development models and the increased efficiency of public R&D investments.

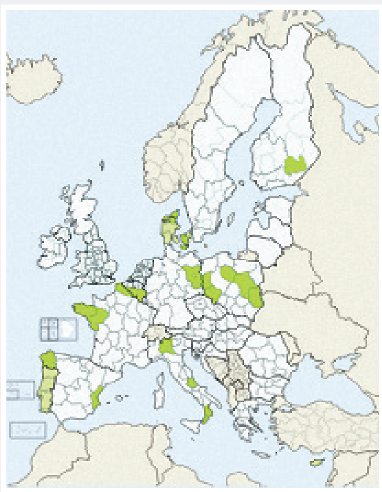
Here uniqueness is achieved by combining internal knowledge (which is personalized, unavailable outside the region, and obtained over the course of the entrepreneurial search) with external knowledge (global trends, other regions' strategies, and (supra)national priorities and programmes). It would not be possible to find a unique development path on the basis of internal knowledge alone because uniqueness is a relative category which becomes meaningful only by comparison. Unlike the conventional approach which implies an analysis and replication of more successful regions' best practices, learning from other

Box 2. **Setting up Regional Specialization Areas in the Context of the EU Priorities and Target Markets**

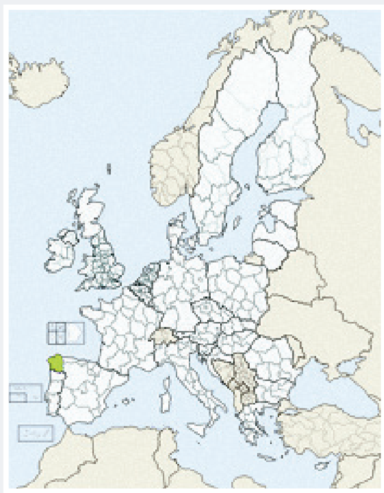
Many of the regions registered on the Platform have chosen agriculture and the food industry as their priority competency areas (the left figure). However, if we overlay the EU's health and safety priorities, the number of competitive regions drops (the figure at the center). Finally, if we project the selected specialization areas over the target health-related markets, just one region retains a competitive advantage (the right figure). Thus, Spanish Galicia found its unique niche in the healthy foods segment. Food industry innovations as a basis of healthy lifestyles and longevity became one of the three priorities of the region's smart specialization strategy for 2014-2020. The region had all the necessary prerequisites: an aging population (23% of the residents were aged 65+) and one of the highest shares of the food industry in the GRP in Southern Europe. Interestingly, for a long time this industry remained quite conservative in terms of the technologies it used. The strategy designers noted this fact and improved upon the conventional approaches by applying innovative solutions.



(1) Regional competences:
agriculture, food industry



(1)+(2) EU priorities:
people's health and safety



(1)+(2)+(3) EU target markets:
healthcare

Source: composed by the authors [Xunta de Galicia, 2014; European Commission, 2016b].

regions in the smart specialization perspective is aimed at finding, and substantiating, one's own, original solutions.

The internal component of smart specialization can by now be deemed thoroughly developed. The Guide describes six strategy development steps: analyzing the regional context, setting up management structures, forging a common vision, setting priorities, implementing policies, and monitoring and evaluating. Additional information is readily available as well — the proceedings of international conferences[4] and specialized reports [*Ketels et al.,* 2013; *Foray, Goenaga,* 2013; *Gianelle, Kleibrink,* 2015]. Therefore, implementing a smart specialization strategy only requires a relevant decision by the regional authorities, since the "entry threshold" for regions outside the EU is relatively low. It is therefore hardly surprising that some non-EU regions have already started designing their own innovation strategies following the smart specialization model [OECD, 2013b; *del Castillo et al.,* 2016].

To provide external knowledge to the EU regions, a specialized open Smart Specialization Platform (S3 Platform, further on referred to as the Platform) was established in 2011 on the basis of the European Commission Joint Research Centre (JRC). Unlike the Guide, the Platform's practical experience as an applied institutional innovation is poorly reflected in the literature [*McCann, Ortega-Argilés,* 2016; *Capello, Kroll,* 2016]. It is designed to provide information, methodological, and expert support for the national and regional authorities and to promote mutual learning and inter-regional cooperation [European Commission, 2016b]. The Platform's research and project team comprises 21 people, and its Coordination Council includes representatives from six General Directorates of the European Commission[5]. A database of priorities was created in the framework of the Platform, currently featuring more than a thousand entries. The priorities are broken down into several categories, allowing regions to present their specialization in considerable detail. The Platform uses various analytical and organizational tools which help to make use of regions' unique competitive advantages when designing their development strategies.

The costs associated with transplanting the external smart specialization component into countries outside the EU would be relatively high, since this requires their national authorities to make relevant decisions and allocate sufficient resources. This probably explains why so far attempts to apply smart specialization strategies were primarily made at the regional level: it is the regions who take targeted steps to improve the strategy's quality by adapting specific principles described in the Guide. There is no information about any attempts to create something like the Platform to deal with the lack of external knowledge at the national or supranational level.

It is commonly believed that the lack of global perspective significantly reduces the quality of the strategy: it would be very difficult (if at all possible) for regions to overcome innovation-related bottlenecks on their own, even if they followed the right recommendations [*Kroll,* 2015; *Capello, Kroll,* 2016]. An authority responsible for setting requirements for strategies and for their valid compatibility is needed to take necessary corrective action. [*Landabaso,* 2014; *McCann, Ortega-Argilés,* 2014]. Fragmented data about specific strategies' flaws [*Reid, Stanovnik,* 2013; *Iacobucci,* 2014; *Capello, Kroll,* 2016] are insufficient to definitively establish which factors, internal or external, create the biggest problems. In particular, this is due to the fact that existing studies are mostly devoted to EU countries where the Platform is in place, which allows them to reduce the shortage of external knowledge. The experience of countries lacking such tools clearly demonstrates the true value of the Platform.

Our objective is to acquire a deeper understanding of the scope for and suitability of applying the smart specialization concept to countries outside the EU. This implies assessing the productivity of its application at the regional level, the sufficiency of locally made decisions and locally available resources, or, on the contrary, the need for an upper-level regulatory authority. In the latter case, decisions made even by the most advanced regions should be deemed insufficient by default; a systemic national-level approach would be preferable (political will, resources, time). In our opinion, the number of countries applying various elements of the smart specialization concept will only keep growing, so it is important to find out exactly which of its characteristics seem clear and logical to the regional authorities, and which should be studied and explained in more detail.

Two hypotheses on how regional innovation strategies adopted by countries outside the EU match the smart specialization criteria are proposed, using Russian regions as examples:

Hypothesis 1: Regional innovation strategies (including those developed before the publication of the Guide in 2012) do have most of the smart specialization characteristics, at least formally.

Hypothesis 2: Without national-level coordination (standardized rules for setting, verifying, and synchronizing priorities, a common analytical database, organizational support), even the most advanced innovative regions will not be able to develop a smart strategy on their own.

The object of our study is strategies, not regions. While we are aware of the mismatch between the actual state of affairs and official documents, we still believe that on the whole, the latter do provide

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[4] E.g.: 1st SMARTER Conference on Smart Specialisation and Territorial Development, September 28-30, 2016, Seville, Spain. See http://www.regionalstudies.org/conferences/conference/smart-specialisation for more (last accessed on 23.03.2017).

[5] Directorates for Region and Urban Policy; Research and Innovation; Education and Culture; Agriculture and Rural Development; Internal Market, Industry, Entrepreneurship and SMEs; Communications Networks, Content and Technology.

reliable indicators of the quality of regional-level strategic management. We also accept that regions may objectively opt for a specialization that might not necessarily match the officially established priorities. At the same time, the current specialization should not be confused with priorities reflecting a vision of the future. Regions seem to be in the best position to forge the latter, since they merge local and global knowledge and, given efficient communication, such priorities do serve as a basis for strategies.

Though originally formulated and institutionalized in the EU, smart specialization rules still are not Europe-specific and can be applied elsewhere. Firstly, they are largely based on best practices accumulated the world over. Secondly, they are particularly relevant in countries which face similar problems with managing regional development, such as uncoordinated support initiatives and the duplication of priorities, which in turn is due to a large territory, significant regional diversity, and the high level of autonomy of national provinces (regions) or union members. The above problems are also present in Russia, albeit not exactly to the same degree as those in the EU, so many of the smart specialization characteristics, even given the lack of standardized federal-level requirements, are in fact reflected in Russian regions' innovative development strategies.

Initial Data and Methodology

The Russian case study is perfect for testing our hypotheses given the relative comparability with the EU in terms of size, geographical diversity, and the relevance of the challenges of duplication and innovation policy fragmentation. The country is among the ten largest in the world in terms of population and GDP at purchasing power parity [Eurostat, 2016; U.S. Census Bureau, 2016; Rosstat, 2016; International Monetary Fund, 2016].

In addition to geographical, environmental, climatic, demographic, and socio-cultural diversity, Russia also demonstrates significant disparity in the regions' socioeconomic development, an uneven distribution of economic potential, and residential patterns.

Differentiation between the most and least developed regions' monthly per capita monetary income deciles is 3.3 times; note that in just 25% of them is this indicator higher than the Russian average value [Rosstat, 2016].

The federal system implies that regional administrations pursue their own policies within their spheres of competence[6], including innovation policy. In 2014, about half of the regions implemented such policies to a varying degree (Figure 1). For example, 42 regions designed strategic innovation activity plans and 35 had in place long-term socioeconomic strategies[7] which paid significant attention to promoting innovation-based development. Seven regions adopted specific innovation strategies, including the Ingush Republic (innovation strategy approved in 2012)[8], Tatarstan (2008)[9], the Kamchatka (2010)[10], Krasnoyarsk (2011)[11], Stavropol (2009)[12], Sverdlovsk (2013)[13], and Chelyabinsk (2012)[14] Regions.

The following hypotheses were tested:

Hypothesis 1: Russian regions' innovation development strategies on the whole do reflect each of the six steps of the smart specialization methodology but only meet a third of the relevant criteria. The steps specifically addressing development and implementation issues (priorities, policies, monitoring and evaluation) match a larger number of criteria than the steps taken at the preparatory stage (analyzing regional context, management, common vision).

Hypothesis 2: Innovation development priorities specified in the strategies are poorly justified; they frequently do not take into account the region's potential and opportunities, and/or the competitive advantages of other territories. In most cases, productivity indicators do not allow one to measure growth in the selected specialization areas. The various formats used to set priorities and performance indicators

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6 Constitution of the Russian Federation, 1993, art. 73. Access mode: http://www.constitution.ru, last accessed on 22.02.2017.

7 Federal Law "On Strategic Planning in the Russian Federation" No. 172-FZ of 28.06.2014.

8 Innovation Development Strategy of the Ingush Republic until 2025. Approved by the Government of the Ingush Republic's Order No. 433-r of 30.06.2012. Access mode: http://www.ingushetia.ru/m-news/archives/Komitet.doc, last accessed on 21.01.2018.

9 Strategy for Development of Innovation and Research Activities in the Republic of Tatarstan until 2015. Approved by the Tatarstan Republic's Presidential Decree No. UP-293 of 17.06.2008. Access mode: http://docs.cntd.ru/document/917029427, last accessed on 21.01.2018.

10 Innovation Development Strategy of the Kamchatka Region until 2025. Approved by the Kamchatka Regional Government's Order No. 594-RP of 03.12.2010. Access mode: http://docs.cntd.ru/document/446224061, last accessed on 21.01.2018.

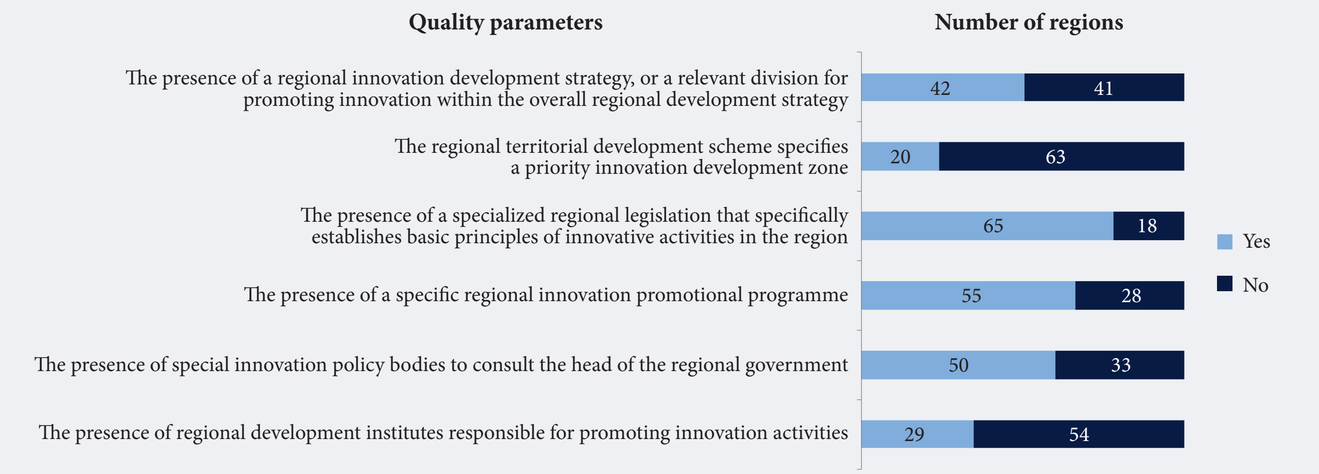
11 Innovation Development Strategy of the Stavropol Region until 2020. Approved by the order of the Stavropol Regional Ministry of Economic Development No. 220/od of 29.06.2009. Access mode: http://docs.cntd.ru/document/424060824, last accessed on 21.01.2018.

12 Innovation Development Strategy of the Krasnoyarsk Region until 2020 "Innovation Region 2020". Approved by the Governor of the Krasnoyarsk Region's Decree No. 218-UG of 24.11.2011. Access mode: http://docs.cntd.ru/document/985024710, last accessed on 21.01.2018.

13 Innovation Development Strategy of the Sverdlovsk Region until 2020. Approved by the Sverdlovsk Regional Government Order No. 646-PP of 22.05.2013. Access mode: http://docs.cntd.ru/document/453135952, last accessed on 21.01.2018.

14 Innovation Development Strategy of the Chelyabinsk Region until 2020. Approved by the Chelyabinsk Regional Government Regulation No. 260-rp of 12.10.2012. Access mode: http://docs.cntd.ru/document/444933641, last accessed on 21.01.2018.

Figure 1. **Quality Indicators of Russian Regional Innovation Policies: 2014**



Note: At the time of the study no data was available for Crimea and Sebastopol.
Source: composed by the authors, based on [HSE, 2016].

reduce the opportunity for comparing the documents and hinder the creation of unique regional strategies.

"Pure" conditions for testing the above hypotheses include absence of the following:

- the "smart specialization" phrase in the 2012–2013 strategies (i.e., those approved after the Guide was published);
- specific indications that this concept was considered and taken into account;
- relevant directives by the federal authorities;
- analogues of the Smart Specialization Platform in Russia.

The paper presents an analysis of seven Russian regional innovative development strategies to assess how they match the smart specialization criteria. Socioeconomic development strategies only containing specific sections on promoting innovation and innovation development concepts were not analyzed, because they do not fully match the definition of a smart specialization strategy. The study was based on open information sources including the regional administrations' official websites and specialized legislation databases.

The regions which adopted innovation development strategies are quite different, both in terms of their macroeconomic indicators (Figure 2), and innovative development level (Table 2).

The regions under study include the leader of the national ranking (the Republic of Tatarstan, 1st place) and outliers (the Kamchatka Region at the 71st position and the Ingush Republic at 82nd). The Krasnoyarsk, Stavropol, Sverdlovsk, and Chelyabinsk Regions are among the top 25 in terms of overall regional innovative potential. The analysis of the sample did not reveal any patterns: specialized strategies were developed in regions with quite different levels of and structures for innovation development.

The first hypothesis was tested using the adapted RIS3 Self-Assessment Wheel tool [European Commission, 2016b]. Basically, the methodology amounts to assessing regional strategies on a scale from 0 to 5 using 18 criteria which break down the six steps of designing smart specialization strategies described in the Guide. Accordingly, the Russian regions' strategies were also checked for matching the smart specialization criteria. The six-point scale was modified to a three-point one (from 0 to 1), where 0 = no match, 0.5 = inferred match, and 1 = clear match (see Table 3).

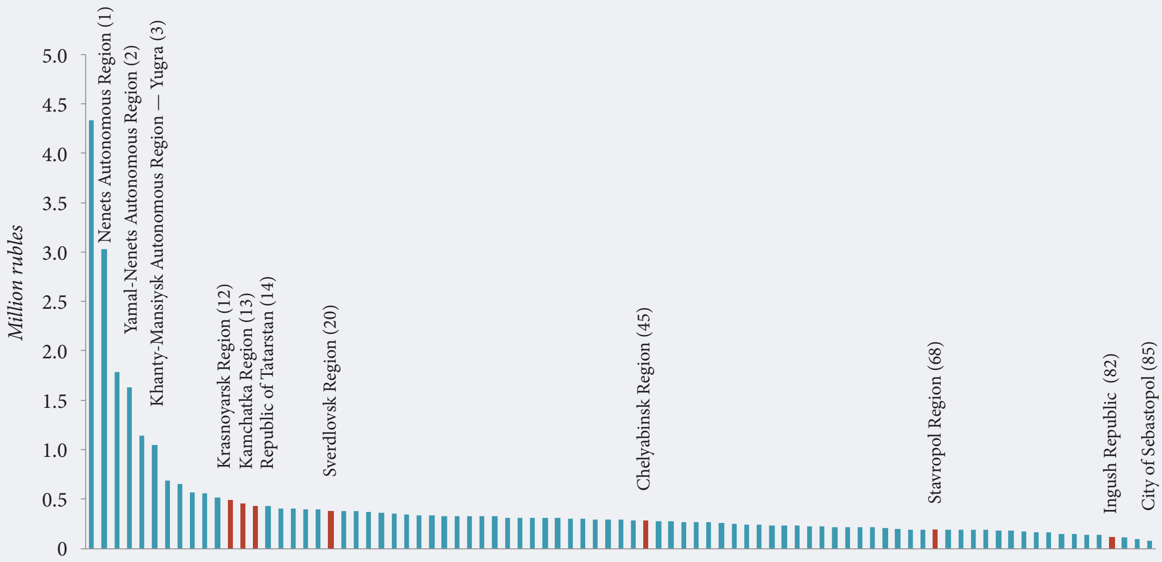
The second hypothesis was tested by checking the validity of specialization industries' selection and that of the performance targets specified in the analyzed documents.

Results

Testing Hypothesis 1

Table 4 and Figure 3 below present the summarized results of the analysis of the regional innovation strategies (detailed results, including the assessment of all documents, are presented in Table 5). The value "7" in the "Total score" column means that all seven documents clearly matched the relevant smart specialization criteria; zero indicates no match at all. A fractional number (e.g., 4.5) means that for at least one strategy a match was inferred.

Figure 2. **Position of Regions that Have Innovation Development Strategies in the Russian Regions' per Capita GRP Ranking (2014)**



Note: regions that have innovative development strategies are highlighted in dark-red.

Source: [Rosstat, 2016].

The calculations show that Russian regional innovation strategies on average match 37% of smart specialization criteria. First of all, it applies to Steps 4 (priorities), 5 (policies), and 6 (monitoring and evaluation), which specify practical approaches to strategy development. As to the preparatory steps, i.e., Steps 1 (analyzing the regional context), 2 (management), and 3 (common vision), all strategies matched the relevant criteria only to a minimal degree (Figure 4)

The weakest aspects of the innovation strategies turned out to be "Analyzing the external environment" (Step 1) and "Involving a wide range of stakeholders" (Step 2). Practically all strategies saw innovations exclusively in R&D terms and ignored global challenges (Step 3). Comparing the regions by their Russian Regional Innovation Index (RRII) values and by the degree of their innovation strategies' matching smart specialization criteria did not reveal any direct correlation between regional innovative potential and strategy quality. The Sverdlovsk Region, the leader in terms of matching the smart specialization criteria (11 out of 18) [HSE, 2016], has a relatively high position in the ranking (the 13th). However, the Krasnodar Region (12th place on the RRII) matches the smart specialization criteria only minimally (4 out of 18), while the Kamchatka Region (72nd place on the RRII) comes second after the Sverdlovsk Region in criteria matching terms (matches 9 criteria out of 18). The Republic of Tatarstan's strategy (1st place on the RRII) matches only one-third of the criteria (6 out of 18) (Figure 5).

To verify this conclusion, we compared the evaluation results for two regions with polar opposite positions on the innovative development ranking: the Republic of Tatarstan (1st place) and the Ingush Republic (82nd place).

Table 2. **Distribution of Regions by Russian Regional Innovation Index and Sub-indices (2014 data)**

Region	Ranking				
	Russian Regional Innovation Index	Socioeconomic Conditions for Innovation Activities Index	S&T Potential Index	Organizations' Innovation Activities Index	Regional Innovation Policy Quality Index
Republic of Tatarstan	1	3	17	2	1
Krasnoyarsk Region	12	19	19	22	6
Sverdlovsk Region	13	14	13	14	26
Chelyabinsk Region	18	12	28	21	29
Stavropol Region	23	24	51	39	10
Kamchatka Region	71	77	77	66	49
Ingush Republic	82	81	83	82	60

Source: composed by the authors based on [HSE, 2016].

Table 3. **Assessment Criteria for Russian Regions' Innovation Strategies**

No.	Criterion	Description
Step 1. Analysing regional context		
1.	Analyzing regional resources	• Analyzing strengths and weaknesses, threats and opportunities for creating innovations in the region • Describing innovative potential in the region's specialization areas • Identifying unique competitive advantages of the regional innovation system's participants
2.	Analyzing external environment	• Comparing the region with other regions • Analyzing the experience of other regions with similar specialization areas (benchmarking) • Analyzing inter-regional cooperation: trade, economic, S&T, etc.
3.	Analyzing entrepreneurial activity	• Assessing the level of the entrepreneurial environment in the region • Presence of clusters, associations and alliances (business and consumer ones), start-up firms, various forms of self-employment, live laboratories • Identifying promising market niches
Step 2. Management		
4.	Putting in place a multilevel management system	• Establishing specialized agencies responsible for strategy development (e.g., a supervisory board, a project office, special working groups) • Allocating duties and responsibilities (general management, current management, designing specific projects)
5.	Involving a wide range of stakeholders	• Involving various groups in strategy development: public authorities, businesses, R&D organizations, civil society, expert community (including experts from other countries/regions)
6.	Developing management and communication techniques	• Use of open, interactive formats for interaction between public authorities, businesses, and citizens over the course of strategy development
Step 3. Common vision		
7.	Using a broad understanding of innovation	• Developing strategies keeping in mind the various forms of innovations including organisational, social, service, and user-induced ones, as opposed to those only based on S&T results
8.	Addressing global challenges	• Setting innovation development priorities (initiatives, projects) on the basis of their contribution to meeting global economic and social challenges
9.	Using scenario analysis	• Preparing several innovation development scenarios for the region • Preparing action plans for each possible scenario
Step 4. Priorities		
10.	Setting priorities	• Identifying a limited number of specific specialisation areas for the region (existing or potential), to promote the development of innovation and create/strengthen unique competitive advantages • Taking into account the results of analysing the regional context and external environment, and the consolidated position of the regional innovation system's participants
11.	Coordinating priorities	• Coordinating one's priorities with national S&T and innovation priorities • Linking the selected priorities to general-purpose technologies
12.	Achieving critical mass	• Allocating adequate resources to implement selected priorities, and making sure the region has sufficient entrepreneurial potential to concentrate resources on the selected priorities
Step 5. Policies		
13.	Using roadmaps	• Making sure the strategy includes implementation plans (roadmaps) and pilot projects in the selected specialization areas
14.	Implementing a balanced set of measures	• Combining horizontal and precision support initiatives to implement the strategy
15.	Creating adequate framework conditions	• Designing and implementing policies to improve the business climate, promote R&D, civil initiatives, etc.
Step 6. Monitoring and evaluation		
16.	Using performance indicators	• Selecting a limited number of key performance indicators linked with specific priorities, objectives, and timeframes
17.	Strategy implementation monitoring system	• In place/absent
18.	Mechanism for updating the strategy	• In place/absent

Note: Two criteria were modified: "Revision of the past priorities" was changed to "Setting priorities", and "RIS3 update" — to "Mechanism for updating the strategy".

Source: composed by the authors based on [European Commission, 2012].

Table 4. **Summarized Evaluation Results of Russian Regional Innovation Strategies**

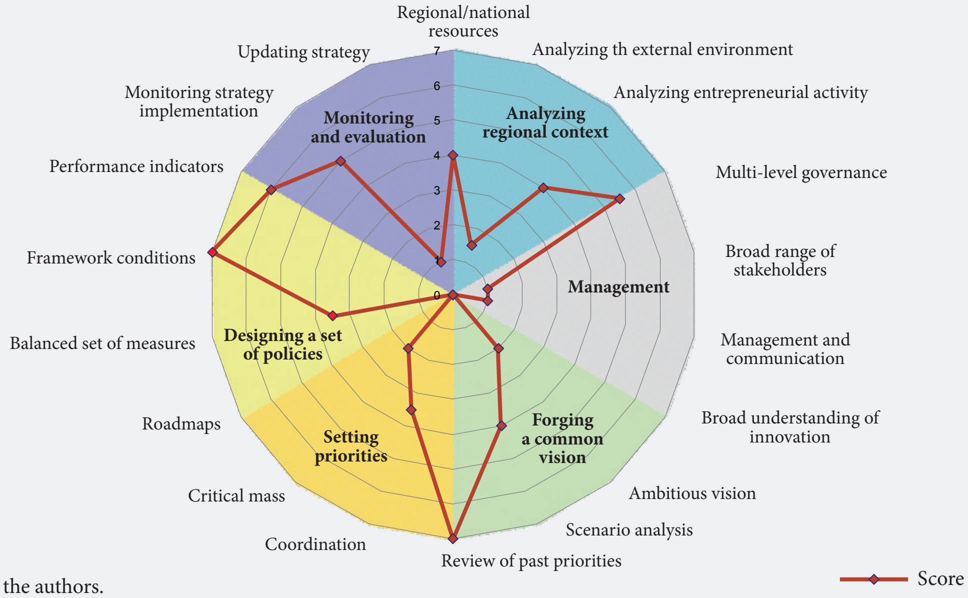
Strategy development step	Evaluation criteria	Total score	Total for the step
1. Analysing regional context	Analyzing regional resources	5	9
	Analyzing external environment	1	
	Analyzing entrepreneurial activity	3	
2. Management	Putting into place a multilevel management system	3.5	9.5
	Involving a wide range of stakeholders	2	
	Developing management and communication techniques	4	
3. Common vision	Using a broad understanding of innovation	0.5	6.5
	Addressing global challenges	1.5	
	Using scenario analysis	4.5	
4. Priorities	Setting priorities	7	11.5
	Coordinating priorities	2.5	
	Achieving critical mass	2	
5. Policies	Using roadmaps	0	11.5
	Implementing a balanced set of measures	4.5	
	Creating adequate framework conditions	7	
6. Monitoring and evaluation	Using performance indicators	7	13.5
	Strategy implementation monitoring system	5	
	Mechanism for updating the strategy	1.5	

Source: calculated by the authors.

The calculations (Figures 6 and 7) show that despite the almost threefold differentiation between these regions' innovative development level[15], their strategies have quite similar characteristics:

- a poor preparatory stage (low scores for analysis, management, and common vision criteria), against the background of a quite advanced practical implementation stage (high scores for priorities, policies, and monitoring and evaluation criteria);
- a fragmented matching of smart specialization criteria: both strategies do reflect each of the six criteria specified in the Guide, but neither matches all the criteria.

Figure 3. **Summarised Results of Assessing Russian Regional Innovation Strategies' Matches with Smart Specialisation Criteria**



Source: composed by the authors.

[15] The RRII differentiation is calculated as the ratio of RRII values of the sample's leader (Tatarstan, 0.5625) and the region at the bottom of the ranking (the Ingush Republic, 0.1909) and was 2.94.

Table 5. **Assessment of Russian Regional Innovation Development Strategies' Matching Smart Specialisation Criteria**

No.	Criterion	Assessment of Russian regional innovation development strategies' matching smart specialization criteria						
		I	II	III	IV	V	VI	VII
Step 1. Analysing regional context								
1.	Analyzing regional resources	0.5	0.5	1	1	1	0.5	0.5
2.	Analyzing external environment	0	0	1	0	0	0	0
3.	Analyzing entrepreneurial activity	0.5	0	1	1	0	0	0.5
Step 2. Management								
4.	Putting into place a multilevel management system	0	1	0.5	0.5	0.5	0.5	0.5
5.	Involving a wide range of stakeholders	0.5	0.5	1	0	0	0	0
6.	Developing management and communication techniques	0.5	0.5	0.5	0.5	0.5	0.5	1
Step 3. Common vision								
7.	Using a broad understanding of innovation	0.5	0	0	0	0	0	0
8.	Addressing global challenges	0.5	0	0	0	1	0	0
9.	Using scenario analysis	0	1	1	0.5	1	0	1
Step 4. Priorities								
10.	Setting priorities	1	1	1	1	1	1	1
11.	Coordinating priorities	0	0	1	0.5	0.5	0.5	0
12.	Achieving critical mass	0.5	0	1	0.5	0	0	0
Step 5. Policies								
13.	Using roadmaps	0	0	0	0	0	0	0
14.	Implementing a balanced set of measures	1	0	1	1	1	0	0.5
15.	Creating adequate framework conditions	1	1	1	1	1	1	1
Step 6. Monitoring and evaluation								
16.	Using performance indicators	1	1	1	1	1	1	1
17.	Strategy implementation monitoring system	1	1	0	0	1	1	1
18.	Mechanism for updating the strategy	0	0.5	0	0	1	0	0

Note: I — Ingush Republic; II — Republic of Tatarstan; III — Sverdlovsk Region; IV — Stavropol Region; V — Kamchatka Region; VI — Krasnoyarsk Region; VII — Chelyabinsk Region.

Source: calculated by the authors.

Despite having similar patterns of strengths and weaknesses, these innovation strategies differ in specific smart specialization criteria. For example, the Ingush Republic's strategy, unlike the Tatarstan's, places an emphasis upon promoting entrepreneurial activity (analysis and priority setting), using a broad understanding of innovation, applying it to address global challenges, and balancing horizontal and precision support measures. Meanwhile, Tatarstan's strategy makes provisions for a multilevel management system, scenario analysis, and an updating mechanism.

The identified differences between the strategies regarding smart specialization criteria (which can be described as subjective) only partially match the objective indicators of the regions' innovation development level (as measured by the RRII).

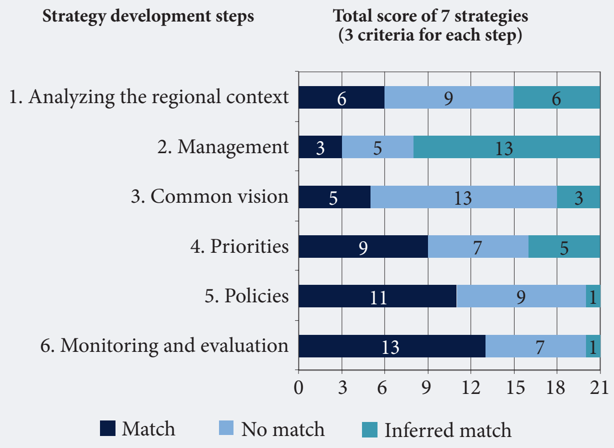
For example, in terms of providing organizational support for innovation policy, the Republic of Tatarstan is the national leader, while the Ingush Republic holds 61st place in the ranking (zero value of this parameter). Another example: the Ingush Republic's innovation strategy does not specifically describe businesses as active participants in innovative activities. This region has zero values for all indicators that are used to calculate the Innovation Activities of Organizations sub-index [HSE, 2016].

Testing Hypothesis 2

The analysis of the strategies included in the sample revealed that all these documents formally meet the "Setting priorities" and "Using performance indicators" criteria. Therefore, at the next step of the study, we checked the validity of the selected regional specialization industries and the adequacy of the applied performance indicators. Figure 8 shows the frequency of mentioning various industries as priority ones in Russian regions' innovation strategies.

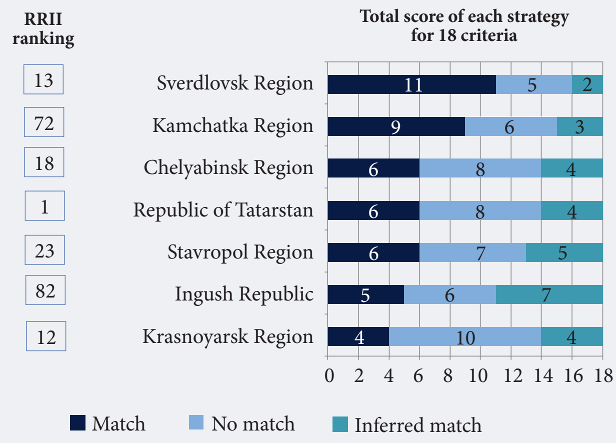
To assess validity of the selected priorities, the sectors' relative weight in the national and regional economy was calculated. Conducting an integrated analysis and preparing recommendations for specific regions goes beyond the scope of this study, so we used only the most common indicators and assessment techniques.

Figure 4. **Distribution of Russian Regional Innovation Strategies' Evaluation Results by Strategy Development Steps**



Source: composed by the authors.

Figure 5. **Comparison of Russian Regions' Innovation Development Rankings with the Number of Smart Specialization Criteria Their Innovation Strategies Match**



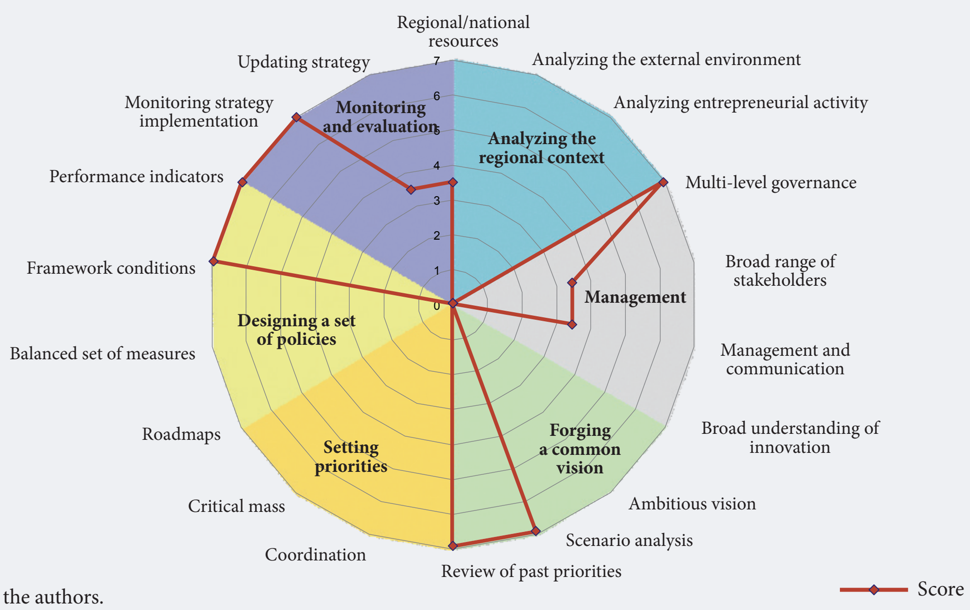
Source: composed by the authors based on [HSE, 2016].

The test analysis covered two sectors: ICT and the nanotechnology industry (Figures 9 and 10). Other industries selected as strategic priorities were not considered. The reason was that in most cases they were obvious choices determined by the regions' traditional specialization (e.g., agriculture in the Stavropol Region, tourism in the Ingush Republic and Kamchatka Region), or alternatively, there were no established economic activities in the region (and, accordingly, no relevant statistical data was available) in such areas as biomedicine or energy efficiency.

In only one out of the five regions that have set the ICT sector as an innovation development priority was this industry's development level higher than the Russian average (in the Republic of Tatarstan). In other regions, this indicator was below the national average value and in some regions, it was even below the average for the relevant federal district, which, in our opinion, puts the decision to set it as a priority in doubt.

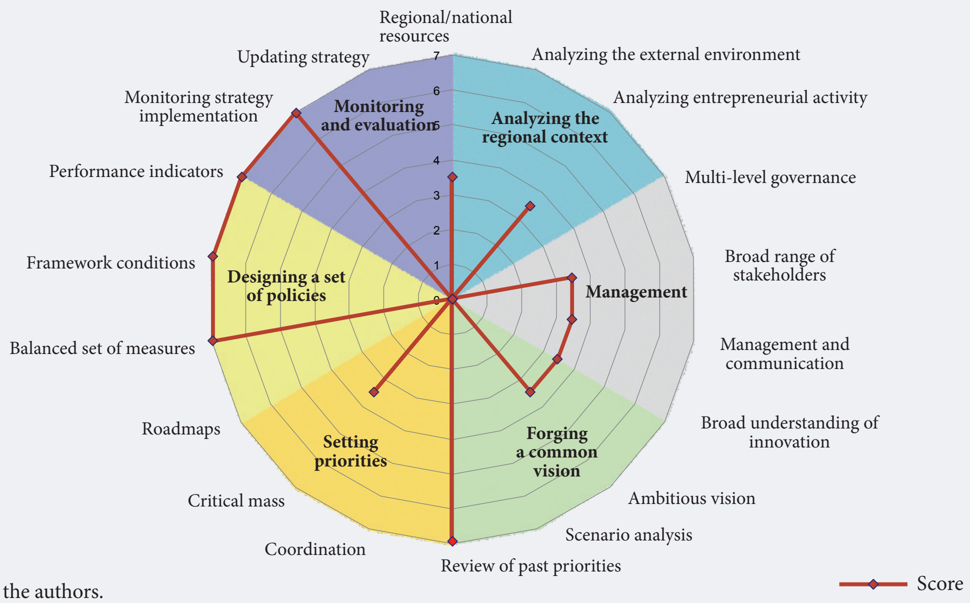
The situation with the nanotechnology industry is quite different: its choice as a priority area by two regions out of three (Sverdlovsk and Chelyabinsk Regions) seems to be valid, although Tatarstan (which

Figure 6. **Evaluation of the Strategy for Development of Innovation and Research Activities in the Republic of Tatarstan until 2015 for Matching Smart Specialization Criteria**



Source: composed by the authors.

Figure 7. **Evaluation of the Innovation Development Strategy of the Ingush Republic until 2015 for Matching Smart Specialization Criteria**



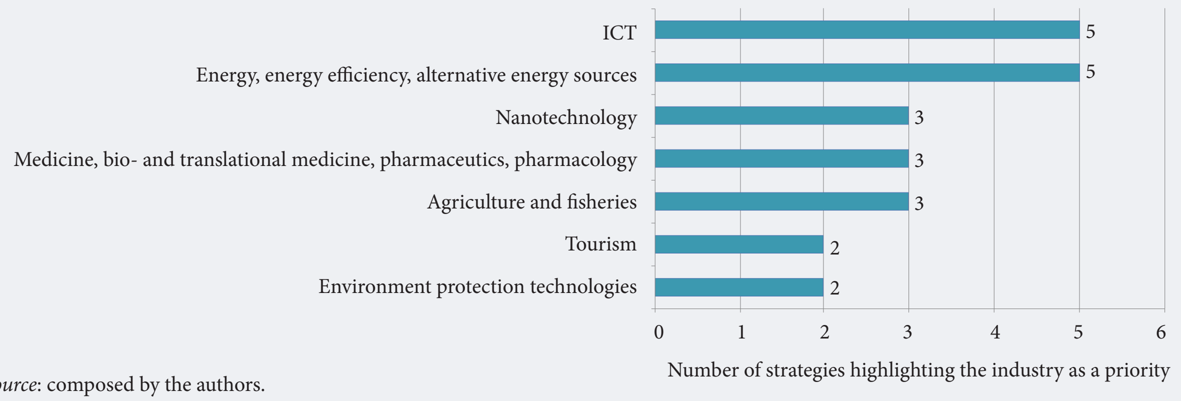
Source: composed by the authors.

has the highest share of nanotechnology products in its total industrial output) did not place a stake on this industry in its innovation strategy.

In most cases, however, priorities were selected simply by naming top-level industries or technologies without going into any detail. Not infrequently, they were poorly substantiated by analysis, and not supported by any specific projects. There are no links to performance indicators: strategies set priority development industries, while the target indicators are designed to monitor progress in the R&D and educational spheres. There are some good examples too, however: for example, the Ingush Republic's strategy provides an analytical validation for choosing tourism, agriculture, and construction materials as priority development areas, and includes specific projects to promote their development. The Kamchatka Region's priorities include two industries: marine economy and tourism, which were chosen taking into account global challenges and which are supported by specific projects.

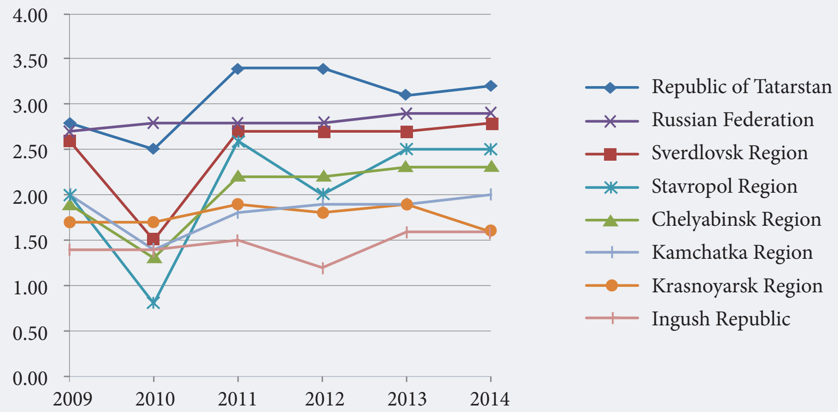
A possible explanation for the above issues may have something to do with the regions' size: in 2015, they were the 74th and 79th in terms of population, and the 79th and 72nd in terms of the number of enterprises and organizations, respectively [Rosstat, 2016], which allowed them to describe projects and stakeholders quite comprehensively. Still, since priorities cannot be seen outside the context of social and economic development prospects, we believe that having a large territory and a low population density (as in, for example, the Krasnoyarsk Region) does not impede the selection of a uniform set of priorities (the number of which may vary, however).

Figure 8. **Frequency of Mentioning Sectors of the Economy as Priority Ones in Russian Regions' Innovation Strategies**



Source: composed by the authors.

Figure 9. **Average Number of Regional ICT Companies' Employees as a Percentage of the Total Regional Workforce**



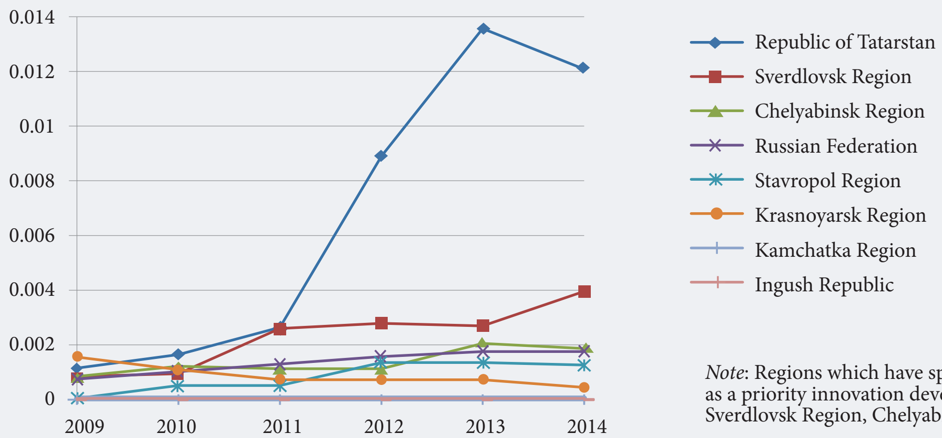
Note: Regions which have specified ICT as a priority innovation development area include the Republic of Tatarstan, Sverdlovsk Region, Chelyabinsk Region, Krasnoyarsk Region, and the Ingush Republic.

Source: composed by the authors based on Rosstat data.

Performance indicators are also formally present in each of the innovation strategies under consideration. However, in most cases they are not linked with the priority industries and are usually intended for monitoring the development of the R&D sector. An exception is the Ingush Republic where education is set as a priority area, with relevant performance indicators suggested for it. Also, the performance indicators mentioned in the strategies are quite numerous (up to 29), while a lack of hierarchy hinders setting targets and evaluating results. Frequently performance indicators are described in very general terms, which are also different from the established statistical standards (e.g., "gross added value in the innovative sector as a share of the gross regional product" or "the creation of innovative enterprises"). This reduces their analytical value, due to the lack of a common data collection and verification methodology, and the incompatibility with other regional and national figures.

Figure 11 shows the distribution of performance indicators included in the strategies under consideration, grouped in line with the RRII sub-index classification [HSE, 2016]. Most of the performance indicators describe the state and development level of the R&D sphere, relevant results and S&T potential, or innovation activities of regional companies and organizations. However, despite the fact that each regional strategy describes framework conditions for innovation, only in two cases were the latter linked with the socioeconomic situation.

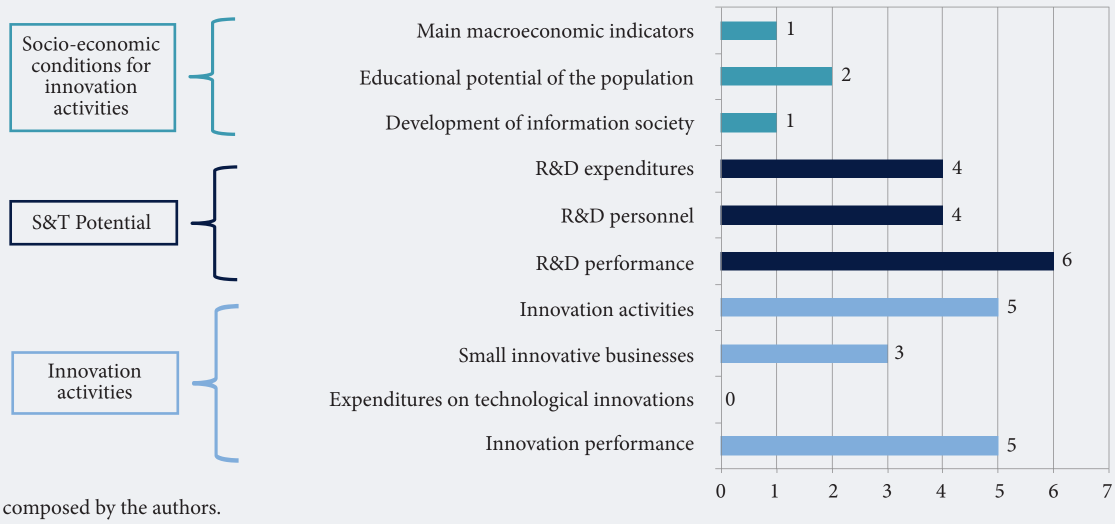
Figure 10. **Share of Nanotechnology-related Shipped In-house Manufactured Products and Provided Services in the Total Volume of Shipped Products** (%)



Note: Regions which have specified nanotechnology as a priority innovation development area include: Sverdlovsk Region, Chelyabinsk Region, Stavropol Region.

Source: composed by the authors based on Rosstat data.

Figure 11. **Distribution of Regional Innovation Strategies by Innovation Activities' Performance Indicators**



Source: composed by the authors.

Summary and Recommendations

The assessment of innovation strategies' matching smart specialization criteria confirmed the first hypothesis that regional innovation strategies were designed without taking this concept into account, though they still feature some of its characteristics. Each strategy includes the following elements: an analysis of the local context, mechanisms for program development and implementation, visions of innovation development prospects, relevant priorities, policies, and performance indicators.

In terms of the six steps described in the Guide, the high scores for some of these criteria are accompanied by low scores for others. The strategies' weaknesses include the following:

- *Poor analytics.* Only two of the seven strategies include a SWOT analysis. Most of the documents do not take into account the external environment, i.e., other regions' strengths and specialization industries. It leads one to believe that innovation priorities were frequently set blindly, without inter-regional comparison. The exception is the Sverdlovsk Region's strategy which includes a benchmarking with other regions with a description of the applied methodology.
- *Poor management mechanisms.* Almost all the regions lack structures responsible for strategy development and implementation. Typically, an official or a regional executive agency performs these functions. Only in the Republic of Tatarstan does the Presidium of the Republican Academy of Sciences along with the Cabinet of Ministers have relevant management responsibilities. Also, most of the documents did not mention that a broad range of stakeholders was involved in their development and implementation. Only in the Sverdlovsk Region and Ingush Republic were businesses named as active participants in innovation activities. In the first case, innovative development priorities were set on the basis of an enterprise survey and in the second, taking into account innovative projects implemented by local entrepreneurs.
- *Using a broad understanding of innovation.* This is one of the more commonly ignored requirements of the smart specialization concept, which implies taking into account various forms of innovation activities. Most of the regional strategies are based on a linear innovation model. For example, the Sverdlovsk regional strategy says that "breaking the innovation chain at any stage limits the scope for innovation-based economic development" [p. 13]. At the same time, innovation in locally-specific activity types can be no less important for the successful development of the economy (e.g., outpatient medicine, retail, social services, culture and recreation, and communal services).

Changing employment models, family relations, and lifestyles promote demand for products and services previously produced by the consumers themselves. Increased life expectancy and advances in healthcare technologies promote the growth of various segments of the medical services market. Investments in improving the quality of life create conditions for consumption-based economic growth. The diverse supply of non-market products in specific regions is becoming an attractive factor, which is manifested through increased employment and purchasing power [*Markusen*, 2007; *Nelson*, 1997].

The results of the study indicate that in smart specialization terms, the regional innovation strategies seem to be more declarative than practical. No strategy contains roadmaps and most of them lack mechanisms for updating priorities and support policies. An exception is the Kamchatka strategy, which specifies that the regional Ministry of Education and Science must annually conduct an analysis of the actual level of innovation activities and adjust the relevant priorities.

Performance indicators are mostly oriented towards monitoring progress in the R&D sector. Innovation priorities are formulated without consideration of the smart specialization principles, i.e., they do not merge traditional economic specialization areas with new emerging S&T areas or imply an orientation towards structural changes in the economy and in future markets. Even regions with high innovative potential, whose strategies formally do match most of the Guide's requirements, cannot ensure that smart specialization ideas will be conceptually implemented.

The best and worst (in terms of meeting smart specialization criteria) innovation strategies have similar weaknesses, and on the whole can be described as fragmentary. The documents' quality does not always directly reflect the regions' innovative potential, which can speed up the implementation of the latter in future. However, this requires meeting not just some criteria, but the whole range of them. The strength of the smart specialization approach lies exactly in its integrated nature, i.e., in the need to apply all the tools simultaneously, each of which was "invented" before the concept actually emerged. Without taking into account the whole set of the interlinked criteria it would be difficult to act systemically, which is a condition of the strategy actually affecting the development of innovation. Similar patterns of strengths and weaknesses of strategic planning noted in totally different regions indicate that there is a single factor in place that determines this common style of strategizing generally, and its typical flaws in particular. We mean the lack of a top-level system which would impose standardized rules for setting, verifying, and synchronizing priorities, and provide organizational support for designing and implementing the regional innovation development strategies.

It can be noted that due to its ontological relativity, the "smart/unique" category is better suited to describe not regional strategies, but those adopted by a whole system of regions (e.g., those registered on the EU Smart Specialisation Platform). This can be interpreted as follows: it is rather difficult to be "smart on one's own" and identify industries or technology areas to achieve supremacy in without taking into account the specialization areas, strengths, and strategies of other regions. So, our second hypothesis that achieving valid comparability and successfully dealing with regional priority duplication and fragmented support initiatives issues requires higher-level (national or supra-national) organizational solutions, is also confirmed.

Such solutions may include the following:

- a database of priorities and projects;
- interactive tools for comparing regions by a wide range of parameters;
- standardized priority-setting rules based on a unified system of classifiers (while strategy development should be delegated to regions);
- methodological and expert support for regional teams (methodological recommendations, best practice handbooks, training, internships);
- mechanisms for regions to review and discuss their S&T and industrial development priorities, for the subsequent centralized approval of strategies through open expert evaluation and "defense" procedures.

It would make sense to integrate such organizational solutions into the smart specialization concept, along with the existing detailed methodological recommendations in the Guide. Meeting some of the specific smart specialization requirements does not really make strategies smart and no public administration level has priority over others. More importantly, their interaction should be analyzed, along with the interaction of the same-level agencies, including various initiatives, formats, regularity, etc. The national (supra-national) level must be a participant in such a dialogue and, in some cases, act as an initiator or organizer, for example, regarding inter-regional cooperation.

Taking the aforementioned organizational solutions further, one comes to the following dilemma. On the one hand, the more regions the system includes, the wider is the scope for benchmarking, identifying unique priorities, and developing high-quality strategies. Accordingly, the existing EU Smart Specialisation Platform may evolve towards growth by integrating new regions located in non-member countries (Norwegian, Turkish, Serbian, and Moldovan regions are already registered on the Platform), and the emergence of a global "smart system". An alternative scenario would be setting up similar systems in nation states with a larger number of regions (e.g., Russia, US, China), or in economic alliances (EAEU, MERCOSUR, NAFTA, etc.), which subsequently may synchronize with one another.

On the other hand, the need to eliminate priority duplication can potentially lead to reduced competition between regions, which would negatively affect the quality of products and services produced in numerous unique industries. In that case, a possible solution would be preserving certain duplication of specialization areas, and therefore competition, as a condition of the smart system's sustainability.

Conclusion

This paper analyzes the scope for applying the smart specialization concept in individual regions of countries outside the EU using Russia as an example. Smart specialization is a scientific concept and at the same time a methodological approach to designing regional innovation strategies adopted by the

EU to reconcile the logic of two government policies. This approach implies establishing standardized conditions for setting national-level innovation priorities. Thus, it solves the problem of duplicating competences and regional support initiatives implemented in various countries. Delegating strategy development and implementation responsibilities from the national to regional level of governance reduces the risks of choosing the wrong specialization areas. From 2009 onwards, smart specialization was actively used in the EU. A central institution was set up, the Smart Specialisation Platform. It helps synchronize regional innovation strategies, sets a framework for identifying regions' unique competitive advantages, and provides them methodological and instrumental support.

The analysis of seven innovation development strategies adopted by Russian regions revealed that all of them featured certain elements of the smart specialization concept (such as selecting priority industries for applying innovations, monitoring results using performance indicators, and creating framework conditions).

At the same time, it should be recognized that designing regional innovation development strategies does not yet have a proper analytical basis in Russia; stakeholders become involved in priority setting only sporadically, while innovations are considered independent of the socioeconomic context.

Some provisions of the smart specialization concept are inherent to high-quality strategies and their application does not require a new synthetic model (such as smart specialization) or special mechanisms in the form of methodological recommendations, platforms, and organizational structures. At the same time, while formally meeting a number of important criteria described in the Guide, regional strategies may fail to accomplish their main objective: mapping the "unique development path" for the region. No clear links between regions' innovation activities and the quality of their innovative strategies in terms of smart specialization was revealed. Apparently, designing a smart specialization strategy at the level of a specific region still remains a formidable task. It requires external knowledge: comparable data about other regions, national priorities and initiatives, and global technology trends. Accordingly, a (supra)national-level approach should be adopted, along with developing standardized rules for setting, verifying, and synchronizing priorities, unifying the available analytical database, and providing organizational support to promote the emergence of a common economic and research area in one or more countries. Thus, the smart specialization concept should be imported into countries outside the EU systematically, involving not only the regional but also national authorities in the process, and potentially, the regional alliances of countries. This is the way to most productively apply the smart specialization concept.

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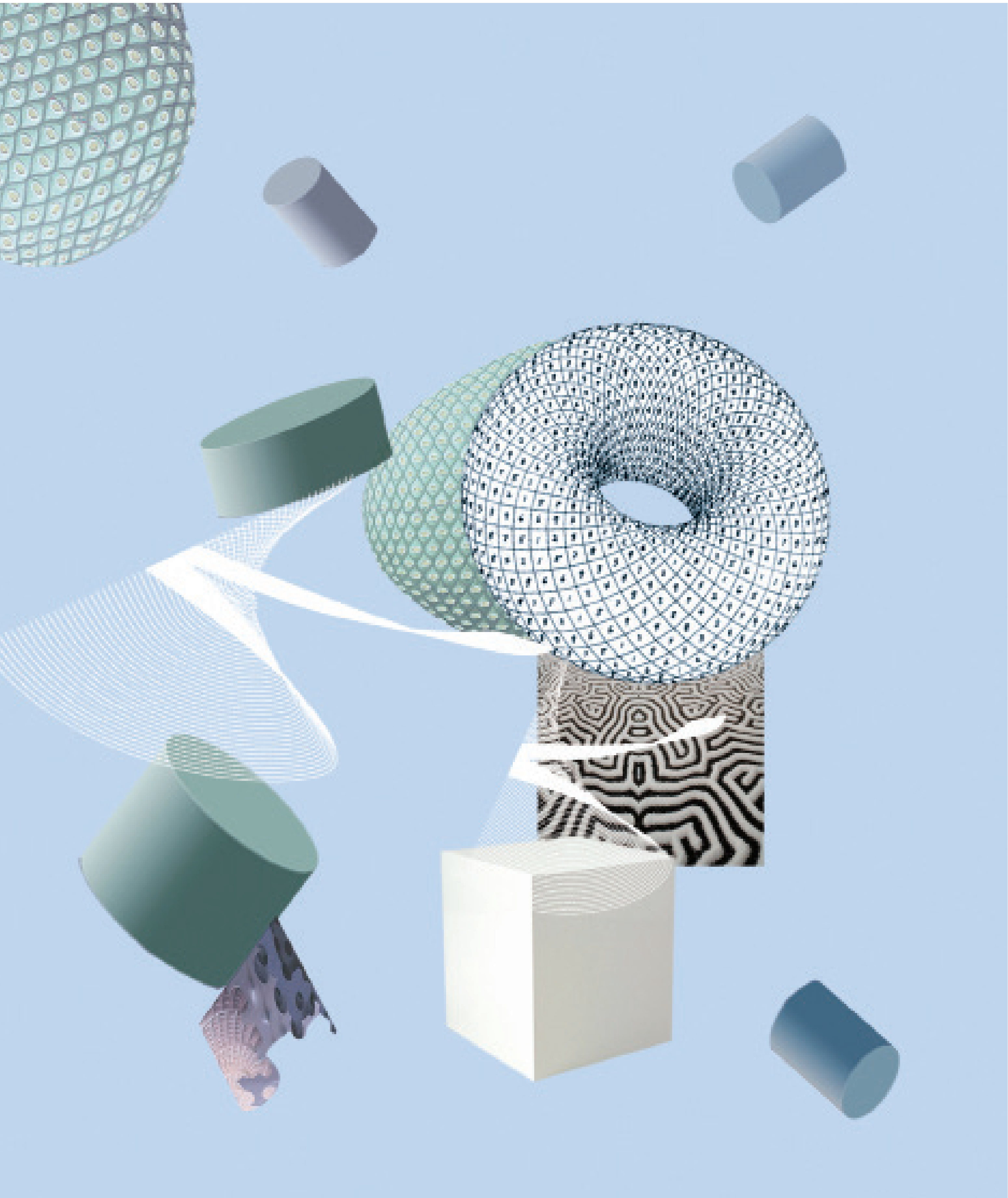

Additive Manufacturing in Healthcare

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Abstract

The presence of additive manufacturing (AM), in particular 3D printing, is relatively young, but dynamic field that is changing the face of many sectors. Additive production technologies provide wide opportunities for the creation of complex and personalized products and the reduction of time, labor, and other expenses. This paper will focus on AM in healthcare and identify the main areas for its application and the most popular materials. The period under analysis is from January 2005 to April 2015. The analysis involved an iterative search to establish the best queries for retrieving data and a patent analysis. The obtained results were assessed by experts in the field. Through this research, three main applications were identified with dental prosthetics being the most prolific. A wide range of materials were identified, where plastics predominate. Polyethylene was most frequently patented for vascular grafts and tendon replacements, while ceramics were found to be the most useful material for dental applications. Only a few patents disclosed the use of metals, titanium being the most prevalent. This research provides valuable insights for the advancement of additive manufacturing in healthcare applications.

Keywords: 3D printing; additive manufacturing; materials; healthcare; dental; vascular graft; patent analysis.

Article type: research paper

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Effective strategy planning for research and development (R&D) is impossible without an understanding of the emerging scientific and technological landscape and the latest breakthroughs. Over the last several years efforts have been devoted to assessing the evolution of technology through an analysis of scientific publications and patents. This research incorporates a competitive technology intelligence (CTI) method through patent analysis and is complemented by an expert assessment.

Competitive technology intelligence is the systematic process of gathering and analyzing information to support strategic planning for innovation. Among other tools CTI utilizes patent analysis as an indicator of technological growth, to identify advances in processes, new materials, and the more active players. Patenting is considered one of the key ways of protecting intellectual property [*Okamoto et al.,* 2017; *Zhang et al.,* 2015], which provide unparalleled value for business, law, industry and policy-making communities. These documents are organized, classified, and processed in such a way that provides information such as inventor's name, owner, claims, etc. Patents can also be used to monitor technology trajectories [*Bonino et al.,* 2010]. Economic indicators have been also associated with patents, for example they help address connections between technology and trade [*Archibugi, Pianta,* 1996] and help elucidate the strong relationship between the activity of an industry and the pattern of industrial specialization. The growth of industries is influenced by technology, and this is better understood through an analysis of the industries' innovative activities and national performance [*Fabry et al.,* 2006; *Rodríguez et al.,* 2014]. Patent analysis has established itself as a great platform for knowledge discovery [*Bonino et al.,* 2010; *Archibugi, Pianta,* 1996; *Fabry et al.,* 2006; *Rodríguez et al.,* 2014; *Abercrombie et al.,* 2012]. For example, Trappey et al. [*Trappey et al.,* 2015] consider patent analysis the major method for predicting new technologies.

Patent analysis can serve as a landscape of the developing technological areas. It represents an important tool for understanding the dynamics of scientific and technological advances, furthermore it has been used since the early 1970s in the US [*Attar, Fraenkel,* 1977]. Currently, it can be used to predict competitors' possible future moves. However, the objectives and final applications depend upon the project in question [*Fujii,* 2007]. For example, previous studies include: the identification of past trends and the predicting of future trends using clusterization and time series of patent data [*Chang et al.,* 2014], the identification of indicators to determine technological investments and markets strategies [*Dehghani, Dangelico,* 2017], and the determination of a technology's diffusion rate, lifecycle, patent expansion potential, and patent power [*Altuntas et al.,* 2015]. Whichever objective is pursued, patent analysis is a highly demanding task that requires a significant degree of expertise on the technological domain to be studied. In this research, expert feedback has been incorporated into the competitive technology intelligence (CTI) analysis in order to obtain the best approach for identifying the use of additive manufacturing in medical applications and their most used materials.

The manufacturing of medical devices has undergone a radical change with the incursion of AM, a relatively new technology that generates products by "printing" layers of materials using a cartesian coordinate robot, as does an ink or laser printer, to deposit or fuse material layer by layer to generate objects in three dimensions. This process can be performed using different techniques, such as selective laser sintering (SLS), thermal inkjet printing, or fused deposition modeling (FDM), among others. These technologies are more common now, with new methods and materials being employed, as well as new applications where the advantages of this technology can be used [*Ventola,* 2014; *Schubert et al.,* 2014]. This technology has a huge impact upon various industries, due to advantages such as the creation of complex shapes, personalized final products (such as implants) as well as a reduction in time and waste.

AM is in fact a promising technology that will revolutionize the healthcare industry, as it provides the opportunity to create custom tools and equipment, as well as tailored medical devices, such as implants [*Ventola,* 2014]. By means of this technology, implant manufacturing time can be dramatically reduced in comparison with traditional methods that involve several processes [*Ventola,* 2014; *Hornick,* 2016]. Moreover, implants can also be generated on the basis of a patient's personal anatomy, thus securing a better fit and reducing the probability of failure common for mass-manufactured implants. For example, to create a prosthesis, the patient's images are obtained by X-ray, a computerized tomography (CT) scan, or magnetic resonance imaging (MRI). A 3D model is generated afterwards and transformed into a 3D print file that is used subsequently to build the necessary part. A similar process has been successfully used to generate cranial, jaw, or pelvic implants, as well as prostheses for the upper and lower limbs [*Hornick,* 2016]. These products involve biocompatible materials such as titanium or stainless steel [*Ventola,* 2014; *Schubert et al.,* 2014; *Hornick,* 2016; *Banks,* 2013; Álvarez, *Nakajima,* 2009].

AM technology has evolved rapidly and has made a huge impact upon patent applications. In 2014, the growth of AM was accelerated, increasing by 31.6% from 2013 to 2014, and 25.9% in 2015 [*Wohlers et al.,* 2016]. Photopolymers were the most used materials in AM by 2016, being used in 45.5% of the applications, followed by laser sintering polymer powders 24.9%, filaments 15.1%, and metals only comprising 11.5%. Such developments are increasing patent activity in the AM industry with continuous growth from 25 issued patents in 1995 to 668 in 2014 [*Wohlers et al.,* 2016]. In the medical sector, intellectual property has grown relatively rapidly since 2009, being dominated by companies more than academic institutions. In 2014, the AM industry was worth $700 million, and just 1.6% was invested in the healthcare industry, meanwhile, by 2024 it is expected to grow to 21% [*Schubert et al.,* 2014]. As this industry continues growing and expectations rise, it is important to track its evolution. Global efforts have been carried out to identify the technologies and applications of AM in the healthcare sector. Recently, Ventola [*Ventola,* 2014] studied the advances and benefits of AM, identifying some future trends. On the other hand, Schubert et al. [*Schubert et al.,* 2014] offered an overview of AM in the healthcare sector and identified potential applications and expected economic growth in this sector. Rodriguez et al. [*Rodriguez et al.,* 2014] presented a patent analysis to identify global trends in biological AM, by determining countries, organizations, inventors, and technological fields. Materials and processes in AM are evolving continuously and constitute a great opportunity to innovate and make decisions to become more competitive. However, patent analysis to track their presence has not yet been developed. To fill this gap, this research presents a patent analysis enhanced by an expert assessment to uncover opportunities for research and innovation on the materials used in AM for medical applications.

Research Methodology

As this research involves two areas, AM and the healthcare industry, the collection of data turns into a more difficult task. A customized search strategy is required to overcome this difficulty, and a set of queries must encompass the appropriate information for the analysis. If a query is poorly defined, it will result in a shortage of relevant information. Queries were defined first for a ten-year period, 2005-2015, up to April 15, when the study was concluded. The main applications and the most used materials are disclosed in this paper as well as the number of patents per year. This can provide insights and a better understanding of advances in the field of additive manufacturing.

Globally, the methodology presented here involves several steps: 1) the planning process, 2) the identification of sources of information, 3) the development of a strategy for information collection, 4) data collection, 5) expert validation, 6) data analysis, 7) experts' validation of the analysis, and 8) the delivery of results. This is done as an iterative process until results are validated and delivered.

The planning process (Step 1) includes the definition of the main goals and activities, including the allocation of resources to identify the materials for and applications of AM in the healthcare sector. The next stage (Step 2) included the identification of the sources of information. For this step, a comprehensive source of information was selected to track the registered inventions, PATSEER[1], which is a powerful web-based platform covering more than 92 million records from the main patent authorities worldwide. It has access to bibliographic data from 140 countries and full texts from 27 authorities[2]. The next step (Step 3) involved the definition of keywords and the generation of the most suitable search queries. This step was completed by performing an extensive analysis of papers and reports from scientific databases combined with expert consultations in order to define a set of keywords to retrieve information. This process was carried out in a recursive way, by modifying the search queries as described below. The step that follows (Step 4) involves the collection of information, where documents were selected by analyzing the titles and abstracts. This step was followed by an expert assessment (Step 5) to determine whether the results were suitable for carrying out the analysis. Data analysis is the next step (Step 6), and this was accomplished with the help of a text mining software, Patent iNSIGHT Pro[3], which is a patent analysis tool that uses advanced algorithms. This software includes sophisticated analytical capacity tools to analyze thousands of documents, thus obtaining an insight into the scientific field. During this step, the results were analyzed and cleaned up to eliminate *noise*, which are patents that could be retrieved but do not relate to the topic of interest. After cleaning out irrelevant patents, the results were assessed by experts, enhancing the validation process and determining the eligibility of the information (Step 7) to develop the analysis and then, finally, to deliver results (Step 8), which include the identification of opportunities to innovate and any possible threats to success.

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[1] Available at: https://patseer.com/, accessed 15.11.2017.

[2] European Patent Office, World Intellectual Property Organization (WIPO), as well as national patent offices of United States, Japan, China, Republic of Korea (South Korea), Canada, Germany, France, Great Britain, Spain, Australia, India, Switzerland, Austria, Brazil, Thailand, Russian Federation, Philippines, Sweden, Norway, Denmark, Finland, Belgium, Netherlands, Luxembourg, and Mexico.

[3] Available at: https://www.patentinsightpro.com/, accessed 15.11.2015.

Table 1. **First patent search**

Query	Title + Abstract	Title + Abstract + Claim	Patents
Additive manufacturing	×	—	960
Additive manufacturing	—	×	1558
Additive manufacturing AND Medical devices	—	×	17
Additive manufacturing AND (Medical devices OR Prostheses OR Orthoses)	—	×	41
(Additive manufacturing OR 3D printing) AND (Medical devices OR Prostheses OR Orthoses)	—	×	86
Source: composed by the authors.			

During the initial process, the most crucial tasks included the definition of keywords and the construction of the search query, which is needed for the proper identification of information that feeds the scientometric analysis. The queries were built using a Boolean search.

After the keywords are determined in Step 3, new complementary terms were added in the search strategy as follows: given a specific term in a given period of time, the search was defined by the abstract, title, and claim, as described in Table 1, then the results were analyzed. The term was eliminated if the results did not fit within the framework of the research and a new term was tested. The algorithm of queries' modification is summarized in Table 2.

The initial timeframe (at the Stage A) was defined as the period from 1700-01-01 until 2015-04-15, the first being the oldest date for the time frame that can be obtained from the platform, 1700-01-01, up to the most recent date, when this research was concluded, 2015-04-15.

Table 2. **Algorithm for Modifying Search Queries**

Number of query	Fields	Query formulation
Stage A. Initial set of search queries (publication date: 1700-01-01 to 2015-04-15)		
1	Title, abstract and claims	additive manufacturing
2	Title and abstract	additive manufacturing
3	Title, abstract and claims	additive manufacturing AND medical devices
4	Title, abstract and claims	additive manufacturing AND (medical devices OR prosthesis OR orthosis)
5	Title, abstract and claims	(additive manufacturing OR 3D printing) AND (medical devices OR prosthesis OR orthosis)
Stage B. Search during a 10-year period (publication date: 2005-01-01 to 2015-04-15)		
6	Title and abstract	(additive manuf*) OR (3D manuf* OR 3-dimension* OR 3 dimension*) OR (3D print* OR 3-D print* OR 3 print*)
7	Title and abstract	((am OR "additive manufacturing" OR additive manufac*) OR (3D manufac* OR 3-dimension* OR 3 dimension*) OR (3D print* OR 3-D print* OR 3 print*) OR (3D bioprint* OR 3-D bioprint* OR 3 bioprint*))
8	Title and abstract	(((am OR "additive manufacturing" OR additive manufac*) OR (3D manufac* OR 3-dimension* OR 3 dimension*) OR (3D print* OR 3-D print* OR 3 print*) OR (3D bioprint* OR 3-D bioprint* OR 3D bioprint*)) AND (medical device* OR prosthe* OR orth*))
9	Title and abstract	(((am OR "additive manufacturing" OR additive manufac*) OR (3D manufac* OR 3-dimension* OR 3 dimension*) OR (3D print* OR 3-D print* OR 3 print*) OR (3D bioprint* OR 3-D bioprint* OR 3 bioprint*)) AND (medical device* OR prosthe* OR orth* AND (polym*)))
Stage C. Search with material term combinations (publication date: 2005-01-01 to 2015-04-15)		
10	Title and abstract	(((am OR "additive manufacturing" OR additive manufac*) OR (3D manufac* OR 3-dimension* OR 3 dimension*) OR (3D print* OR 3-D print* OR 3 print*) OR (3D bioprint* OR 3-D bioprint* OR 3D bioprint*)) AND (medical device* OR prosthe* OR orth* OR implant*) AND (plast* OR polym*)))
Stage D. Final Search (publication date: 2005-01-01 to 2015-04-15)		
11	Title, abstract and claims	(((am OR "additive manufacturing" OR additive manufac*) OR (3D manufac* OR 3-dimension* OR 3 dimension*) OR (3D print* OR 3-D print* OR 3 print*) OR (3D bioprint* OR 3-D bioprint* OR 3 bioprint*)) AND ((medical device* OR prosthe* OR orth* OR implan*))) AND (medical application terms) AND (material terms)
12	Title, abstract and claims	((additive manuf*) OR (3D manuf* OR 3-dimension* OR 3 dimension*) OR (3D printing OR 3-D print* OR 3 print*)) wd2 (medical devices OR prosthe* OR orth*) AND NOT (veterinary OR animal* OR pets)
Source: composed by the authors.		

Box 1. Materials terminology

- Acrylonitrile Butadiene Styrene (ABS) Plastic
- Alkyd
- Aluminum
- Carbon Fiber
- Clay
- Elastomers
- Epoxy
- Fiberglas
- Furan
- High-density Polyethylene
- Melamine
- Methacrylic
- Nickel
- Nylon
- Polyether Ether Ketone (PEEK)
- Palladium
- Phenolic
- Plastic
- Polyparaphenyleneterephtalamide
- Polyamide
- Polyamideimide
- Polycarbonate
- Polyetherimide
- Polyethylene
- Polyethylene Terephthalate
- Polylactic Acid
- Polyolefin
- Polyphenylsulfone
- Polypropylene
- Polyvinyl Chloride
- Polyvinylidene Chloride
- Room-Temperature-Vulcanizing (RTV) Silicone
- Rubber
- Silver
- Stainless Steel
- Steel
- Thermoplastic
- Thermoset
- Titanium

Source: composed by the authors.

From the searches carried out using the Queries 1 to 5, it was found that the keywords listed above are indexed with different terms on the patents, which were used to comprise all the denominations related to 3D printing technology. The Boolean operators: OR, AND, and NOT were also used, as well as the asterisk (*) to encompass all words with the same root but different ending. We describe how to complete the search in the following paragraphs.

According to the feedback from experts, it was determined that the main inventions were developed from 2005 onwards, so at the Stage B the timeframe was established for ten years and the search parameters for the stage B were adjusted as shown for Query 6 in the Table 2.

A technological level search (additive manufacturing) was developed using the parameters described for Query 7 in the Table 2.

The next step was made in order to narrow the results to only medical application terms according to Queries 8-9 (see Table 2).

Stage C was focused on finding material combinations. Query 10 in Table 2 shows an example of the strings generated, a string built with the terms for plast* and polym*.

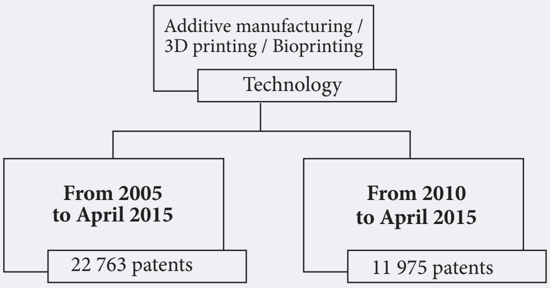
Finally, at Stage D approximately 200 searches were carried out in order to identify the use of additive manufacturing for inventions dealing with different parts of the human body and materials involved. Box 1 lists the material terminology used to collect patent information. Forty materials were identified, each one was combined with the different medical application terms. After this search, the main applications were identified from the patent analysis combined with the expert assessment. The obtained insights showed that the largest amount of patent activity in this field was focused on dental, vascular graft, and tendon applications, thus, a specific analysis was developed for each using the following search strings (query 11, see Table 2).

Results

In total, 1,558 patents were obtained using the search string with "additive manufacturing" in the abstract, title, or claim during the period from 1700-01-01 to 2015-04-15. The number of results was further reduced to 960 patents when the query was shortened to search only within the abstract and title. A fewer number of patents, 17, was obtained when the string was modified including additive manufacturing and medical devices. The search was further improved by using Boolean operators, as previously described, to include only innovations for medical devices, prosthesis, or orthoses in combination with additive manufacturing. From this search, 41 patents were retrieved. In total, 86 patents were found when the keyword "3D printing" was added to the previous entries, as shown in Table 1. Despite the constraint to medical devices, words related to the veterinary field were recurrent, and as they did not fit the scope of this paper, they were omitted, resulting in a more specific query (query 12 in Table 2).

This query excludes the terms for veterinary, animal, or pets and uses the proximity operator "wd2". This operator searches terms related to additive manufacturing or 3D printing with a proximity of two words

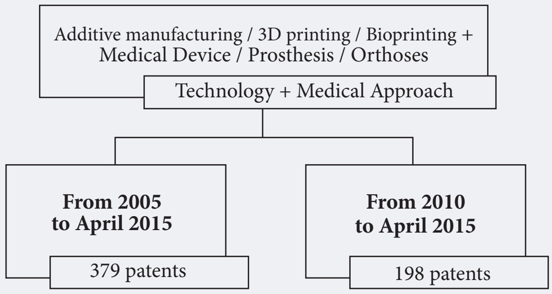
Figure 1. **Technology-based Search Query Results**



Note: This and the following two figures demonstrate patent search results from 2005-01-01 to 2015-04-15 and 2010-01-01 to 2015-04-15

Source: composed by the authors.

Figure 2. **Technology and Medical Approach-based Search Query Results**



Source: composed by the authors.

from the terms for medical devices. This query produced 115 patents over the period stated (2005-01-01 to 2015-04-15), with only nine patents published by 2005, and a higher number of patents, 20, published in 2014. This search did not produce results for the partial year of 2015 (through 2015-04-15).

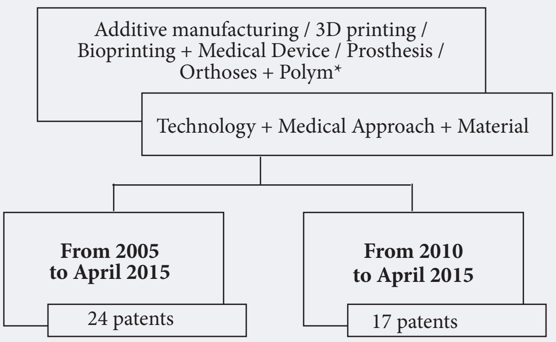
More related terms were gradually added to the preliminary queries and the search periods were also modified. A total of 15,521 patents were obtained from 2005-01-01 to 2015- 04-15 when the search was carried out with Query 6, focused on a general search for additive manufacturing. Query 7, also for additive manufacturing, included more terms related to this technology, and two periods were defined, 2005-01-01 to 2015-04-15 and 2010-01-01 to 2015-04-15. This query yielded 22,763 patents from 2005-01-01 to 2015-04-15, and 11,975 patents from 2010-01-01 to 2015-04-15, as shown in Figure 1.

Query 8 encompassed terms related to technology and "medical application" for the previously defined periods. This query resulted in 379 patents from 2005-01-01 to 2015-04-15 and 198 patents were found from 2010 to 2015-04-15, shown in Figure 2.

The next step consisted of the inclusion of terms related to materials. The search string identified as Query 9, incorporates the terms polym* and is an example of the queries that encompass the terms for each of the materials listed in Table 3. This string yielded only 24 patents from 2005-01-01 to 2015-04-15 and 17 from 2010-01-01 to 2015-04-15, as shown in Figure 3.

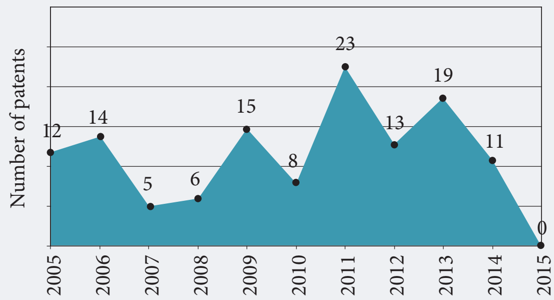
As previously mentioned, the main medical applications for AM were determined to be dental, vascular graft, and tendon prostheses, therefore specific analyses were developed for them. Each of these terms was combined with the keywords for the materials listed in Table 3. The same period was defined for the searches, 2005-01-01 to 2015-04-15. In total, 120 searches were performed using these combinations of terms, obtaining a total of 1,479 patents. They were analyzed and those not related to the topic were eliminated. The final set of documents obtained was as follows: 126 patents focused on AM for dental applications, 108 for tendon replacement, and 23 for vascular grafts.

Figure 3. **Technology, Medical Applications, and Material-based Search Query Results**



Source: composed by the authors.

Figure 4. **Patent Activity in Dental Applications**



Note: This and the following two figures demonstrate patent search results from 2005-01-01 to 2015-04-15

Source: composed by the authors.

The area with the most patent activity for the ten-year period was found to be the dental industry with 126 patents. A patent analysis was performed to identify the most frequently used materials. The analysis showed a total of 23 different materials; the top 15 are listed in Table 3. Only four of them were present in more than ten patents. Ceramics, found in 24 patents, was the most commonly used material for dental applications, followed by titanium, found in 20 patents, wax, used in 16 patents, and plastic, found in 12 patents. Figure 4 shows the patent activity in dental applications per year for the period from 2005-01-01 to 2015-04-15. Although this was the industry with the most activity, it does not have a uniform trend. To determine the patent average per year, the search period was divided in two, from 2005 to 2010 (previously to 2011, which is the year with the maximum number of patents, 23), and from 2012 to 2014. The results showed an average of 10 patents per year from 2005 to 2010, while the for the period from 2012 to 2014 the average was 14.3 patents per year.

After dental applications, tendon prostheses were the following most patented innovation, with a total of 108. These patents employed a higher number of materials: 34. Table 4 lists the 15 most popular, where it can be observed that polyethylene was the most used material, contained in 46 patents; followed by plastic present in 37 patents and polypropylene, which was used in 20 patents. Tendon applications demonstrated steady patent activity between 2005 and 2014, as shown in Figure 5. The patent average per year was also determined for two periods. Before 2012, the year with most patents (24), the average was 8.8, while for 2013 to 2014, the average was 11.5. Finally, no patent activity was registered in 2015 up to 2015-04-15, when the search concluded.

Third place in AM patenting activity was occupied by vascular graft applications, with 23 patents, which employed a total of 32 different materials. Table 5 lists the top 15 materials, with only three found in more than five patents. Polyethylene was the most used material, present in 10 patents, followed by plastic (in general) in 8 patents, and finally furan in 6 patents. Figure 6 outlines the patent activity per year over the period from 2005 to the partial year of 2015, which reached a peak in 2006 with 6 patents. Vascular graft applications had an average of 2.3 patents per year.

A comparison between dental, tendon, and vascular graft applications can be observed in Figure 7. They reached their peak in 2011, 2012, and 2006, respectively. The highest average number of patents per year was found for dental applications, with 12.6 patents per year, followed by tendon applications with 10.8, and vascular with only 2.3 patents per year.

Regarding materials, plastics were found to be the most widely used material. Polyethylene represents 13% of the materials registered for tendon applications, 11% for vascular graft applications, and only 2.5% of the materials for dental applications. On the other hand, ceramic materials were used most in dental applications, being the prevalent material in 20% of dental patents, 4 % of those for tendon applications, and just 1% for vascular graft applications. Metals are not as widely used as plastics in AM for the

Table 3. **Additive Manufacturing Top Materials for Dental Applications**

Material	Patent Frequency
Ceramics	24
Titanium	20
Wax	16
Plastic	12
Steel	9
Nickel	5
PEEK	5
Stainless Steel	4
Thermoplastic	4
Polyethylene	3
Silver	2
Alkyd	1
Epoxy	1
Melamine	1
Nylon	1

Source: composed by the authors.

Table 4. **Additive Manufacturing Top Materials for Tendon Applications**

Material	Patent Frequency
Polyethylene	46
Plastic	37
Polypropylene	20
Wax	18
Polylactic acid	17
Ceramic	16
Polyamide	16
Titanium	15
Steel	14
Thermoplastic	14
Furan	12
Nylon	11
Clay	10
Paper	10
Polyvinyl chloride	10

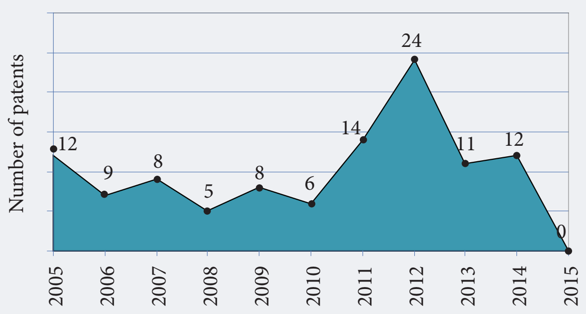
Source: composed by the authors.

Table 5. **Additive Manufacturing Top Materials for Vascular Graft Applications**

Material	Patent Frequency
Polyethylene	10
Plastic	8
Furan	6
Nylon	4
Polyamide	4
Polylactic acid	4
Polypropylene	4
Wax	4
Clay	3
Epoxy	3
Paper	3
Polycarbonate	3
Polyolefin	3
Silver	3
Melamine	2
Methacrylic	2

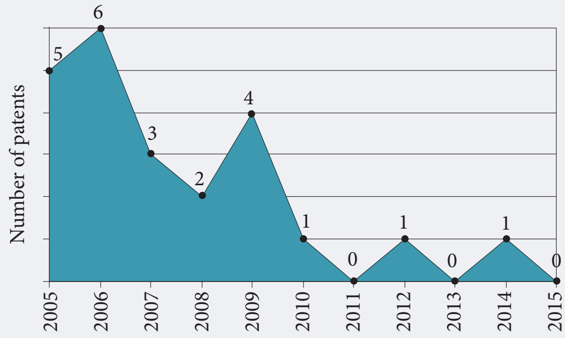
Source: composed by the authors.

Figure 5. **Patents in Tendon Applications**



Source: composed by the authors.

Figure 6. **Patents in Vascular Grafts Applications**



Source: composed by the authors.

healthcare sector, however, titanium represents the second most used material for dental applications, with use in 17% of the patents. This metal also represents 4% of materials in tendon applications, and 2% of the metals used in vascular graft developments. The second most used metal was found to be stainless steel, representing 3% for dental applications, 3% of the materials in tendon applications, and 2% of the materials for vascular grafts.

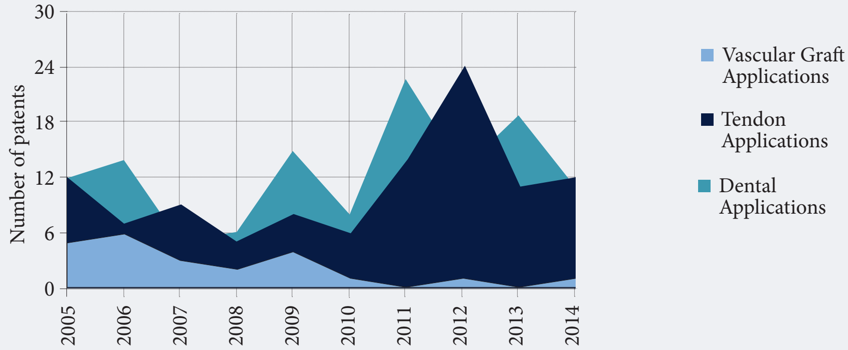
Conclusion

The identification of the main global applications of additive manufacturing in the healthcare sector and the most used materials was conducted in this paper. The authors employed a patent analysis combined with an expert assessment. This methodology can be used across a wide range of disciplines. Although studies have been developed to identify global trends and the main actors using AM technology, there is still not enough discussion about patent activity for AM's main applications and materials in the healthcare industry, which makes such a study relevant for strategic R&D planning.

In this research, three main medical applications of AM were identified: dental implants, vascular grafts, and tendon replacement. Over the analyzed period, small variations in the frequency of patent activity per year were observed. Despite this, the increase on average of patents per year was observed from 2011 to 2014 for dental and tendon applications.

The obtained results were consistent with what has been reported on the use of materials [*Wohlers et al.*, 2016], which demonstrates the predominant use of plastics over metals. The use of metals has been found to be limited, with titanium and stainless steel among the most frequently employed metals. The majority of the medical devices such as jaw implants, hip, knee, and shoulder prostheses are mainly comprised of these metals, which are difficult to use in tailored manufacturing carried out by traditional

Figure 7. **Patent Activity for Dental, Tendon, and Vascular Graft Applications**



Note: The figure demonstrates patent search results from 2005-01-01 to 2014-12-31
Source: composed by the authors.

methods, which results in extremely expensive end products. This offers an opportunity for innovation in the development of such products using AM, where the overall cost and the manufacturing time could be substantially reduced.

The development of the search query involved an extensive manual iterative process to test the information collected and it required validation by experts. An automatic method could be developed to carry out this process, thus reducing the time to perform the high number of searches.

This methodology was successfully applied for the identification of the main applications of and materials used by AM technology in the healthcare sector, but it can be implemented to identify potential research opportunities across a wide range of disciplines.

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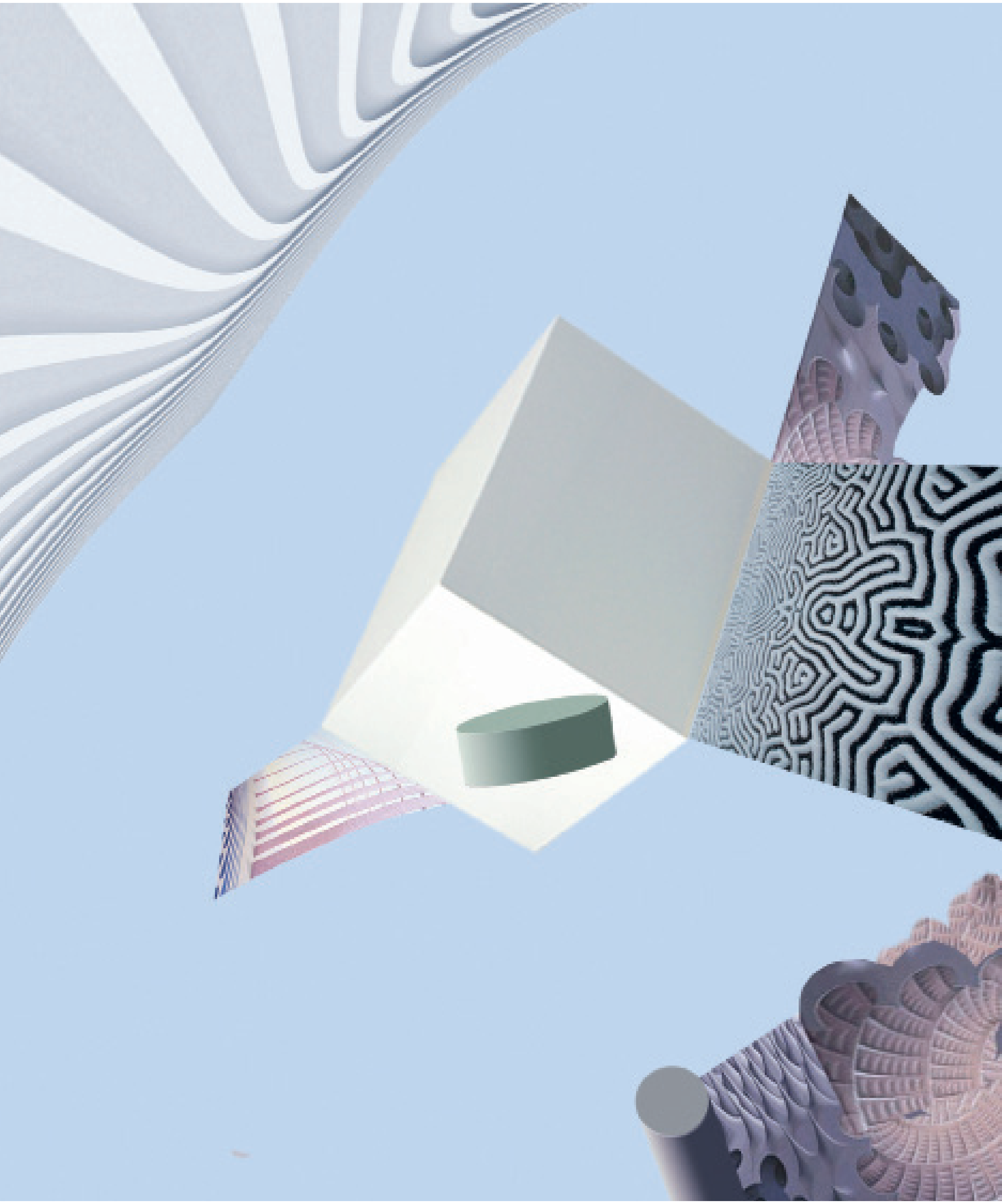

Mapping the Research Landscape of Agricultural Sciences

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Abstract

A research landscape is a high-level description of the current state of a certain scientific field and its dynamics. High-quality research landscapes are an important tools that allow for more effective research management. This paper presents a novel framework for the mapping of research. It relies on full-text mining and topic modeling to pool data from many sources without relying on any specific taxonomy of scientific fields and areas. The framework is especially useful for scientific fields that are poorly represented in scientometric databases, i.e., Scopus or Web of Science. The high-level algorithm consists of (1) full-text collection from reliable sources; (2) the automatic extraction of research fields using topic modeling; (3) semi-automatic linking to scientometric databases; and (4) a statistical analysis of metrics for the extracted scientific areas. Full-text mining is crucial due to (a) the poor representation of many Russian research areas in systems like Scopus or Web of Science; (b) the poor quality of Russian Science Index data; and (c) the differences between taxonomies used in different data sources. Major advantages of the proposed framework include its data-driven approach, its independence from scientific subjects' taxonomies, and its ability to integrate data from multiple heterogeneous data sources. Furthermore, this framework complements traditional approaches to research mapping using scientometric software like Scopus or Web of Science rather than replacing them. We experimentally evaluated the framework using agricultural science as an example, but the framework is not limited to any particular domain. As a result, we created the first research landscape covering young researchers in agricultural science. Topic modeling yielded six major scientific areas within the field of agriculture. We found that statistically significant differences between these areas exist. This means that a differentiated approach to research management is critical. Further research on this subject includes the application of the framework to other scientific fields and the integration of other collections of research and technical documentation (especially patents).

Keywords: text mining; topic modelling; science mapping; scientific landscape; agricultural science; publication activity; scientometrics; young researchers; Russian Science Index.
Article type: research paper

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The research landscape reveals the structure of and major trends in knowledge creation [*Oldham et al.,* 2012; *Christofilopoulos, Mantzanakis,* 2016]. The process of constructing it is often referred to as mapping studies. These terms are similar to the generally accepted concepts of "patent landscape" and "patent mapping"[1]; the only difference is, the former are applied to academic publications as opposed to patents.

Information and analytical systems are usually used to map patent and scientific landscapes, such as Google Patents, PatSearch, Exactus Patent, Scopus, Web of Science, etc. However, they require having a representative base of documents, which, for various reasons, is not always possible, for example, Russian agricultural studies are poorly reflected in international scientometric databases. According to InCites, the number of agriculture-related papers indexed in the Web of Science Core Collection (WoS) and published between 2012–2016 is no more than 2,000 (the results differ depending on the selected classification). The most popular and most rapidly growing area is soil science or pedology. Also, agricultural sciences are represented 90% less often than medicine- and health-related sciences. A random check revealed that very few Russian doctorate holders specializing in this area have even a single publication indexed in the WoS or Scopus. Therefore, these databases are unsuitable for mapping the landscape of Russian agricultural sciences.

An alternative to international scientometric databases is the Russian Science Citation Index (RSCI) database, which more accurately reflects the structure of Russian science [*Zibareva et al.,* 2015]. However, the RSCI in its current state cannot be used as the sole data source for mapping a scientific landscape for several reasons [*Eremenko,* 2014; *Fradkov,* 2015]. Inaccurate links between publications and authors, difficulties surrounding the correction of such shortcomings, and the inclusion of all scientific publications in the RSCI regardless of their quality (which potentially allows one to "beef up" one's figures) present serious problems. For example, not so long ago, more than 300 low-quality publications were excluded from the RSCI, but the quality of the remaining ones has not been assessed [*Ekonomov,* 2017]. To prevent the artificial "inflation" of the scientometric figures, the RSCI adopted more stable versions of popular scientometric indicators: h-index without self-citation, core RSCI h-index, and the Herfindahl Index for journals. However, the quality of the primary data (and in particular the links between authors and publications) still leaves much to be desired. A number of other issues were revealed in the course of our study, which will be described below. The aforementioned limitations may be explained by low publication activity, insufficiently developed citation culture in agricultural sciences, and the RSCI's own flaws. Other researchers have also come to similar conclusions [*Sidorova,* 2016].

To deal with at least some of these problems, we suggest using additional data sources, in particular data about defended theses available at the State Supreme Certification Commission (VAK). According to Russian legislation, researchers' qualifications are assessed in the scope of the national attestation system, which awards Candidate of Sciences and Doctor of Sciences academic degrees in line with the nomenclature of the research specializations. It can be argued that a researcher who defended a thesis in the relevant scientific domain does have certain competences in the field — which should improve the quality of the research landscape. Also, the VAK database includes data about researchers' ages, which can be taken into account when conducting an analysis, thus ensuring a focus on the activities of young researchers.

Another common problem with mapping research landscapes is different classifications, which are supposed to help with the analysis by structuring subject areas but, in effect, only hinder it. The Russian State Classification of S&T Information (RCSTI), the Universal Decimal Classification (UDC), and the VAK nomenclature of research specializations could be used to analyze agricultural sciences. However, these classifications are not coordinated with one another and are very different. They also evolve: with time some codes are excluded and new ones are introduced. Plus, the subject area under consideration does not always fit the taxonomy suggested by the classifications — not by far. Accordingly, assigning codes to specific studies can produce very questionable results, and not infrequently, incorrect ones. The above issues can be dealt with by applying computerized text analysis, in particular clustering and thematic modeling techniques [*Shvets et al.,* 2015]. These approaches allow one to structure subject areas without using any existing classifications. When such tools are applied, the initial set is divided into groups on the basis of specified criteria.

In this study we have grouped the abstracts of Russian researchers' candidate and doctor theses on the basis of a full-text analysis. The resulting groups are seen as *research areas*.

The landscape mapping process comprised of three main stages:

- drafting the initial list of researchers and indicators of their activities;
- grouping the researchers by research area;
- comparing the groups and analyzing the indicators' dynamics.

The suggested methodology was tested for young researchers specializing in agricultural sciences, wich is particularly relevant for knowledge areas poorly represented in Scopus and the WoS. The computerized

[1] Order of the Russian Federal Service for Intellectual Property No. 8 from 01.01.2017. Available at: http://www.consultant.ru/document/cons_doc_LAW_212062/, accessed 15.12.2017.

tools for analyzing native-language texts that the methodology is based upon allow one to aggregate data about researchers' publications and thesis-writing activities from various sources, regardless of how structured it happens to be.

Initial Data

The abstracts of candidate and doctor theses, the Russian Ministry of Education and Science's information about researchers awarded academic degrees in agricultural sciences (full name, organisation, date of birth (VAK data)), and the RSCI scientometric data (http://elibrary.ru) provided the informational basis for this study.

The initial sample was comprised of researchers under 40 years of age (at the time of the study, i.e., in 2016), who have defended a thesis in agricultural sciences between 2008-2015, inclusively. The limited timeframe for the theses defense was due to a lack of the VAK data from earlier periods. Altogether, the sample included 2,572 young researchers.

The data provided by the VAK included four top-level research specialization codes: 06 (agriculture), 05 (engineering sciences), 03 (biological sciences), and 25 (Earth sciences); 10 second-level codes, and 32 third-level ones (full research specialization identifiers). Interestingly, some of the codes belonged to the old version of the VAK classification, while others belong to the new one, so applying them to map a research landscape without additional processing was very problematic.

A set of full-text abstracts of candidate and doctor theses collected on the website of the Russian State Library was used to find out the structure of the scientific domain under consideration. The abstracts were linked to the RSCI and VAK data using the researchers' full names and the names of the organizations where they conducted their dissertation studies.

The researchers' scientometric indicators were collected automatically. A full-name search of the eLIBRARY author index was conducted, followed by searching for their organisations (relevant fields of the authors' RSCI pages and the VAK database were compared). Year of birth and first publication date were also taken into account in order to exclude profiles with incorrectly linked publications. If all of the above conditions were met, the software module was launched to import the relevant scientometric indicators into the database containing the initial data for subsequent landscape mapping. Working with the RSCI information system revealed a number of its flaws:

- a small share of updated author profiles (only 56%);
- lack of data about researchers' age (which does not allow one to analyze young researchers on their own);
- lack of sufficiently powerful analytical tools or data uploading mechanisms for subsequent analysis using other tools;
- low informative value of core RSCI publications' h-index (for 75% of the analyzed researchers its value did not exceed 1);
- a single thematic classification, which does not allow one to categorize the research areas and analyze them from various perspectives. To compare, the aforementioned WoS does offer an opportunity to use different classifications to analyze a particular area's structure.

The chi-square test revealed no statistically significant differences in automatically generated research areas' distribution in the general population (2,572 researchers), and in the sample (56% of the authors with successfully updated RSCI profiles). This is grounds to believe that the sample was representative of the initial list of researchers drafted on the basis of VAK data. All subsequent operations with scientometric indicators were performed only for the 56% of researchers with successfully linked RSCI profiles.

The initial data set was presented in the form of a table with the following columns:

- full name;
- year of birth;
- academic degree;
- year of defending thesis;
- specialization code;
- organization;
- thesis abstract identifier;
- number of publications;
- h-index;
- h-index without self-citation;
- h-index for core RSCI publications;
- total number of citations;
- average weighted impact factor of journals where the papers were published;
- average weighted impact factor of journals where the papers were cited;
- research areas.

Each row of the table corresponds to a particular researcher. Data in the field "Research areas" was entered in line with the structure revealed by thematic modeling of the set of full-text abstracts.

Establishing the Thematic Structure of the Subject Area

In order to identify agricultural sciences' research areas on the basis of the set of full-text abstracts of young researchers' theses obtained from the VAK database, a probabilistic thematic model of the latent Dirichlet allocation (LDA) was built [*Blei et al.,* 2003]. This methodology has repeatedly allowed one to correctly interpret the results of grouping similar texts, which was reflected in a number of Russian and international studies [*Garousi, Mäntylä,* 2016; etc.]. It provides an opportunity to obtain a generalized description of the thematic structure of the text array being analyzed. The Gensim library software version of LDA was used during our experiment [*Rehurek, Sojka,* 2010].

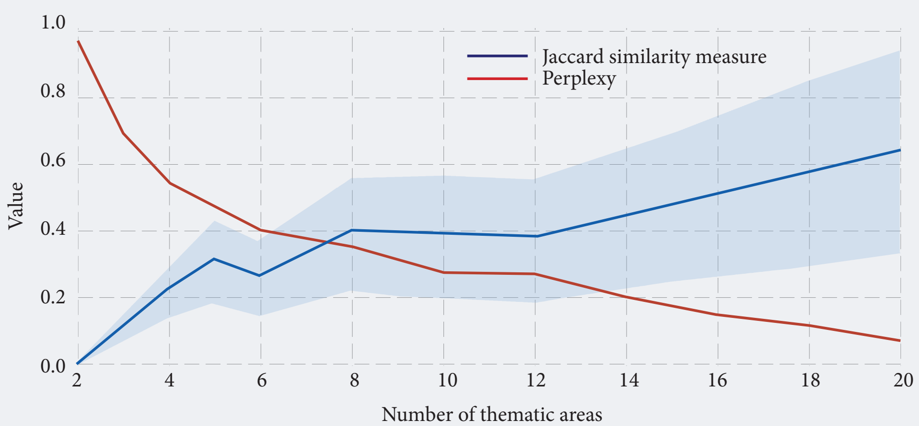
The set of attributes was selected using the "bag-of-words" approach. Since the abstracts contained no author-specific keywords or phrases, the only way to determine the studied texts' vocabulary was by analyzing their full texts. A linguistic analyzer was applied to extract relevant words and phrases from the full texts of the abstracts and was capable of conducting morphologic, syntactic, and semantic analysis, including semantic role labeling, for texts in Russian and English. The morphology of Russian-language texts was processed using the ATP library techniques [*Sokirko,* 2001]; the syntax — with the help of the MaltParser software [*Nivre et al.,* 2007] pre-trained using a marked-up SynTagRus array [*Nivre et al.,* 2008]. Similar procedures for English-language publications were performed using Freeling library tools [*Padró, Stanilovsky,* 2012]. The relational-situational analysis technique developed by the Systems Analysis Institute of the Federal Research Centre for Informatics and Management of the RAS [*Osipov et al.,* 2013], which provided a basis for processing semantics. An assessment of results of a marked-up array analysis are presented in [*Shelmanov, Smirnov,* 2014]. The high efficiency of the applied analyzer is indirectly confirmed by the results of its previous practical applications, including its ability to reveal text borrowing (PAN CLEF-2014) [*Zubarev, Sochenkov,* 2014] and to conduct a full-text search (ROMIP-2008) [*Smirnov et al.,* 2008]. The tool allows one to identify specific words and name groups combining syntactically linked words, in which a noun plays the leading role [*Suvorov, Sochenkov,* 2015]. The resulting phrases are normalized by bringing the main word to the normal form, after which the form of the dependent word is chosen from all possible variants whose morphological characteristics match those of the main word.

Perplexy was chosen as the main criterion to assess the thematic model's quality [*Hofmann,* 1999]. It describes the model's ability to restore the initial probabilistic distribution of the analyzed document set's vocabulary (words and phrases): the lower this indicator's value, the better the model describes the data. The most significant parameter for building the model is the number of thematic areas (or, in other words, classes). The higher this value, the more flexible the model becomes, so it will describe the initial data increasingly better (therefore, the perplexy value decreases). However, if we set an excessively high value, thematic areas would significantly overlap and the breakdown would be hard to interpret. Accordingly, the issue of setting the right number of thematic areas arises. In this study, the Jaccard measure was applied to assess thematic areas' similarity [*Manning et al.,* 2008] by using lists comprising 30 words and phrases most typical for each area. The best number would be the one providing a sufficiently low perplexy figure, combined with a not too high degree of similarity.

We shall use the term *research areas* (or just *areas*) to refer to the results of thematic modeling conducted in line with the above scheme. Following this procedure, some of the abstracts could be included in several areas at the same time, which provides an opportunity to identify and analyze groups of interdisciplinary studies.

Figure 1 presents graphs of the thematic model's normalized perplexy, the normalized average value of the Jaccard similarity measure for the areas, and the dispersion of these values. When the number of areas

Figure 1. **Perplexy and Jaccard Similarity**



Source: composed by the authors.

Table 1. **Research Areas Automatically Generated by Processing Full-Text Abstracts Published in 2008–2015**

Research area	Keywords and phrases (automatically generated)
Meat and dairy animal farming	cow, animal, milk, cattle, live weight, lactation, bull calf, milk yield, genotype, milk production, monthly index, live, cow group, female, cross-breed, dairy, line, goal, contemporary, Indian ink, monthly age, mare, steppe, Holstein-Friesian breed, blood, herd, ram, heifer, first calf heifer, birth, youngsters, animal group, meat production, animal, head, contemporary, meat
Plant selection	hybrid, line, score, fruit, standard, sort sample, population, disease, stock, coastal, early, combination, sprout, grain weight, new variety, ear, genotype, decade, fruity, selection, variability, economic, blossom, apple tree, seed weight, planting, potato, cross-breeding, shoot, create, collection, original material, damage, diameter, soil, maturing, nursery, lodging, garden
Forage	ration, experimental group, control group, mixed fodder, live weight, additive, feeding, animal, broiler, protein, digestibility, live, organism, preparation, broiler chicken, bird, blood, fodder calcium, chicken, piglet, preservation, egg, raw protein, feeding, head, analogue, metabolism energy, scientific and economic experiment, pig, cubs, goal, inclusion, piggy, chicken, cellulose, meat, duration of experiment, substance, digestibility, methionine
Silvics	plantation, tree, forest, pine, wood, earth, cutting, oak, diameter, forest stand, stock, incline, class, belt, pinery, tier, care, fir grove, timber, cover, agro-landscape, burbot, distribution, fir, undergrowth, crown, forest shelter belt, forest type, cone, timberland, horizon, model, fescue, herbage, northern, tillage, common pine
Pedology	irrigation, quantity, watering, edge, preparation, solution, heavy metal, loss, fraction, July, rice, irrigation regime, root rot, pest, plant louse, acid, incentive, Kuban, amaranth, mine, environmentally, larva, speed, September, biologically, water regime, horizon
Field crops	winter wheat, mineral fertilizer, barley, spring wheat, kg/ha, crop rotation, cwt/ha, seeding rate, sowing time, green mass, grass, rye, herbicide, fallow, predecessor, fertilizer application, corn, mix, winter rye, seed processing, pea, manure, oats, tillage, lucerne, preparation, perennial grass, nitrogen fertilizer, black earth, ploughing, soil layer, soya, fertilizer dose, grain quality, clover, germination, l/ha, crop capacity, dressing, seeding technique

Source: composed by the authors.

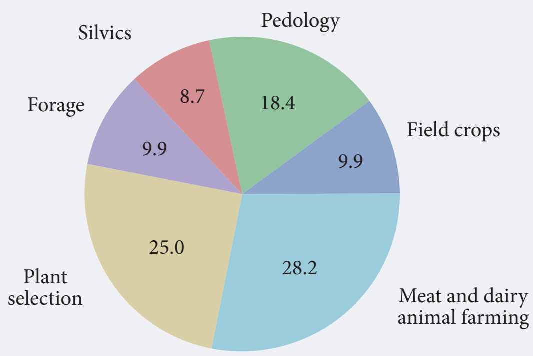
grows from 6 to 8, the dispersion of the Jaccard similarity measure significantly increases: by more than 50%. Pairs of areas emerge with a high share of common vocabulary, while perplexy drops insignificantly. This and the interpretation of the thematic breakdown clearly suggest that the best number of areas would be six. It ensures that the resulting thematic breakdown can be properly interpreted and provides an acceptable balance of perplexy and Jaccard similarity values.

Names of the areas, together with corresponding typical keywords and phrases, are presented in Table 1. They were formulated by the authors on the basis of the lists of keywords and phrases automatically generated during the testing of the thematic LDA model.

Figure 2 shows the shares of theses defended in each of the automatically generated research areas. In comparison, Figure 3 presents the distribution of this indicator by 15 agricultural research specialization nomenclature codes with the highest activity.

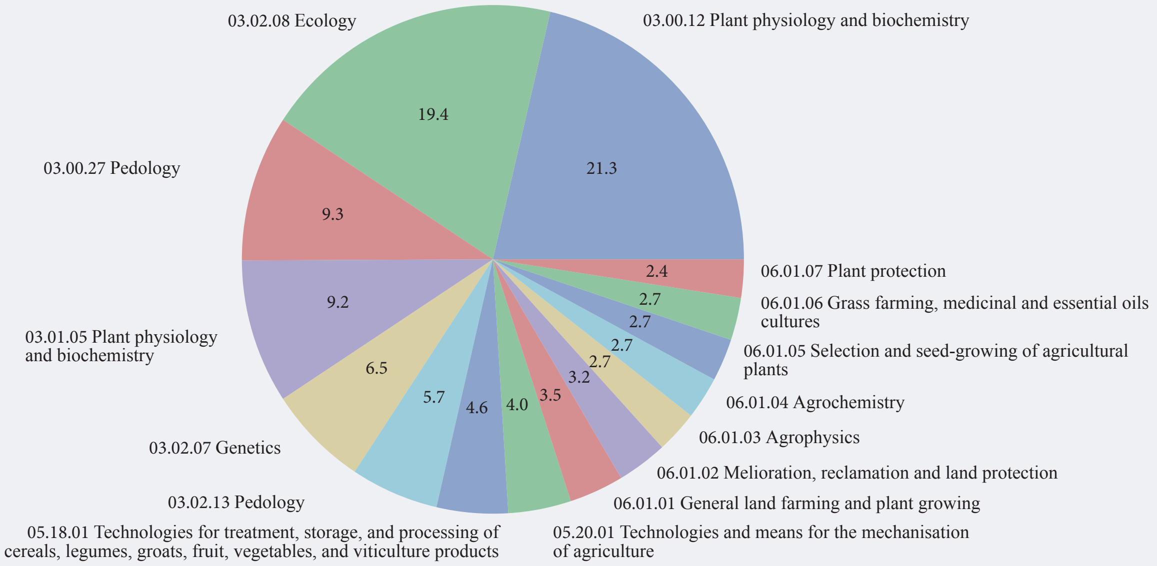
The distribution presented in Figure 3 is rather skewed (few popular specialization areas and a long "tail" of those with few defended theses). It would be hard to conduct a comparative analysis of research areas on this basis for several reasons. Since the list of research specializations simultaneously contains old and new VAK nomenclature codes, comparing them turns into a formidable challenge with no definitive solution. Also, due to significantly different sample sizes for each specialization, estimates of scientometric indicators' distribution parameters have different confidence intervals (and for less popular specializations, they become increasingly larger). For particularly rare research areas, estimating such

Figure 2. **Distribution of Defended Theses by Research Areas (%)**



Source: composed by the authors.

Figure 3. **Distribution of Defended Theses by Top 15 Agricultural Research Specialisation Nomenclature Codes** (%)



Source: composed by the authors.

parameters becomes totally futile, which makes it impossible to compare them with better-represented research areas.

Comparing Figures 2 and 3 reveals that the distribution of defended theses by automatically generated research areas is less skewed than the one by research specialization codes. This simplifies further thematic analysis and its validity for structuring research areas and assessing publication activity indicators can be considered confirmed. An important difference between research areas and research specialization codes is that the former overlap: any researcher may belong to several research areas at the same time. Accordingly, the study takes interdisciplinarity into account, which is a major characteristic of present-day research.

Figure 4 shows the annual numbers of defended agricultural sciences-related theses between 2008-2015 inclusively. The columns' colored sections indicate the shares of theses defended in each specific research area during the relevant year. We can see that the emphasis is shifting from field crops and pedology towards plant selection.

Analysis of Young Researchers' Scientometric Indicators

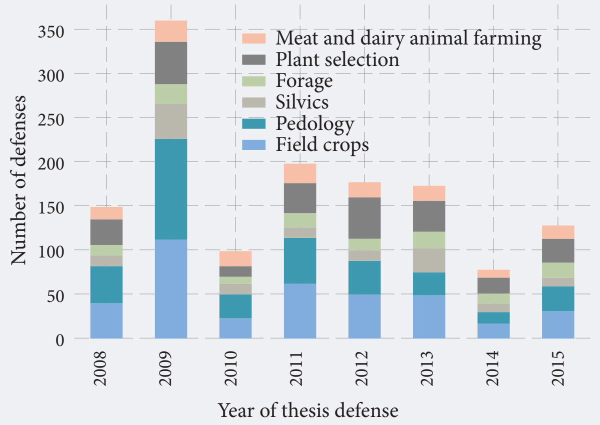
The scientometric indicators were analyzed using simple histograms — calculations of the density distributions with Gaussian smoothing [*Scott,* 1992]. The comparison graphs are presented as violin plots [*Hintze, Nelson,* 1998]. The Python 2.7 programming language and the Jupyter interactive development environment were applied for data processing purposes. The graphs were built using the Matplotlib [*Hunter,* 2007] and Seaborn (https://seaborn.pydata.org/) libraries.

As noted, less than 56% of young Russian researchers specializing in agricultural sciences have updated RSCI profiles. This means that they pay very little attention to monitoring their publication activity. After the eLIBRARY profiles were linked with the VAK data, records containing all known parameters suitable for further analysis remained for only 1,419 researchers. It turned out that only 107 researchers had an h-index value of 5 or above (out of the more than 2,500 researchers on the initial list). As to the h-index without self-citation, only 78 young researchers have it at 5 or above.

Figure 5 shows the correlation between the researchers' age and number of publications. Each dot corresponds to a specific researcher (their age is shown on the horizontal axis, and the number of publications at the time of the study — on the vertical one). The linear trend (correlation) is shown as a straight line. The oval lines describe density of the joint "age and number of publications" distribution.

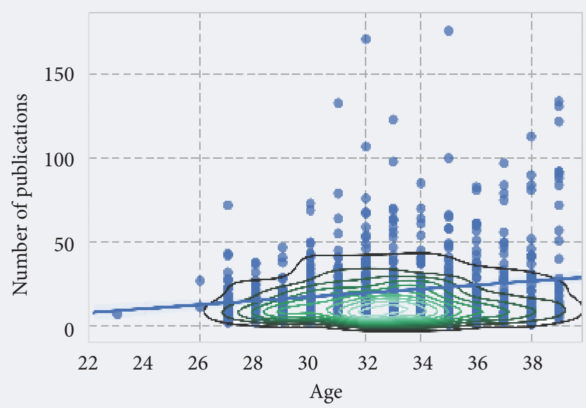
From a demographic point of view, the graph in Figure 5 shows that researchers specializing in agricultural sciences are most productive at the ages of 32–34. Typically, they are young, actively working, and publishing candidates of sciences. Another spike in activity occurs at the age of 39–40; presumably this is the most productive period of young doctors of sciences or candidates getting ready to defend their doctoral theses. The 30-year threshold is preceded by a smooth growth of publication activity, which stabilizes during the next five years.

Figure 4. **Dissertation Activity Growth by Research Area**



Source: composed by the authors.

Figure 5. **Linear Correlation and Density of Joint Distribution of Researchers' Age and Number of Publications in the RSCI**



Source: composed by the authors.

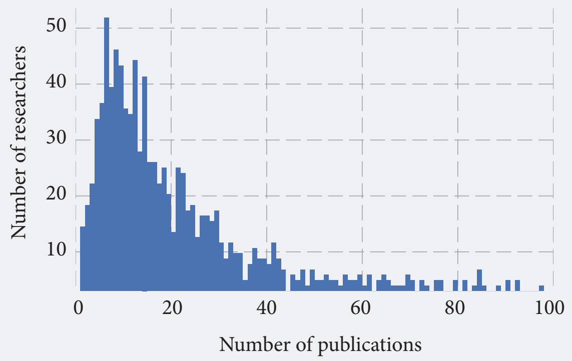
Figure 6 presents a histogram of distribution of the number of publications (limited to 100). Most of the researchers have between 8 and 25 publications to their credit; the largest number is 176.

Figure 7 shows histogram of h-index distribution without self-citation. We can see that most of the researchers have an h-index between 1 and 3. The highest value in the sample is 22.

Figures 8–11 present violin plots showing the empirical distribution of the various scientometric indicators between automatically generated research areas. Each figure represents a graph of core probability density estimation (symmetrical in relation to the vertical axis), with Gaussian smoothing. The wider the figure, the higher the share of researchers with the corresponding index value. Dotted lines inside the figures mark the 25th, 50th, and 75th percentiles. To assess the statistical significance of the differences in distributions by specific research areas, the Mann–Whitney U-test was applied [*Mann, Whitney,* 1947]. The objective was to make sure that in some areas the average indicator value was higher than in others, so the application of that specific criterion seems to be valid. The criterion value and the corresponding p-value were calculated for all possible research area pairs (15 altogether). The statistical significance threshold (critical p-value) was set at 0.05.

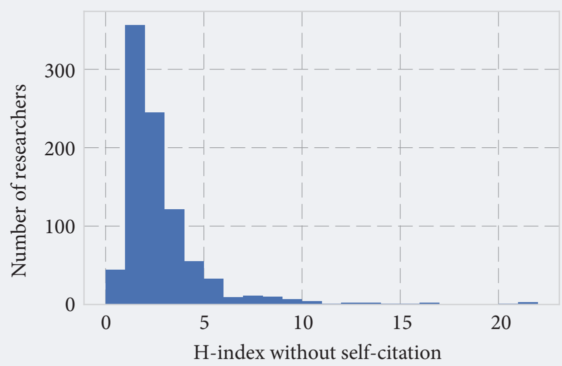
Figure 8 presents distribution of the h-index (without self-citation) by automatically generated research areas. The figures' width is proportional to the number of researchers with corresponding h-index values. Researchers whose h-index is below 5 are not shown on the graph. They were cut from the sample to show the difference between the levels of leading researchers' citations in each research area. The graph shows that world-class researchers (h-index of 10 or more) are represented in various research areas to differing degrees. The application of the Mann–Whitney criterion[2] established that if the significance threshold is

Figure 6. **Histogram of Number of Publications Distribution by Researcher**



Source: composed by the authors.

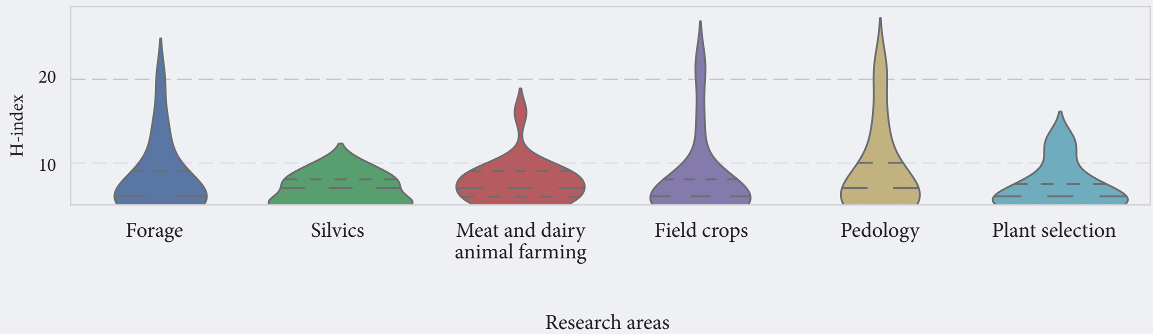
Figure 7. **Histogram of H-index Distribution (Without Self-Citation)**



Source: composed by the authors.

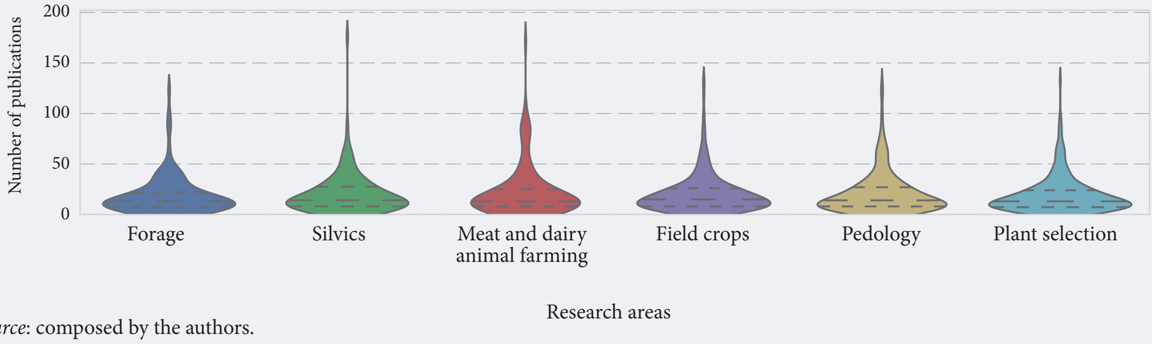
[2] The Mann–Whitney criterion is calculated based on the basis of all h-index values (including those under 5).

Figure 8. **H-index Distribution (Without Self-Citation)**



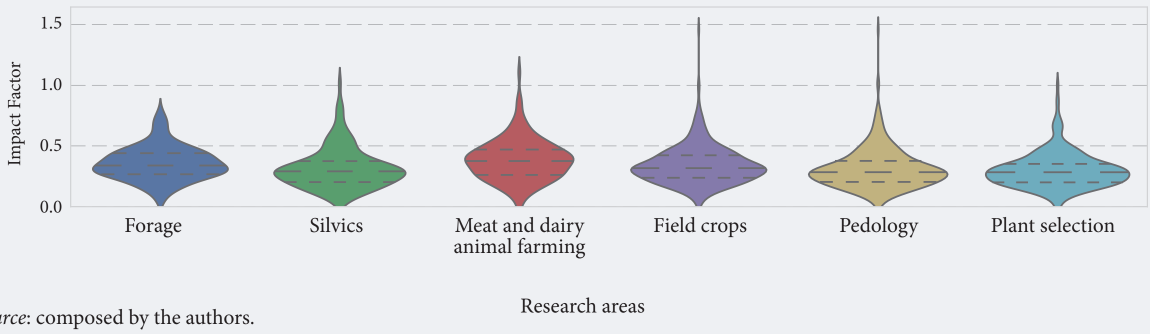
Source: composed by the authors.

Figure 9. **Number of Publications Distribution**



Source: composed by the authors.

Figure 10. **Distribution of Average Weighted Impact Factors of the Journals Where the Researchers' Papers Were Published**



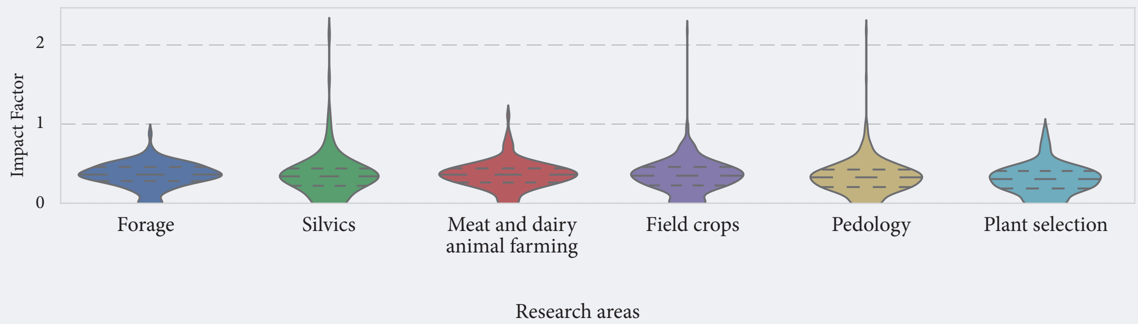
Source: composed by the authors.

set at 0.05, in 40% of all cases (six research area pairs) the average h-index in one area was higher than in the other one. The most significant divergence was noted for the following pairs: "silvics – meat and dairy animal farming" (p=0.007), "meat and dairy animal farming – plant selection" (p=0.0003), and "field crops – plant selection" (p=0.0006). The least significant difference was found for the pair "forage – meat and dairy animal farming" (p=0.44).

Figure 9 shows distribution of researchers' publications in each area. We can see that all researchers' publication activity remains at a similar level. No statistically significant variations between the average numbers of publications in each area were discovered (average p=0.28).

Figures 10 and 11 show the impact factors of the journals that publish the researchers' papers and that of the publications which cite these papers. We can see from the graphs that the distributions in the various research areas are quite different. Statistically significant variation between impact factors of the journals where the papers were published and the journals where they were cited have been found for ten and seven research area pairs, respectively (67% and 47% of the pairs). The most significant variation of the average indicator values were found for the following pairs: "meat and dairy animal farming — plant selection" (p=0.0005), "forage — plant selection" (p=0.0004), "field crops — plant selection" (0.0008).

Figure 11. **Distribution of the Average Weighted Impact Factors of Journals That Cited the Researchers' Papers**



Source: composed by the authors.

The least significant difference was noted for the combinations "forage — meat and dairy animal farming" (p=0.37) and "silvics — field crops" (p=0.32).

It would be interesting to consider the differences between the impact factors of the journals that have published the papers and the ones that have cited them in the scope of the same research area. The graphs show that, for example, the journals that cite papers on silvics and pedology (unlike other research areas), have a much higher rating than the journals which originally published the papers. This was confirmed by the Mann-Whitney U-test, with p=0.03 and p=0.02, respectively.

The above gives firm ground to conclude that certain differences exist between particular research areas of agricultural sciences in terms of scientometric indicators and citation alike. This is suggested by the results of the statistical Mann-Whitney U-test, which, in turn, confirm the need to use different approaches when analyzing the productivity of researchers specializing in different research areas in the scope of the same scientific discipline.

Conclusion

The paper proposes and tests a new research landscape mapping methodology. Its originality lies in the combination of full-text analytics and traditional statistical processing of scientometric data to improve the reliability, sustainability, and interpretability of research landscapes. The proposed approach corrects the flaws of manually constructed taxonomies which tend to lean towards an excessive level of detail and offer little opportunity for one to compare research areas with one another. The methodology is especially relevant for disciplines poorly represented in international scientometric databases such as Scopus and the WoS. Note that the proposed technique for combining various data sources does have alternatives, but in the authors' opinion, it does help one solve the various problems described in the paper.

The suggested toolset does not replace traditional scientometric tools but supplements them, allowing one to obtain a more holistic and more easily interpretable picture in order to accomplish specific objectives in the area of analyzing and assessing scientific development. Its advantages include an opportunity to identify emerging prospective interdisciplinary research areas (a "data-based" approach). Accordingly, it can be applied, for example, to address global challenges mentioned in the S&T Development Strategy of the Russian Federation[3].

The experimental testing of the methodology for the first time allowed us to map the research landscape of the agricultural sciences, using young researchers aged under 40 as a sample. Six major research areas were identified: forage, silvics, meat and dairy animal farming, field crops, pedology, and plant selection. The highest values of bibliometric indicators were noted in pedology. The significant divergence of the abovementioned areas' scientometric indicators suggest a need to use individual approaches when assessing relevant research results.

In the authors' opinion, the prospects for the further development of this methodology include mapping other research landscapes, designing algorithms for identifying promising research areas, and building area-specific rankings of researchers and R&D organizations. The scope for the application of text analysis techniques to compare S&T documents from various sources must be explored (such as databases of academic papers, patents, etc.), which cannot be automatically linked to each other due to the lack of a comprehensive classification. Such a comparison could provide a basis for the integrated analysis of specific S&T areas and for mapping more complex research landscapes.

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[3] Approved by the RF Presidential Decree No. 642 of 01.12.2016 . Available at: http://publication.pravo.gov.ru/Document/View/0001201612010007, accessed 14.11.2017.

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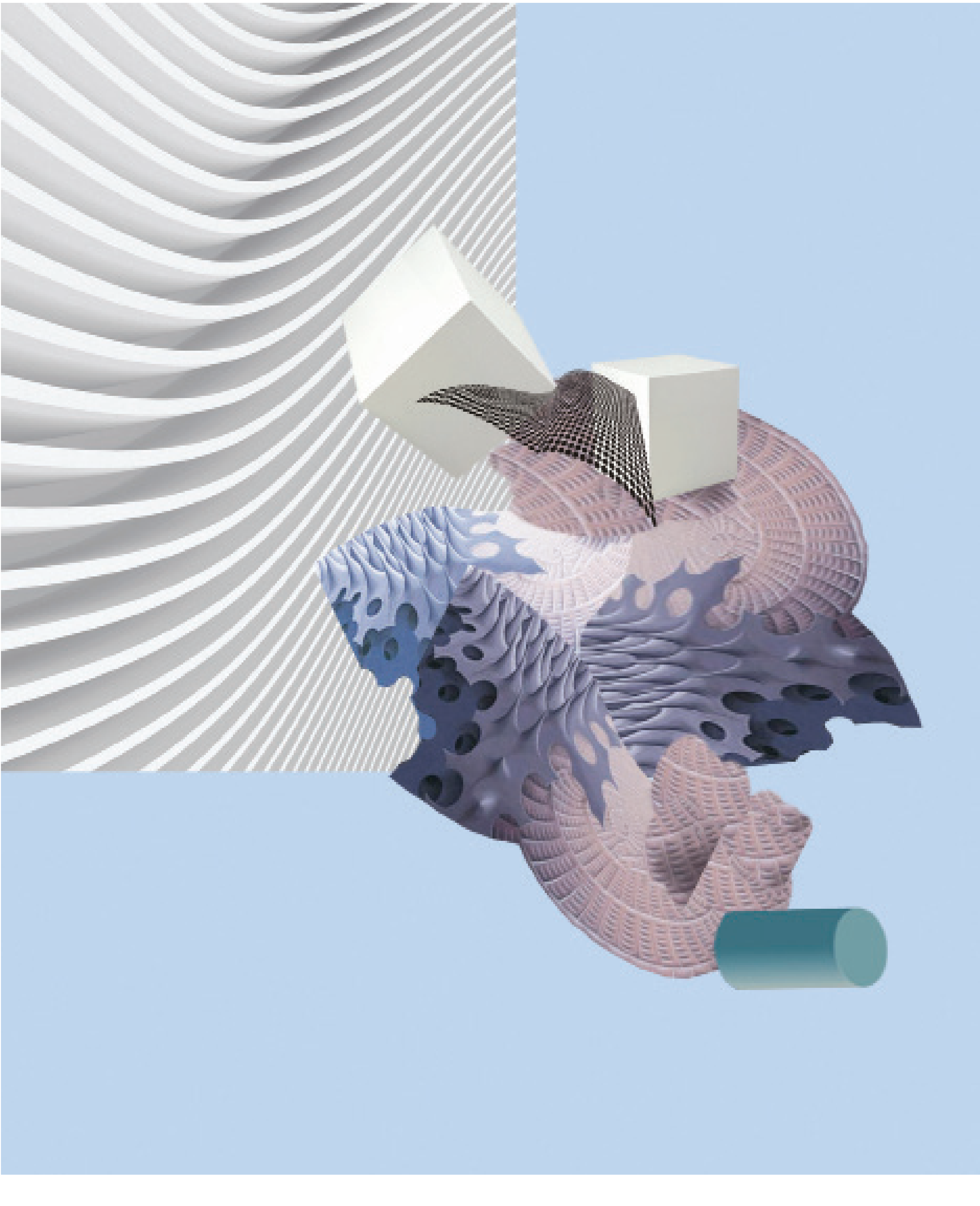

The Knowledge Triangle in the Healthcare Sector — The Case of Three Medical Faculties in Norway

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Abstract

The paper investigates the social role of education and the relevance of university programs for meeting the real needs of society, which has gained particular political importance in recent years. Attention to this topic, in turn, has fueled interest in the concept of the «knowledge triangle», which implies a synergistic effect from the interplay of education, research, and innovation. Existing studies on the interaction of higher education institutions (HEIs) with society and policy in this field are primarily focused on the links between science and innovation and on the contributions of HEIs to economic development and growth. Many researchers focus on the interaction between universities and the industrial sector, but ignore HEIs' involvement in creating innovations in the public services sector. This is rather peculiar considering that innovation in the public sector has received increased policy attention over recent years and is seen as essential for improving the efficiency and quality of public services and for addressing some of the major societal challenges, linked, for example, to an ageing population and maintaining the welfare state.

This paper looks at the healthcare sector, where HEIs interact with private industry as well as public healthcare services. It builds upon a study from Norway carried out in 2015 in the framework of an OECD project, which mapped and analyzed knowledge triangle policies and practices at the national and institutional level. This study showed that the interplay between education, research, and innovation is a key concern in national policy for the development of the healthcare sector and that knowledge triangle interactions with both the private and public sector is a central aspect of the current practices at medical departments at Norwegian HEIs. The linkages between the medical faculties and public healthcare services are especially interesting, as they provide patterns of interaction beyond those patterns identified in the existing literature and because education plays a central role.

Keywords: knowledge triangle; higher education; public sector; private sector; healthcare industry; Norway.

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* For more details see the special issue of *Foresight and STI Governance* "Knowledge Triangle: Universities in Innovation System" (2017, vol. 11, no 2). — *Editorial note.*

As in policy, the focus of academic literature on the interaction between higher education institutions (HEIs) and society has primarily been on the relationship between research and innovation and the role university research may play in economic development and growth. Lately, the quest for HEIs that provide relevant education for society has entered the political agenda (e.g., [Norwegian Government, 2017]) and given rise to the re-introduction[1] of the concept of the 'knowledge triangle', which assumes that there are potential synergies between education, research, and innovation.

Furthermore, reflecting the focus on the contribution of HEIs to economic growth, most studies have investigated their interaction with the industrial sector [*Perkmann et al.,* 2013]. Little attention has – to our knowledge – been placed on how HEIs interact with and contribute to innovation in public sector services. This is rather peculiar considering that innovation in the public sector has received increased policy attention over recent years and is seen as essential for improving the efficiency and quality of public services and for addressing some of the major societal challenges that are linked, for example, to an aging population and maintaining a welfare state.

This paper looks at the healthcare sector, where HEIs interact with private industry as well as public healthcare services. It builds upon a study from Norway carried out in 2015 in the framework of an OECD project[2], which mapped and analyzed knowledge triangle policies and practices on the national and institutional level [*Borlaug et al.,* 2016]. The study shows that the interplay between education, research, and innovation is a key concern in national policies for the development of the healthcare sector, and that the interactions within the knowledge triangle with both the private and public sector are a critical aspect of current practices at the medical departments at Norwegian HEIs. The linkages between the medical departments and public healthcare services are especially interesting, as they provide other patterns of interaction beyond those identified in the existing literature and the fact that education plays a central role here.

The Interaction between Higher Education Institutions and Society

Many studies have investigated the relationship between research and innovation and the channels of interactions between HEIs and private firms. One strand of these studies focuses solely on 'entrepreneurial activities' building upon, amongst other things, insights from the studies of the entrepreneurial university (e.g., [*Clark,* 1998; *Etzkowitz et al.,* 2000]). Entrepreneurial activities involve, on the one hand, entrepreneurial education programs and entrepreneurial research activities such as patenting, licensing, and start-ups as well as systemic and institutional initiatives for supporting and enhancing these types of activities with the use of technology transfer offices and science parks [*Siegel et al.,* 2003; *Clarysse et al.,* 2005; *Perkmann et al.,* 2013]. This is a typical example of the knowledge triangle where student projects and the commercialization of research lead to the introduction of new products, processes, services, and businesses.

However, another strand of the literature has emphasized that the commercialization of research accounts for a relatively small part of the knowledge transfer from universities to society [*Cohen et al.,* 2002; *Schartinger et al.,* 2002; *Bekkers, Bodas Freitas,* 2008]. In fact, one study from Norway reports that no more than about six percent of the scientific staff engage in these types of activities [*Thune et al.,* 2014]. Other and more important channels for interaction are collaborative and contract research [*Meyer-Krahmer, Schmoch,* 1998; *Perkman, Walsh,* 2007; *d'Este, Patel,* 2007], mobility (university faculty working in industry/public sector and vice versa) [*Gübeli, Doloreux,* 2005; *Bekkers, Bodas-Freitas,* 2008], informal networks and conferences [*Meyer-Krahmer, Schmoch,* 1998; *d'Este, Patel,* 2007], and paid and unpaid consulting services [*Amara et al.,* 2013]. These formal and informal channels enhance the potential for interlinkages between research and innovation as the HEI researchers obtain access to critical knowledge needs in the private sector while the private sector receives access to research at HEIs and may as such contribute both directly and indirectly to innovation.

As these studies show, we have relatively good insights into the linkages between HEIs and the private sector when it comes to research and innovation, but our knowledge about the channels of interaction with regard to education is more limited. There are, however, some relevant studies. Bekkers and Bodas-Freitas [*Bekkers, Bodas-Freitas,* 2008] have focused on the hiring of graduate students and student internship programs as important knowledge transfer channels, and Tømte et al. [*Tømte et al.,* 2015] have emphasized continuing education. The latter study found that employees in both the public and private sector improve their knowledge bases and obtain access to relevant research through courses at HEIs, and that HEIs interact with employers to provide relevant courses. A survey of Norwegian academic staff shows that this was in fact one of the most important channels of interaction between HEIs and the public and private sectors [*Thune et al.,* 2014]. The same survey also shows that academic staff more often collaborate with the public sector than the private sector, but these channels of interaction are, to

[1] Used in the Lisbon Strategy (2000–2010) [European Parliament, 2010], and under Sweden's EU Presidency in 2009.

[2] For more details see the special issue of *Foresight and STI Governance* "Knowledge Triangle: Universities in Innovation System" (2017, vol. 11, no 2). — *Editor's note.*

our knowledge, poorly studied. There are many reasons for this: one — as pointed out above — is the emphasis on HEIs' role in economic development and growth. Another is that HEIs themselves in many countries belong to the public realm and have traditionally played a key role in educating public sector staff. Therefore, interactions with the public sector may be seen as an embedded part of HEIs' mandate. Finally, studies of innovation in the public sector seem to have focused on internal administrative, often technology-driven, processes, and not on cooperation with external actors [*de Vries et al.,* 2016].

Against this background, it is especially interesting to investigate the channels of interaction between HEIs and public service providers, and how they collaborate on education, research, and innovation. The literature on the knowledge triangle concept assumes that the interaction between education, research, and innovation can be strengthened by so-called orchestration tools [*Sjoer* et al., 2016], which are the platforms and processes that may be found both at the systemic and institutional levels. In this paper, we focus on such tools and the many channels of interaction between three different medical departments and external actors in both the public and private sectors.

The Norwegian System and Main Policies for Education, Research, and Innovation within the Healthcare Sector

In Norway, state-owned universities and university colleges are mainly responsible for education and research within the medical sciences. Historically, there has been a division of labor between the different types of institutions. The universities have been responsible for the research-intensive scientific fields, such as medicine and dentistry, and the university colleges were responsible for shorter professional programs within nursing and other fields with relatively low levels of research. This picture is changing, however, as recent mergers between universities and university colleges have resulted in the establishment of integrated medical and healthcare faculties covering a broad range of different medical sciences.

Generally, the faculties of medicine and healthcare carry out education and research in close cooperation with the public healthcare system. The specialist healthcare services — or public hospitals — in Norway are organized as health trusts administered by regional healthcare authorities that are owned by the Ministry of Health and Care Services. The historic ties to the medical faculties at the universities have been very strong, and interactions between the public hospitals and the higher education sector have been institutionalized in various ways. First, the hospitals have a legal responsibility to take active part in the education of healthcare personnel, for example, by offering practical training to students at HEIs, which is a function for which they receive earmarked government funding. Research is also a legally stipulated task for the hospitals and the regional healthcare authorities receive dedicated research funding from the Ministry of Health and Care Services. The research funding is allocated to the hospitals that work in close cooperation with universities and university colleges. In accordance with government guidelines, the regional health authorities have cooperative bodies with HEIs in their respective regions that are responsible for the allocation of the research funding, as well as for the discussion of matters of mutual interest in the areas of education and research. Much of the research funding goes to projects involving both hospital and HEI staff, and collaboration between the professional and academic fields is moreover underpinned by the widespread use of dual affiliations. Collaboration between the university hospitals and medical faculties is particularly strong, with a high degree of integration in terms of staff, equipment, and infrastructure.

The primary healthcare system covers a broad range of services offered by the municipalities, which also cooperate with HEIs and, in particular, the institutions offering shorter healthcare education programs. However, the municipalities do not have the same explicit responsibility to carry out health-related education and research as the regional healthcare authorities, and therefore do not receive earmarked government funding for these tasks. This means that the cooperation between HEIs and the municipal healthcare services is not institutionalized in the same way because it primarily involves healthcare sciences and professions with limited research activity and relates mainly to education.

Policies for Research and Innovation

Over the past decade, several government ministries in Norway have initiated the so-called 21 Strategies, which are national research and innovation strategies within priority areas for research-based development and value creation in the 21st century. There are currently nine such strategies for priority areas ranging from the oil and gas sector to health and care, which have been developed with the involvement of several ministries, research institutions, industry, and other societal stakeholders.

The Health&Care21 strategy stands out by emphasizing the importance of an integrated approach to education, research, and innovation, and this policy explicitly refers to the knowledge triangle concept. Knowledge triangle interactions are seen as essential for the realization of the three main goals set out in the strategy, which are to achieve better public health, breakthrough research, industrial development, and economic growth.

The strategy is concerned with facilitating innovation through increased interactions between education, research, and the healthcare services, as well as between education, research, and industry. It recommends that many of the mechanisms that are in place to ensure cooperation between public hospitals and HEIs are introduced in the municipal healthcare services. This includes giving municipalities a stronger, more explicit legal responsibility to fulfil this task and dedicated funding for contributing to education and research, as well as the establishment of regional cooperative bodies for municipalities, HEIs, and other research institutions.

The linkages between educational and research institutions and industry are described as underdeveloped, reflecting – among other things – the limited size of the Norwegian healthcare industry and the lack of a culture of and incentives for cooperation. Thus, key recommendations include introducing incentives for HEIs and health trusts to engage in patenting, commercialization, and innovation cooperation with industry, as well as compulsory courses in entrepreneurship and innovation in healthcare-related educational programs.

Besides allocating research funding to the regional healthcare authorities, the Ministry of Health and Care allocates funding for healthcare-related research and innovation through the Research Council of Norway (RCN). Unlike research funding agencies in many other countries, the RCN covers all disciplines and research-performing sectors and provides support for industrial R&D and research-based innovation. The Research Council has developed a separate policy for innovation in the public sector, where the fundamental idea is that interactions within the knowledge triangle should be strengthened through so-called practice-oriented R&D. Practice-oriented R&D takes place during the close cooperation between institutions for research and education and public sector professions, with the aim to develop research-based solutions to practical problems as well as to strengthen knowledge-based education and professional practice. The Research Council's efforts in this area have so far been targeting two sectors, the educational sector — spanning from kindergartens to higher and continuing education, and more recently, to the health, care, and welfare sector.

Case Studies

The case studies were performed as a part of the OECD study on the knowledge triangle [OECD, 2017], and are based on a predefined template. In order to ensure the variation and comparability of the sample, we studied three different medical faculties at three HEIs; the Faculty of Medicine at the Norwegian University of Science and Technology (NTNU), an integrated medical faculty at UiT — the Artic University of Norway, and The Faculty of Health at the University College Buskerud and Vestfold (HBV)[3]. The case descriptions below are based on document studies and interviews with the deans and a group interview with two to four members of the academic staff, all of which were conducted in 2015 (for more details see [*Borlaug et al.,* 2016)]).

NTNU Faculty of Medicine

The Faculty of Medicine (FM) at NTNU is a classical medical faculty offering a medical doctorate program as well as bachelor's, master's, and PhD programs in several medical and healthcare-related areas, including a master's program in pharmacology. The faculty is organized in seven departments and hosts several research centers.[4] The main areas of research include translational research, medical technology, health surveys, and biobanking.

As a medical faculty, the FM is strongly embedded in the regional healthcare services, with particularly close ties to the regional health authority *Helse Midt-Norge* and its subordinate hospitals. The faculty is fully integrated with St. Olav's Hospital, and the two institutions make up the Integrated University Hospital in Trondheim. The national system for cooperation between the specialist healthcare services and HEIs means that the FM has close institutionalized ties with *Helse Midt-Norge*. It is an important platform for interactions between education, research, and innovation. The integration of the FM and St. Olav's Hospital in the Integrated University Hospital is explicitly based on the idea of the knowledge triangle. In practical terms, the two institutions function as one organization, they are physically co-located and represented on each other's boards and have joint leadership meetings, cooperating bodies for education and research, and a high number of bridging positions.

The tight integration is also reflected in the funding sources of the faculty. Basic government funding accounted for 34% of total R&D expenditures in 2013. Of this funding, 24% was Research Council funding, and 30% of the funding came from other public sources. The high share of funding from other public sources reflects the importance of research funding from *Helse Midt-Norge*, which makes up about 50% of external funding at the faculty. According to data of National R&D statistics and NIFU, industry accounted for a small share of total R&D expenditure in 2013 — less than 2%.

Integrated education, research, and innovation cooperation with the specialist healthcare services, and particularly St. Olav's Hospital, is an essential part of the faculty's activity. Other types of cooperation such as with the primary healthcare services are considered to be important, but underdeveloped

[3] Abbreviations are built up from Norwegian-language titles of the HEIs. — *Editorial note.*

[4] NTNU merged with three university colleges in 2016 and has now a different structure.

because the majority of the educational programs are directed towards the specialist healthcare services. The faculty also has long traditions in close research and innovation collaboration with the technology departments at NTNU, for example, within the field of ultrasound technology, where it has resulted in a spin-off company which is now part of GE Vingmed Ultrasound. Still, there is potential for stronger cross-disciplinary cooperation, according to our respondents.

There has not been any systematic integration of innovation in the educational programs at the faculty, but the newly established master's program in pharmacology includes a mandatory course in innovation. The objective is to give the students an introduction to the drug development process "from idea to final product", and the course draws upon the expertise of the university's technology transfer office. Another initiative is earmarked funding for PhD positions in innovation projects. The faculty funded three PhD positions in innovation projects in 2014-2015, and another two positions in 2016.

Industry collaboration is widespread and takes many different forms. The FM has a cooperative agreement with GE Vingmed Ultrasound, and the company rents offices in the Integrated University Hospital, funds PhD and postdoctoral positions, and is involved in education and research at the faculty through part-time positions. Moreover, the faculty has hosted two Centres for Research-based Innovation in recent years, both with GE Vingmed Ultrasound as an industrial partner: Medical Imaging Laboratory, MI Lab (2007-2015), and the Centre for Innovative Ultrasound Solutions, CIUS, which was started up in 2015. CIUS is a collaboration with researchers from St. Olav's Hospital and technology departments at NTNU and around ten national and regional industrial partners. There are several master's students associated with the Centre, but our respondents point out that intellectual property rights issues prevent direct student involvement in research cooperation with the industrial partners.

Whereas cooperation with the specialist healthcare services is institutionalized, cooperation with industry and commercialization is largely dependent upon individual interest and drive, according to our respondents. For instance, one of our respondents established his own consultancy firm based on previous work experience in the medical industry. Another point they make is that education in many cases is the responsibility of the members of academic staff who are the least active as researchers, while those who engage in research and innovation may not take part in education, primarily because of time constraints. This may have a bearing on the interest in research and innovation among students, and good role models for knowledge triangle practice are considered important.

The faculty is also engaged in commercialization and makes active use of the university support system for innovation, including internal funding for the development of research ideas with innovative potential and the technology transfer office. One example of when researchers at NTNU and St. Olav's Hospital have collaborated closely with the TTO was the development of a method and surgical navigation device for the treatment of severe headaches, called MultiGuide.

UiT — the Artic University of Norway — The Faculty of Health Sciences

The Faculty of Health Sciences (FHS) covers the traditional academic areas of medicine, dentistry, pharmacology, and psychology, as well as the shorter professional programs such as nursing, physiotherapy, etc., which have traditionally been offered by the university colleges. FHS is strongly embedded in the public healthcare sector in Northern Norway and has close ties to the primary and specialist healthcare services and the dental care services in the region. Interactions with the public hospitals governed by the regional health authority *Helse Nord* are especially strong and there is a high degree of integration between the faculty and the University Hospital in Northern Norway (UNN), which is located on the university campus. *Helse Nord* is furthermore an important source of research funding for FHS. Local and regional industry plays a limited role as a collaborative partner and funding source and, with the exception of funding from *Helse Nord*, national research funding seems to be more important than regional funding.

The close ties between FHS and the healthcare services in northern Norway are reflected in the composition of the Faculty Board, where both UNN and a municipality in Troms County are represented. There are no industry representatives on the board. External representation is said to be important because it brings in stakeholder prospects and provides broader societal legitimacy for strategic decisions.

The national system for interaction between HEIs and specialist healthcare services provides an important platform for education, research, and innovation cooperation between the FHS and the public hospitals in northern Norway. The cooperative body with *Helse Nord*, which allocates the research funding that the regional health authority receives from the Ministry of Health and Care Services, is said to play a major role in developing cooperation channels between the faculty and the hospitals.

Cooperative bodies are in place at the level of individual hospitals as well and the FHS has worked systematically to develop an institutional basis for interactions with UNN. The two institutions have joint leadership meetings and joint education and research committees, which function as important arenas for regular strategic dialogue and joint initiatives.

There is furthermore extensive use of dual affiliations, through which hospital staff work at the FHS and academic staff work in the hospitals. FHS currently employs more than 300 people with their primary employment in specialist healthcare services, who are said to contribute significantly to the quality and relevance of the educational programs. Dual affiliations have traditionally been most common within medicine, but the FHS is working to increase the number across all healthcare sciences and professions. The faculty has, as the pioneering faculty in Norway and in cooperation with UNN, established 30 dual affiliations for both hospital and university staff within areas other than medicine. It is planned to expand this initiative to the municipal primary healthcare services. However, the municipalities' lack of tradition, an explicit mandate, and earmarked funding for active involvement in education and research poses a challenge both for the establishment of dual affiliations and for the systematic interactions between education, research, and professional practice in the primary healthcare services more generally.

The FHS has a strategic focus on innovation in education, and more specifically on developing new forms of education to meet the needs of the healthcare services. As an integrated healthcare faculty, the FHS places a strong emphasis on so-called "cross-professional learning" in the educational programs and has introduced joint courses for all students with the objective of teaching them how to interact and cooperate across healthcare professions. The faculty is also in the process of developing joint areas for practical training through various pilot projects carried out in close collaboration with the healthcare services. The projects have been initiated by dedicated faculty staff as well as by actors in the healthcare services, and embedded at the faculty level. This is seen as an example of innovation in education that has been directly motivated by the needs for new types of competence in the healthcare sector following a recent major national healthcare reform.

The FHS is also engaged in commercialization and innovative collaboration with industry, mainly in the areas of medical biology and pharmacology. It utilizes the services of the local technology transfer office and has collaborative projects with firms that include the Centre for Research-based Innovation, MabCent, marine bioactivities and drug discovery (2007–2015), and two industrial PhD projects at the Department of Pharmacology. Within the area of pharmacology, innovation is closely integrated in education at both bachelor's and master's levels, and the department is actively developing master's projects with direct industrial relevance.

University College of Buskerud and Vestfold — The Faculty of Health Sciences

The Faculty of Health Sciences (FHS) specializes in four areas of study — nursing, optometry, radiography, and health technology, as well as the promotion of healthcare. It offers shorter study programs that qualify students for healthcare professions within these areas, as well as programs and courses for specialization and further education by professional practitioners. These are areas with relatively weak research traditions, but their research activity and competence has been increased over time, and the faculty offers a cross-disciplinary PhD program in personalized healthcare (focused on the development of healthcare services based on practical needs).

The FHS engages in close cooperation with the local and regional healthcare sector, primarily the municipal primary healthcare services when it comes to education, both through practical training for students and continuing education for professional practitioners. Practical training is an important mechanism for the systematic interaction and knowledge exchange between the faculty and the healthcare services and contributes to the quality and relevance of education as well as continuous and incremental improvements in professional practice. Continued education also plays a central role in the development of healthcare services, and the FHS has an extensive portfolio of courses commissioned by actors in industry and working life, which are tailored to their particular needs.

Innovation in education is a central area of activity that includes the development of innovative educational designs, as well as teaching students about innovation. The faculty has, for example, worked systematically to integrate the innovation concept and innovative thinking in all bachelor's-level programs through a project with funding from the government's "Entrepreneurship in Education" initiative.

The way our respondents see it, knowledge triangle interactions are an inherent part of the activities of a medical faculty offering professional education in close cooperation with the healthcare services. A key point in this context is that innovation is understood broadly, as something that includes incremental improvements in healthcare services based on the continuous exchange of knowledge between students, academic staff, and healthcare professionals.

It is important to note that research at FHS is practice-oriented, illustrated by the fact that the faculty has received project funding from the Research Council's program for practice-oriented R&D in health and welfare services. The projects link research, education, and professional practice, with the aim to strengthen the knowledge base and thereby improve the quality of the healthcare professional education and the healthcare services.

The main campus for the Faculty of Health is part of the *Papirbredden Knowledge Park*, where the university college is co-located with knowledge-based companies, innovation support agencies, and the regional innovation company *Papirbredden Innovation*, which was established with HBV as one of the founding partners and owners. The company is a collaboration with municipalities, private industry, and a national agency, furthermore it engages in innovation projects, commercialization, and business development within the region's priority areas. *Papirbredden Innovation* has health and welfare technology as a priority area. The university college is also represented on the board of the *Driv Incubator*, an Industrial Development Corporation of Norway (SIVA) incubator which specializes in healthcare-related commercialization and start-ups. In close cooperation with *Papirbredden Innovation*, the faculty initiated a process in 2007 to establish a cluster of local technology firms specializing in the development of healthcare and welfare technology, primarily for the municipal primary healthcare services. The cluster, which has received funding from a public program, is an important platform for enhancing the systematic innovative collaboration between the FHS, municipalities, and private industry. The role the FHS plays in innovative projects is primarily that of a facilitator of innovation processes in the healthcare services, for example, it could do so through a scientific consultancy, competence development, and formative research. The commercialization of research results is not a central activity at the faculty.

In 2012, FHS opened a center for the testing and demonstration of the technology developed by the healthcare innovative cluster. The center brings together students and staff at the faculty, the technology firms, and municipalities as well as other users of health and welfare technology. The FHS uses the center actively for educational purposes, and the students are introduced to the new technologies through simulation training and lectures from technology producers and from users in the municipal healthcare services.

Discussion and Conclusions

As the case studies show, the differences in academic profiles between the three health faculties have a strong bearing on the intensity of the collaboration and the channels of interactions with the public and private sectors. Within research-intensive fields such as medicine and pharmacology, we find patterns: i) an entrepreneurial university where staff and students are involved in entrepreneurship and commercialization ii) institutionalized collaboration on education, research, and innovation with public hospitals; and iii) research-based innovation collaboration with private industry. Other health sciences with weaker research traditions are characterized by different patterns and notably collaborate with i) both public hospitals and municipal healthcare providers on education and incremental service innovation, and ii) with municipalities and private technology firms on the development and implementation of health and welfare technologies.

In particular, the faculties at NTNU and UiT that cover research-intensive medical sciences are involved in Centres for Research-based Innovation, as well as commercialization and entrepreneurial activities. Here we see patterns of what we can call the entrepreneurial knowledge triangle (i.e. [*Clark,* 1998]). NTNU and UiT also have strong integrated education, research, and innovation cooperation with the specialist healthcare services, and especially the university hospitals in their respective regions. These practices are intrinsically linked to the national system for interaction between the public hospitals and medical faculties, where the hospitals have a legal responsibility and receive dedicated government funding for engaging in education and research. There are strategic collaborative bodies in place, based on government regulations, which discuss matters of mutual interest in the areas of research and education and are responsible for the allocation of research funding. The system is also characterized by the extensive use of dual affiliations and the close physical integration between the medical faculties and the university hospitals. These top-down, formal, and institutionalized channels of interactions strengthen the opportunities for knowledge triangle practices between the specialist healthcare services and medical sciences.

The two faculties that offer shorter programs for professional healthcare education, UiT and HBV, cooperate with the municipal primary healthcare services when it comes to practical training for students and continuing education for healthcare professionals. This contributes to the development of competences based on the needs of the healthcare services and thereby improvements in professional practice. However, for several reasons there are fewer systematic and integrated knowledge triangle interactions than between the medical sciences and the specialist healthcare services. First, the primary healthcare services do not have the same explicit mandate to contribute to the education of healthcare personnel and do not receive government funding for engaging in practical training of students. Second, the shorter healthcare educational programs and the corresponding fields of professional practice have traditionally not been based on research to any significant extent. Thus, the collaboration concerns primarily the training of undergraduate students and the development of courses for continuing education and, to a lesser extent, research collaboration. However, the health faculty at HBV engages in extensive innovative collaboration with technology firms and municipalities on developing and implementing health and welfare technologies in the primary healthcare services.

The differences in collaboration patterns and the degree of institutionalized ties between the medical faculties and the hospitals, municipalities, and private firms illustrate the importance of long-term agreements and funding for collaboration on education, research, and innovation. Collaboration between HEIs and the private sector is primarily based on bottom-up initiatives, and it might be that good examples and practices of collaboration between HEIs and the public sector may be transferred to private sector collaboration. This implies, however, new types of policies at both the national and institutional levels. One way that HEIs may strengthen their knowledge triangle interactions with industry can be through establishing strategic long-term partnerships on research and collaboration with important firms. This may not only encompass one-on-one partnerships, but could involve multiple firms from the same sector. At the national level, there are already cluster programs that serve a similar function as they offer long-term funding for collaboration on education, research, and innovation. These may, however, be developed to include other instruments for collaboration such as the extended use of dual affiliations that emphasize other qualifications beyond research and scientific publications.

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Hearing the Sound of the Wave: What Impedes One's Ability to Foresee Innovations?

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Abstract

This paper offers a broad view on foreseeing innovation, which is not limited solely to early detection at the micro level. The author defines innovations as ongoing processes of changes in the various fields of social and economic life, which result from human creative activity. Noting that innovation is an uncertain, relatively chaotic, and disordered process characterized by inherent risks, the author aims to define the most general and universal barriers impeding one's ability to recognize the signs of future innovation and to anticipate their consequences. Considering examples of "disruptive innovation" in the technological, social, political, and economic spheres of life, the author sees these innovations as arising from certain condition and events, not as simple random occurrences. Most of them are effects of particular causes. However, these causes are often hidden within events that are difficult to observe and phenomena encapsulated in weak signals. The inability to detect and recognize such pre-emerging warnings of upcoming innovations may be attributed to the massive amount of information and noise flooding today's world. This problem is exacerbated by the lack of knowledge, techniques, and experience for dealing with huge amounts of information, the lack of the required skills, and, finally, by human cognitive biases. Faced with this deluge of misinformation, any person can eventually be misled and make mistakes. This paper posits that, in order to mitigate such risks, an individual must avoid the three cognitive biases: the symmetry of delusions, aggressive neglect, and the curse of knowledge. These cognitive biases are the barriers to foreseeing innovation.

Keywords: disruptive innovations; emerging innovations; exponentially scalable events; proactive innovation management; big data; "symmetry of delusions"; "aggressive neglect"; "curse of knowledge".

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The current literature on management and technological development offers numerous definitions of innovation, with varying nuances and emphases (see, e.g.: [*Schumpeter*, 1942; *Drucker*, 1985; *Damanpour*, *Schneider,* 2006; *Gopalakrishnan, Damanpour*, 1997]). However, they all share concepts such as development, change, and transformation. Depending on the specific context, transformation and change may remain local, i.e. those taking place at the micro-level, or those that turn into major shifts in various spheres of human activities disrupting the established practices and customary methods. Innovative transformations can only be foreseen by considering individual changes occurring at the micro-level in the scope of a broader context of technological, organizational, marketing, legal, cultural, consumer-related, and other changes inherent to the development of any society. Fostering an innovative culture requires adopting a broad approach to perceiving the world and its development, including newly created and updated knowledge in a wide range of domains.

Practical experience of managing innovation-based development shows that limiting the perception of innovation to solely the local level and ignoring the diversity of available data hinder an adequate assessment of the various aspects of specific promising innovations, the key risks associated with innovative projects, their potential scale, and the timely discovery of alternative solutions. This paper builds upon the ideas and arguments suggested in the previously published study of the role of information in the innovative process, including the management and implementation of innovative projects and dealing with uncertainty and information asymmetry over the course of decision-making [*Milovidov,* 2015a, 2015b].

The role of information in the innovation process can be analyzed in the framework of either mainstream or evolutionary economics [*Castellacci*, 2008]. In the first case, an emphasis is placed upon finding the optimal balance for distributing information between participants of the innovation process and identifying information asymmetry and uncertainty. The second approach focuses on collecting and processing data to accumulate tacit and implicit knowledge and competences, which knowledge management theory places at the top of the data-information-knowledge-wisdom pyramid (DIKW) (see, e.g., [*Cleveland*, 1982; *Erickson, Rothberg*, 2014]). Both these approaches are based on peoples' ability to identify important information in the data flow, distinguish between significant and irrelevant facts, filter out information noise, analyze signals, and minimize the risk of making the incorrect innovation and management decisions. Another aspect is related to barriers and obstacles hindering the development and practical application of information processing abilities. What is it that stops individuals from recognizing and analyzing important information, detecting barely perceptible signals of emerging new developments, foreseeing innovative changes, and assessing their scale and strategic direction?

To answer the above questions, we examine the results obtained in two research areas. The first area comprises uncertainty and risks associated with the development process (including innovation-based development), and issues such as determinate and random events and chaotic transformations. The disruptive innovation concept appears to be particularly productive in the scope of this area [*Bower, Christensen,* 1995; *Christensen,* 2003]. Similar aspects were studied in the context of climate change [*Lorenz*, 1972], the growth of financial markets [*Taleb*, 2007], and political processes [*Frank et al.* 2012]. The second area comprises a large body of studies devoted to the processing of information, data mining, development of text processing algorithms, signal interpretation, and big data. The language and communication vagueness theory [*Russell,* 1923] seems to play a key role in this domain, along with the fuzzy sets concept [*Zadeh*, 1965], which gave a powerful impulse to the development of unstructured data analysis, the recognition of patterns and differences in large data arrays, and artificial intelligence research [*Kohl,* 1969; *Liu et al.*, 2000; *Carvalho et al.*, 2003; *Zhong*, 2003; *Ruiz et al*, 2014].

The first section of the present paper analyzes the general indications of unexpected, obscure information signals and events that are potentially capable of radically changing society. The second section examines data processing principles that could help one foresee innovation and help reduce the level of uncertainty and randomness of events. The third section highlights the obstacles which hinder the foresight of innovations and reduce the ability to "pre-hear" them, to use a rare verb from Dahl's Dictionary.[1] The ability to perceive emerging but barely detectible changes is a key skill not only for professionals, but for everyone open to new developments.

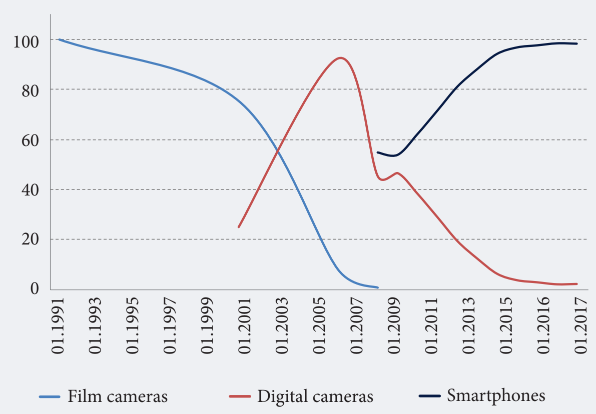
Disruptive Innovations: a Flock of Black Swans

Major unpredictable changes in the external environment are frequently caused by obscure factors, which are impossible to foresee. The fear of sudden social and natural calamities caused by a chain of incomprehensible events has been disturbing humanity for centuries and is aptly reflected in our mythological, literary, and philosophical heritage. Very small things turning into something huge is a natural trait of our world, and many mind-boggling transformations were caused by people's economic or social activities, specific actions, and exploits.

Numerous scientists have tried to conceptualize the exponential transformation of initially weak impulses. More productive approaches to studying these processes were suggested in the mid-20th century, such as the "butterfly effect" [*Lorenz*, 1972], "disruptive innovations" [*Christensen*, 2003], "black swans" [*Taleb,* 2007], and "femtorisks" [*Frank et al.,* 2012]. These metaphors are now widely used to describe unpredictable radical changes and major events. Before taking a closer look at such processes, we consider several examples from the technological domain which provide rich food for making generalizations and conclusions.

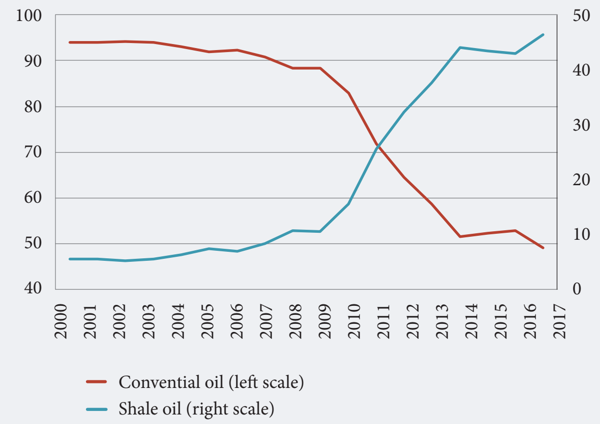
[1] To use a rare verb from Dahl's Dictionary. Available at: https://dic.academic.ru/dic.nsf/enc2p/332542, accessed 26.01.2017.

Figure 1. Photographic Equipment Development Waves in 1991-2017 (% of Total Camera and Smartphone Sales)



Source: composed by the author based on CIPA and Statista data.

Figure 2. Production of Conventional (the left scale) and Shale (the right scale) Oil in the US in 2000 — October, 2017 (% of the Total Output)



Source: composed by the author based on the US EIA data.

Figure 1 illustrates the development of photographic equipment. In the 1940s-1950s, photography was becoming increasingly popular around the world, while the hardware was becoming increasingly more affordable. Between 1951 and 1997, sales of single-lens film cameras grew from 258,000 to 36.6 million units [CIPA, n.d.]. In 1999, the digital camera was launched onto the mass market, so film cameras' monopoly very rapidly ended. By 2005, their market share dropped below 8%, compared with 92% for digital ones. Since 2007, when film camera sales ended completely, smartphones challenged the dominance of digital cameras. In 2010, sales of digital cameras peaked at 121.5 million units versus 304 million for smartphones (or 71% of the market). Although digital camera sales currently remain at the peak level for film cameras, i.e., at about 35-36 million units a year, their market share has dropped to a mere 2.4%. According to the Statista web portal, smartphone sales are now approaching 1.5 billion units.[2]

Another example is the US shale oil production technologies. As in the previous case, we can see the same technology waves and comparable proliferation rates (Figure 2). The only difference is the rate of new technologies' maturing: digital photography took a somewhat longer time to arrive than the hydraulic fracturing of oil strata.

Similar innovation waves were observed in the social sphere as well, although they are much harder to identify and visualize than technology-related ones. The development of advanced internet technologies and search engines significantly increases the opportunities for detecting trends and popularizing innovations, both technological and socio-political. Statistics of search queries 'best smartphone camera', 'oil shale fracking', and 'Brexit' (Figure 3) show that these have become more popular among internet users.

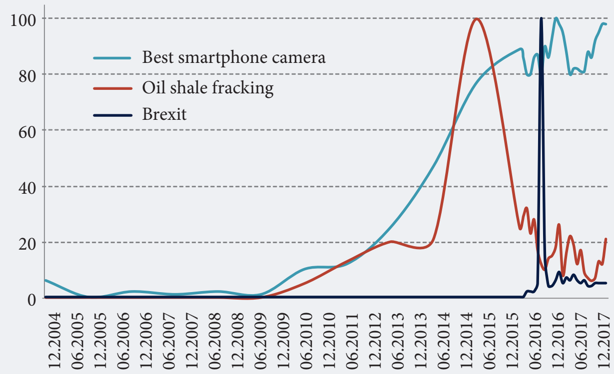
Different growth rates of interest in innovations of various kinds are worthy of note. Users' interest in the best smartphone camera grew gradually and cumulatively, in line with the increased supply. The number of such queries peaked when the total supply of smartphones had reached 1 billion units. The number of oil fracking-related queries grew at a much more explosive rate: in 2013–2014, the topic's popularity literally skyrocketed. The peak level in 2014 coincided with the record daily US shale oil output — approximately 4.8 million out of the total 8.2 million barrels, according to the US Energy Information Administration (EIA).[3] The outcome of the British referendum on leaving the EU also led to an exploding information bomb: internet users' interest peaked in a matter of days, and then faded quickly.

A declining interest in a topic, however, does not imply that the relevant innovations became less important. All the above innovations had significant long-term consequences. The wide use of smartphones contributed to the further 'democratization' of photography, increased popularity of 'selfies' and of social networks offering extended opportunities for posting photographs (such as Instagram, Snapchat, etc.). Greater use of smartphones also led to the development of specialized smartphone accessories, mobile applications, and software for processing smartphone-taken pictures. Besides the social effects and the emergence of new communication formats, the move from the camera to the smartphone significantly affected the photographic and mobile equipment industry. Increased shale oil production had significant consequences in a wider range of industries and spheres of activity. First, it promoted the development of oil production technologies and reduced related costs, but it also changed the way of life in several US regions, contributed to the emergence of new supporting industries, caused structural changes in global energy markets, and led to major economic, social, and political shifts in many countries. It would be harder to assess the chain of

[2] Available at: https://www.statista.com/statistics/263441/global-smartphone-shipments-forecast/, accessed 04.01.2017.

[3] Available at: https://www.eia.gov/energy_in_brief/article/shale_in_the_united_states.cfm, accessed 15.02.2016.

Figure 3. **Frequency Growth of Google Search Queries 'best smartphone camera', 'oil shale fracking', and 'Brexit' in 2004-2017 (scores)**



Note: in this and subsequent figures, the vertical axis measures the interest in the topic (the score of 100 denotes the highest number of relevant search queries submitted in a particular region within a specific period of time, 50 represents a 50% lower value, and 0 — no more than 1% of the highest level).

Source: composed by the author based on the Google Trends data.

Brexit consequences at this stage, but it may germinate seeds of future radical geopolitical, economic, and social transformations.

The above considerations allow us to formulate several hypotheses:

H1. Innovations, or events that entail radical change and long-term consequences, may be either *cumulative, impulsive, explosive,* or *sudden* by nature.

H2. In terms of their impact, innovations' consequences may be either *narrow*, i.e., only affecting the area where the initial innovative impulse emerged (or related ones) or *wide*, i.e., affecting a potentially unlimited range of totally different spheres of human activities.

H3. Most innovations, whether socio-political or technological, turn out to be *unpredictable* for most consumers, and only attract mass attention when they become facts of everyday life.

H4. The exponential development of innovations normally takes place against a level background, and comprises a set of *very small, insignificant events*, discoveries, inventions, or other initiatives and actions seemingly appearing from nowhere, *from ground zero*.

H5. Any, even the most insignificant, innovations may have *scalable consequences*. Their concealed potential makes it much harder to detect trends and forecast the emergence of innovations, and therefore requires ongoing monitoring of innovative changes, the adoption of more efficient management practices, and the analysis of innovation-related data in a standardized, technological way.

The above hypotheses reflect, in a concentrated form, many years of research that has attempted to conceptualize the processes occurring in a wide range of domains. The novelty of Table 1 below lies in presenting a structured summary of existing definitions of exponential processes, together with their more important characteristics: obscurity, unpredictability of the initial impulse, spontaneity, wide scope, cumulativeness, and scalability. Besides, the definitions proposed by various researchers are compared with the 'exponentially scalable event' category suggested by this paper.

Table 1. **Definitions of the Exponential Transformation of 'Weak Initial Impulses'**

Process	Definition	Characteristics						
		I	II	III	IV	V	VI	VII
Butterfly effect [*Bradbury*, 1975; *Lorenz*, 1972]	A process triggered by an insignificant impulse (event), which entails determinate, chaotic, random transformations with large-scale consequences	+	+	+	–	–	+	+
Disruptive innovations [*Christensen*, 2003]	Innovations in areas such as technological development and company operations, including finance, marketing, management, and product range, which may lead to significant changes in the balance of forces in the market, including pushing out major players	+	+	–	+	+	–	+
Black swan [*Taleb*, 2007]	An unpredictable event with major consequences	+	+	+	–	–	+	+
Femtorisks [*Frank et al.*, 2012]	Small, barely discernible events with significant consequences in the socio-political sphere	+	+	+	–	–	+	+
Exponentially scalable events [*Milovidov*, 2015a,b]	Any event which may affect the environment where it occurred, triggers other subsequent events, and starts off a sequence of changes when each next (scalable) event increases the effect of the previous one	+	+	+	+	+	+	+

Legend: I — obscure initial impulse; II — unpredictable; III — spontaneous; IV — cumulative; V — narrow scope; VI — wide scope; VII — scalable.

Note: '+' means the relevant criterion is included in the definition, '–' means it is not.

Source: composed by the author.

Principles of Detecting Emerging Innovations

Exponential, chaotic, and unpredictable scaling of initial impulse events is one of the key factors of the overall uncertainty of socio-economic, political, and technological processes which accompany (and affect) the current stage of human development. At the starting point of the triggering impulse, it is very hard to predict exactly how the events will unfold, what consequences they will have, and how they will affect human activities when the effect of the impulse starts to fade and is replaced by the new factors it has engendered.

Is it possible to calculate and forecast all consequences of a specific cause? Is it possible to develop an efficient algorithm for exponential scaling of very insignificant, obscure events? So far, no theoretical approach has provided credible answers to these questions. The world remains unpredictable at the local level, while forecasts and predictions, even the most correct ones, are practically never accurate in their details, which are often crucial. Without pretending to provide exhaustive answers, we suggest here some methodological and logical solutions that would minimize the risks of missing important events capable of causing major changes in the future and would help one avoid having to face their unpredictable consequences. We formulate the key principles of detecting innovations, information signals and impulses, and foreseeing their causal relations with future events and changes.

Ongoing Monitoring of Current Innovations. Monitoring the flow of events means we can track the chronology of specific processes. This principle is literally embodied in the works by Plato and Plutarch (see, e.g.: [*Plato,* 1994; *Plutarch,* 2008]), where events and phenomena of the external world are sequentially numbered. The numbers are added, multiplied, divided, ranged in series, applied to create geometric figures and lines — all to reveal a sequence, a pattern, or an interconnection. The works of ancient historians and philosophers are dotted with numerical calculations, i.e., the authors not only enthusiastically practiced arithmetic but studied the surrounding world highlighting all the obscure links and combinations. Ongoing monitoring gives *volume* to information, which makes processing it easier.

Proactive Observation and the Prioritization of Events. At the core of any prognostic activity lies interested, active perception, a focused desire to uncover and detect hidden changes in the surrounding world. Such a view implies universality, a contentious, debatable nature of any statement — the principle which in the 20th century was called 'falsificationism' [*Popper*, 2002], 'problematization', or 'the archaeology of knowledge' [*Foucault*, 1994]. Problematization is a scientific analysis technique based on refuting and finding errors and weaknesses in any hypothesis, claim, or concept. It is a way to question whether the object or phenomenon the subject is facing is indeed what it seems or claims to be. The problematization technique allows us to model individuals' behavior in uncertain situations by asking new questions and pointing out contradictions implied by, or following from, their actions [*Milovidov*, 2015b]. A proactive approach to problematization can verify the collected data and check its *veracity*.

Balance between the Causes and Effects of Events. The Danish philosopher Søren Kierkegaard noted: 'As to the cause and effect relationship, something isn't right there also if I'm not mistaken. Sometimes a huge cause has extremely insignificant effects, or even none at all, while a silly trifling cause may lead to colossal consequences.'[*Kierkegaard*, 2016]. The disproportionality baffles witnesses of unexpected, unpredictable consequences caused by small, insignificant events. However, those who try to establish an incorrectly understood causal proportionality frequently miss the extremely small intermediate transformations. A tacit, latent symmetry of causes and effects is hidden in the flow of exponential, scalable events.

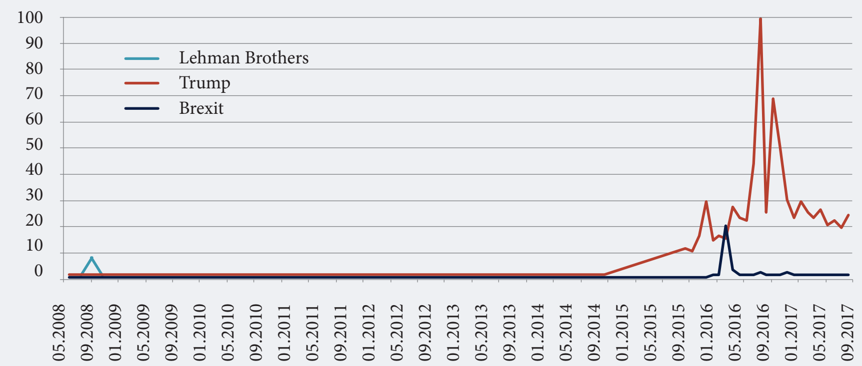
Returning to the example of photographic technologies' development, the average growth of film camera sales between 1951 and the peak in 1997 was 792,000 units a year; the relevant value for digital cameras was in excess of 10 million units between 1999 and the peak in 2010; and for smartphones — more than 160 million units between 2007 and 2015. Thus, the proportion of sales growth rates was 1:13 for film and digital cameras, 1:16 for digital cameras and smartphones, and 1:207 for film cameras and smartphones. These figures indicate that, compared with the growth of film camera sales, the emergence and proliferation of smartphones is an unprecedented explosive impulse. Smartphones have overturned our existing ideas about photographic and mobile communications technology. Even half a century ago, such figures would have seemed totally impossible, while today the growth rate of the smartphone market does not appear extraordinary given the dissemination of other popular technologies. The rates of abandoning some technologies in favour of others also turn out to be comparable. With time, and with the accumulation of practical experience, our perception of the relative importance of various changes alters. New important events even out the scale of previous ones.

Figure 4 illustrates the frequency of search queries for three 'innovations': recent unusual and unexpected events, namely the crash of the Lehman Brothers bank, Brexit, and the election of Donald Trump. The peak scores for each of them reached 100, but if we overlay the curves we can see that each previous event was noticeably less popular than the following ones. The farther back an event, the less important it seems to be compared with the present-day scoops.

Establishing causal proportionality requires us to take the *velocity* factor into account, which affects the relative importance of events.

The Discernibility and Visibility of Events against the Overall Information Landscape. This principle is directly connected with the previous one as the identification of events requires long-term systemic observation, collecting data and facts, and an inclination (ability) to identify specific features, very small signs, and faults, i.e., everything that makes observation proactive, inquisitive, oriented towards checking and re-checking

Figure 4. **Comparative Frequency Growth of Google Search Queries on Popular Topics in 2008 — October, 2017 (*scores*)**



Source: composed by the author based on the Google Trends data.

the validity, verifying, or falsifying data. It is equally important to establish a reference point against which the changes will be checked and determine the scale of events to be tracked, the proportions of causes and effects, and the frequency and regularity of their occurrence. Accomplishing these objectives involves an ongoing proactive comparative analysis of events' *variety*.

Innovation theory uses the term '*innovation at the edge*', which does not imply that such inventions are backward, amateurish, or inferior. The term is supposed to stress the alternative nature of cutting-edge (and typically very promising) innovative ideas compared with the academic mainstream. Such innovations, ideas, discoveries, and even vague insights fall outside the major areas of technological development where large R&D centers and leading companies concentrate most of their intellectual and financial resources. As early as March 2001, *The Economist's* Technology Quarterly review noted that: 'No question that technology is now driven by a centrifugal force, pushing power out from the centre to the edge.' [*The Economist*, 2001].

Small companies take the lead increasingly often in developing new technologies. A democratization of innovation is occurring, a division of control over the movement of ideas which *'cuts out whole layers of middle managers whose job had been to shuffle questions and answers between bosses and staff.'* (*Ibid.*) However, such a decentralization of innovation activity participants (in the technological and also socio-political domain where new social groups, voluntary public associations, informal networks, and civic activists play an increasingly important role) make the task of detecting and tracking emerging innovations even more difficult. Following the 'beaten track' and adhering to established views and ingrained preferences results in a 'blindness' among individual high-ranking managers and experts, and even whole corporations. Max Bazerman in his book 'The Power of Noticing' noted: 'Finding the best solutions often requires dropping the proposed options and looking beyond the immediately obvious.' [*Bazerman*, 2014].

Most disruptive technologies that really revolutionize the technological structure and ways of life emerge outside the mainstream, or at its 'edge.' Such innovations are discernible: when they emerge, they clearly stand out among those widely applied in society. However, many companies lack the resources and consistency required to detect the difference and, more importantly, to assess the prospects, scalability, and exponential proliferation of these innovations. For example, in 1975 Steven J. Sasson, the engineer at Eastman Kodak which for years dominated the film and printing services market, invented the first digital camera. In 1986, Kodak engineers presented the first megapixel camera. However, rigid adherence to the strategy focused on manufacturing 'chemical photography' equipment, mistakes made by the management, and ill-conceived corporate business deals resulted in the company losing leadership not only in the digital photography innovation but in its core business field as well, bringing it to the brink of bankruptcy [*Chunka*, 2012].

Similar examples can also be found in the social and political domains. For example, there were signals which allowed one, if not to predict, then at least not to rule out British citizens' 2016 vote to leave the EU, or Donald Trump's victory in the US presidential elections in 2016. If more attention was paid to the market situation and the growth of debt, the crisis of 2007–2008 might have been less surprising. The reasons for Enron's bankruptcy in 2001 and Lehman Brothers bank's bankruptcy in 2008 lay in their financial reports, open business deals, and decisions made by management, none of which were secret. The weak signals suggesting problems simply remained unnoticed at the right time. Analysts use dynamic processes, new facts, and published data as sources where they try to find patterns like the current state of affairs, while in fact they should search for differences.

Taken together, the above principles of detecting exponentially scalable events can serve as an algorithm for processing data inputs. In turn, any algorithm can, up to a point, be automated. Let us try to match these principles with the main components of the concept of Big Data, i.e., the so-called four Vs: *volume, veracity,* *velocity,* and *variety*. Because they are innovative themselves, Big Data technologies can serve as powerful tools for foreseeing a wide range of disruptive innovations.

What Hinders Hearing the Sound of the Wave?

'No one errs willingly' [*Segvic*, 2000] — this commonplace adage reflects everyone's sincere and natural desire to avoid making mistakes. Countless theoretical and practical studies analyze management errors and make recommendations on how to avoid these mistakes. However, faults are inevitable, so important events, disruptive innovations, and 'black swans' constantly test the experts' professionalism and crisis management skills.

There are two ways to approach the issue of discerning emerging change and innovations. The first approach looks at the issue from the point of view of management practices and organizational mechanisms employed by specific companies, including self-discipline, self-organization, and employees' individual responsibilities. The second approach focuses on individuals' psychological and emotional perception of reality, their reactions, and attitudes toward events. In some cases, the second approach can be more productive as efficient management practices and advanced information technologies do not provide an insurance against making mistakes. Often, accumulated knowledge, qualifications, and education inspire an illusory and dangerous feeling of infallibility.

Let us consider three kinds of distortions in individuals' cognitive biases: error of judgement, hindering the adequate perception and analysis of information inputs, and creating the conditions for perceiving the emerging change as accidental and unexpected. All these distortions result in people who are unable to recognize the hidden determinacy of events and detect signals which can be transformed into scalable consequences.

Symmetry of Delusions. A state of persistent false confidence evenly distributed throughout society or within certain social groups [*Milovidov,* 2013], the symmetry of delusions is quite hard to identify at a given moment in time as proving that specific opinions are wrong is difficult. Mass consciousness rejects the disproof of commonplace views and social expectations. The symmetry of delusions in most cases can only be revealed *post factum*, after the events which radically undermined the established beliefs have happened. There are numerous examples of illusions shared by society being utterly crushed, one being economic and financial crises. Such turmoil always comes unexpectedly; just the day before, economic agents see no reason to worry, and enjoy continued growth. Signs of a symmetry of delusions can be found in practically every financial crisis including the famous tulip fever of the 17th century. The historian of the global financial system, Charles Kindleberger, sneered about this: 'What is really interesting is how the insiders and outsiders joined forces to ensure financial crises happened regularly, at least once a decade between 1551 and 1886, though according to the economic theory outsiders have to get some sense first.' [*Kindleberger,* 1993].

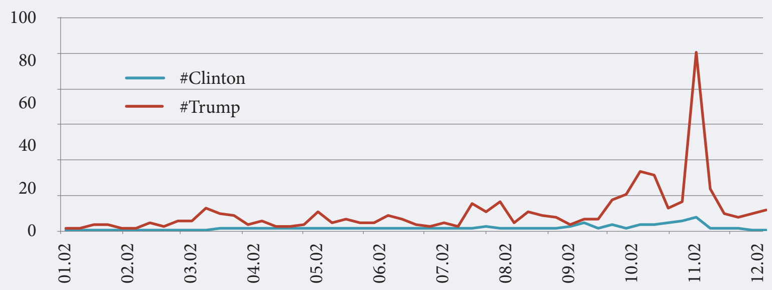
What else besides symmetry of delusions can explain the fact that market upheavals always happen unexpectedly? That was the case in Russia on the eve of the infamous default of 1998, or before the global crisis of 2007–2008; the same happens today when energy prices sharply drop or skyrocket, or the central banks raise the interest rate. The 'black swan' phenomenon described by Nassim Taleb [*Taleb,* 2007] is based on nothing else but symmetry of delusions. Symmetry of delusions is an inertial perception of reality, a tendency to fit the current events into the context of past ones, and to see the future as a projection of what is happening now. That is why most forecasts and predictions turn out to be wrong. Their dependency on previous events, or the 'allure of the known' [*D'Souza, Renner*, 2014], is too high, regardless of how true the 'known' actually is. Meanwhile, signals indicating a disruption of the current trends are often so disproportionally weak that they fail to attract any attention.

Symmetry of delusions is very common in business, administration, and science. Thomas Kuhn conceptualized the structure of scientific revolutions and introduced the concept of 'normal science' as science that is firmly based on previous achievements and remains in the scope of the current paradigm. In other words, 'normal science' according to Kuhn represents established views that are shared by the professional community, which provide the basis for further research [*Kuhn,* 1962]. A scientific revolution essentially amounts to a disruption of the paradigm — a leap in new knowledge creation. Individualism, critical thinking, proactivity, and scepticism regarding commonly shared ideas and attitudes help counter and resist the symmetry of delusions.

Aggressive Neglect. Aggressive neglect of information, facts, or phenomena is expressed as individuals' conscious refusal to accept something that does not match their views or understanding. The term 'aggressive neglect' was suggested by the ornithologists Sidney Ripley, George Hutchinson, and Robert McArthur in their 1959 papers on birds' behavior. The scientists noted a surprising phenomenon: that birds of the same species were so fiercely aggressive towards other bird species that sometimes they neglected hatching and nurturing their own young, i.e., the procreation function. In effect, the most aggressive birds were harming their own species [*Ripley*, 1959]. Taking Ripley's hypothesis further, Hutchinson and McArthur called the observed phenomenon 'aggressive neglect' — 'a bird neglecting its progeny while it behaves extremely aggressively towards another bird' [*Hutchinson, MacArthur,* 1959].

In the case of the 2016 US elections, opinion polls indicated Hillary Clinton had an obvious advantage over Donald Trump. The political establishment was not prepared to treat the Republican candidate seriously; even in his own party he was considered an upstart. The US elites' behavior resembled the aggressive neglect of signals and warnings that contradicted common beliefs or popular opinions. The consequences of this

Figure 5. **Comparative Eynamics of #Trump and #Clinton Hashtags' Popularity in 2016 (*scores*)**



Source: composed by the author based on the Google Trends data.

situation turned out to be fatal for the Democratic candidate's team, and affected the result. Was it possible to hear the wave? Certainly, yes. Figure 5 clearly shows that throughout the year, up until election day, Trump's popularity in internet queries exceeded Clinton's. The average score of the Republican candidate's popularity during the whole period was 10 compared to 1 for the Democratic candidate. Most analysts preferred not to see these data, unlike their more observant colleagues. As early as 2004, the Indian innovator and entrepreneur Sanjeev Rai created the artificial intelligence system 'MogIA', which can process up to 20 million data points aggregated in social networks and other internet services, including search platforms. His system accurately predicted the results of the two most recent US election campaigns. In October 2016, a month before the latest US presidential election, Rai predicted Trump's victory based on the results produced by his system [*Kharpal*, 2016; *Murnane*, 2016].

Another example of aggressive neglect is the management of Kodak, who were unable to see the significance of the company's own engineers inventing the first digital camera. Later, Steven J. Sasson recalled that his invention was greeted by management with the words *'that's cute — but don't tell anyone about it.'* [*Deutsch*, 2008] The growth of Trump's popularity leading to his largely unexpected triumph and Kodak's digital camera were 'innovations at the edge', which emerged outside mainstream thinking. The same can be said about the discovery of X-rays, which were initially perceived as an elaborate mystification [*Kuhn*, 2009]. There are numerous examples of aggressive neglect adversely affecting rational thinking, leading to neglecting facts and warnings and ultimately turning out to be destructive. Aggressive neglect multiplies the errors engendered by symmetry of delusions.

Curse of Knowledge. The term 'curse of knowledge' comprises overconfidence and overestimating one's own abilities, leading people to rely on their knowledge and experience so much that they cannot imagine possibly being wrong while exaggerating the probability of others' making a mistake. It was originally suggested in the scope of a survey of financial market players whose behavior was determined by the level of their knowledge. Colin Camerer and his colleagues discovered that most well-informed market players tended to discount the actions of their less knowledgeable counterparts. In effect, they totally disregarded them, relying exclusively on their own knowledge and ideas. That was frequently why strong players made mistakes and lost money: in certain situations, a lack of knowledge is much more preferable than its overabundance [*Camerer et al.*, 1989].

The curse of knowledge certainly does not apply exclusively to financial markets. More generally, it can be compared with an inductive approach to a problem. In examining the core of the issue, a researcher tries to study every detail but at the same time loses their peripheral vision, i.e., the ability to take external aspects into account. The curse of knowledge frequently results from the desire to substantiate the old paradigm, the normal science; it is linked to the development of incremental technologies and major pressure groups' commitment to established values and opinions. First, people contaminated with the curse of knowledge are sure that they know exactly how the world works. Second, they are ready to defend their views, and third, they would resist any radical innovations that question their convictions. Ultimately, the curse of knowledge, along with symmetry of delusions and aggressive neglect, lead to errors. According to Jim Collins and Morten Hansen, arrogance borne by success is the first step towards a company's downfall [*Collins, Hansen*, 2011].

Discussion

Analyzing the reasons why people cannot see important, albeit obscure information signals, and take them into account when making decisions allows us to improve the overall approach to using information when managing innovative projects, designing strategic plans, development programs, and roadmaps, at both the micro- and macro-levels of public sector foresight activities. Attempting to do the following in several areas would help to accomplish this objective.

Putting into place a holistic, adjustable information processing system, developing relevant algorithms and big data analysis technologies to minimize the impact of the subjectivity factor. This requires, for example, adopting legislation to review the norms hindering the efficient processing and productive use of information. Biased thinking and biased perception of signals and events would become worse for the wider the circle of active stakeholders in strategic planning and foresight because an increased number of stakeholders leads to the emergence of various groups, which might see other groups as rivals. Clashing points of view and competition between their proponents affect how information available to stakeholders is evaluated. At some stage, cooperation aimed at accumulating information and developing a common system of knowledge on particular issues may be replaced by defiance, trying to defend certainly false ideas that are shared by one's circle, and an aggressive neglect of other people's opinions. Accordingly, all stakeholders, regardless of their group membership, may become hostage to the curse of knowledge.

Standardization of corporate innovation management. We are still at the beginning of this path, although things are moving quite quickly. The European innovation management standards (CEN/TS 16555)[4] already include organizational algorithms for collecting, processing, and analyzing data at all stages of innovation management. They imply exchanging information, documenting it at companies, and promoting cooperation between in-house and external experts and professionals specializing in applying the innovation management system for the purposes of creating, exchanging, and disseminating new knowledge (CEN/TS 16555-1 'Innovation Management. Part 1: Innovation Management System'). Strategic monitoring, or intelligence-related issues are regulated separately (CEN/TS 16555-2 'Innovation Management. Part 2: Strategic Intelligence Management'); here, the goal is to promote the development of prognostic competences, forecast innovation-related events, and identify information critically important for making strategic decisions. Strategic intelligence comprises collecting, processing, analyzing, and generating information and knowledge which would make a significant contribution at the more important innovation management stages (GOST 56273.1-2014/CEN/NS 16555-1:2013). Its principles are also described in the intellectual property management standard (CEN/TS 16555-4 'Innovation Management. Part 4: Intellectual Property Management').

In order to prevent cognitive bias, certain steps have already been taken by adopting the standards 'Managing innovation thinking' (CEN/TS 16555-4 'Innovation Management. Part 3: Innovation Thinking') and 'Managing collaboration' (CEN/TS 16555-5 'Innovation Management. Part 5: Collaboration Management'). The developers stress that innovative thinking and collaboration (essentially, external expert evaluation) are particularly important for making decisions in highly uncertain and risky situations. Their recommendations largely match the principles of working with information as described above, such as a proactive approach, causal proportionality, or discernibility of events, which help to minimize cognitive bias. No standard can completely eliminate biases of this kind, but it does not mean that this goal is unrealistic by definition, or that any formalization of innovation management would be inefficient by default. Individuals' perception of information signals will always remain arbitrary up to a point, but standardizing procedures for their interpretation and application, and building relevant competences would help to minimize the adverse effects of subjectivity factors on decision-making.

Managers and professionals responsible for, and specializing in, strategic planning and foresight should improve their skills required to manage and control their cognitive states and emotions, and suppress spontaneous impulses fraught with making mistakes. Ultimately, the success of overcoming cognitive biases depends on individuals themselves. They do not always realize they are being held captive by their illusions. There are no ready-made procedures for dealing with this issue; much depends on unconscious reactions, the overall cultural level, and experience. One must learn to avoid cognitive biases all the time, and nurture a culture of interested and careful observation. Without such skills, people today can be very susceptible to all sorts of ideas and suggestions, they may fall victim to informational noise that hides the actual essence of events, lose their connection with reality, and become hostage to external circumstances.

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