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HHL LEIPZIG GRADUATE SCHOOL OF MANAGEMENT

Dissertation

National Innovative Capacity

An Established Concept Revisited

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Abstract

National innovative capacity, a central driver of countries' long-term economic growth, has been one of the focal points in innovation research for roughly thirty years. Initially proposed as an index to measure technologic invention over time, this concept has become the widely accepted standard for measuring the performance of (sub) national and sectoral innovation systems toward being an analytic tool attributed to innovation systems theory. Country comparison, knowledge flows, and R&D forecasting are in the center of analysis feeding the concrete practical use of innovation policy optimization. In this regard, a rich body of studies has contributed indispensable knowledge about the determinants of innovative capacity. However, the multi-dimensional interconnections have not been covered in depth. Thus, to gain a holistic understanding of the "DNA" behind national innovative capacity a new "comparative" view of these determinants is necessary. To this end, this dissertation proposes revisiting the focus, unit and parameters of analysis that predominate within current national innovative capacity studies and sets forth three interlinked academic articles that focus on different layers of innovative capacity in countries. Besides furthering academic discourse on the determinants of innovational outcome, this conceptual revision leads to a new approach on national innovation capacity research. Its intention is to make policy makers aware of certain pathways leading to the same outcome. This knowledge will enable them to pursue a dynamic approach of supporting the innovative processes in countries by defining appropriate innovation strategies that consider both the countries' specific preconditions and the sub-systems perspective.

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List of abbreviations

DNA	Deoxyribonucleic acid (allegory)
EU	European Union
fsQCA	fuzzy set Qualitative Comparative Analysis
GDP	Gross Domestic Product
ICF	Innovative Capacity Framework
NIC	National Innovative Capacity
NIS	National Innovation Systems
OECD	Organisation for Economic Co-operation and Development
UK	United Kingdom

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1. Introduction

"INNOVATION DISTINGUISHES BETWEEN A LEADER AND A FOLLOWER"

- Steve Jobs (1955-2011) -

Not just since Steve Jobs and his wise statement on innovation has mankind been aware of innovation as the power that drives technical progress and economic growth (List and Colwell, 1856; Schumpeter, 1939; Solow, 1956).

Innovation emanates from interaction and knowledge flows, and various systems of innovation shape manifold innovation processes. Innovative capacity refers to the level of invention and the potential for innovation in any nation, geographical area or economic activity (Villa, 1990), thereby reflecting "the ability […] to produce and commercialize a flow of innovative technology over the long term" (Furman et al., 2002, p. 899). Various innovative capacity comparisons can be found in both practical and academic backgrounds, not only comparing countries but also targeting regions, cities or industry sectors. Among them, the Global Innovation Index (Dutta et al., 2015) can be named as the most prominent evaluation of countries' innovative capacity. The annual results of this far-reaching study can even be found within the financial section of newspapers[1] in the format of country rankings.

In this connection, almost inevitably two questions arise. Firstly, how can innovation be measured? And secondly, why are some countries more innovative than others? These issues build the foundation of national innovation systems (NIS) theory, a highly important research stream within economic sciences (Albach, 2006). The terms "innovative capacity", "innovation strategy" and "innovation policy" dominate the rhetoric in this scientific field (Acs et al., 2016; Sun and Grimes, 2016; Teixeira, 2014). In its core, the *innovative capacity* concept claims to offer an explanation of the several measurable determinants that influence the innovational outcome of a certain system, be it the whole state,

[1] See e.g. Handelsblatt GmbH (2016): WirtschaftsWoche Online - Global Innovation Index 2016 - Das sind die innovativsten Länder der Welt. Retrieved from: http://www.wiwo.de/politik/ausland/global-innovation-index-2016-das-sind-die-innovativsten-laender-der-welt/14017512.html (March 08, 2017)

an industry cluster or even a single company. This knowledge will enable legislators to define the right *innovation strategies* and implement them with the help of appropriate *innovation policies*, the catalysts for innovative growth (Edquist, 2001, 2009, 2013, 2016; Johnson et al., 2003). Institutional changes, changes in economic incentives or the setting of new quantified targets are just a few means of these policy-based interventions.

A consistent framework that includes a measurable indicator is necessary to apply innovation systems theory. With their "innovative capacity framework" Furman et al. contributed significantly to this crucial requirement in 2002. Their novel framework built upon earlier attempts to measure and explain innovational outcome. Derived from growth theory, these earlier innovation indexes intended to show the influence of technological change on economic growth and provided regular diagnostics of national performance in invention over time (Romer, 1986, 1990; Solow, 1994; Villa, 1990). Besides drawing on ideas-driven growth theory, the Furman framework relies on two other distinct areas of prior research: the cluster-based theory of national industrial competitive advantage (Porter, 1990) and research on NIS (Nelson, 1993). From Furman on, the framework has been applied diverse contexts:

- comparison of developed and developing countries (Dezhina and Etzkowitz, 2016; Freeman, 2002; Hu and Mathews, 2005; Joshua, 2016; Krammer, 2009; Krstic et al., 2016; Marxt and Brunner, 2013; Nelson, 1992; Varblane, 2012; Varblane et al., 2007);
- comprehension and explanation of knowledge processes (Guan and Chen, 2012; Lundvall, 2007; Lundvall, 1998; Lundvall, 2010; Lundvall et al., 2002) and technology transfer (Hekkert and Negro, 2009; Mowery and Oxley, 1995; Paik et al., 2009);
- assessment of efficiency as well as forecasting of R&D activity (Moon and Lee, 2005; Robinson et al., 2013; Wang and Huang, 2007).

In this course of application, the innovative capacity framework (ICF) has been modified and incrementally enhanced by broadening the scope of the underlying concept (Castellacci and Natera, 2011, 2013; Faber and Hesen, 2004; Filippetti and Peyrache, 2011; Furman and Hayes, 2004; Hu and Mathews, 2005; Lee and Kim, 2009). Besides the introduction and testing of new data sets, variables and statistical methods, other perspectives moved into the center of analysis: global innovation systems (Binz, C., Truffer, B., Coenen, L., 2016), regional innovation systems (Cooke, 2002) and local innovation systems (Martin and Simmie, 2008).[2] In addition to these alternative territories, the original idea has also been expanded from country comparison to the innovative output of industrial sectors (Malerba, 2002) or single technology areas (Bergek et al., 2015) such as biomaterials. However, this use is not yet a common practice. In any case, the methodology and goals of innovation systems research largely remain the same. The combination of elements of growth theory, the Schumpeterian school of thought and modern, systemic approaches to innovation pave the way to suitable answers on both the “DNA” of innovation ecosystems as well as the respective measures to maximize the outcome of its “innovation generation processes”.

[2] A comprehensive literature review on each of these research branches is provided as a thematic basis within the academic articles that constitute this dissertation (see appendix).

2. The purpose of revisiting the NIC concept for innovation policy

In summary, the national innovative capacity (NIC) concept has evolved toward a conceptual framework to NIS theory that feeds the concrete practice of improving innovation policy based on political, economic and social objectives (Edquist, 2009; Seliger, 2014). Policy measures are predominantly initiated on a national scale (Acs et al., 2016) and further research in this field should aim for the advancement of mostly linear national innovation policies toward becoming more holistic instruments of state intervention (Edquist, 2016). Therefore, sub-national perspectives must be transformed into institutional arrangements that reflect and aggregate the parameters of a smoothly working innovation system – from the bottom (local level) to the top (supra-/national level).

In aiming for this goal, policy makers need to know about the determinants of NIC and their interdependencies in terms of levels. Such lessons on the decisive factors of innovational outcome should enable the persons in charge of innovation strategy to learn and benefit from the winning formulas and mistaken paths of other countries.

To this end, a thorough insight into the basic theory of NIS and its emergence and development is necessary to recognize the NIC framework as an explorative learning instrument of NIS research, with its results that transfer descriptive theory to legislative practice. About 450 papers and studies constitute the body of the most seminal academic and practical works in this field of research. Considering them within a big picture that consists of these studies' research questions, research designs, variables and data sets as well as statistical methods and results of analysis leads to a holistic configurational view on NIS/NIC research. This approach of interpreting the current state of research has led to the revisiting of the concept of NIC in three respects in support of drawing the right conclusions for future innovation policy design:

- First, focus of analysis: using a comparative approach (path analysis) instead of a regression model to both appropriately consider the particular strengths and weaknesses of countries and identify the different approaches pursued by the countries that lead to the same outcome;
- Second, unit of analysis: transferring the ICF to sub-national entities, such as industrial sectors and cities, as they “are becoming, or have already become, more important than the nation-state” (Freeman, 1998, p. 3; Lundvall, 2007);
- Third, parameters of analysis: improving the complexity, choice, and source of the model's indicators, since innovation systems are complex phenomena and assessing all relevant determinants is nearly impossible (Balzat and Hanusch, 2004). Each model is a strong simplification of the underlying innovation ecosystem, and assuming a “one-fits-all” set of parameters across aggregation levels inevitably reduces the explanatory power of the entire analysis.

This dissertation not only contributes novel knowledge on increasing the NIC owing to a better understanding of the determinants of NIC, including the sub-systems perspective. It also proposes a new approach to NIS research that bridges the gap between the macro (NIS) and meso levels (sectoral and local innovation systems), which builds the foundation for the future implementation of a fully-fledged coordination process in countries that allows for the dynamic reconfiguration of NIS (Kaiser and Prange, 2004) from the bottom to the top. Such a process has an optimal effect at the interface between countries’ research and technological development policy and industrial policy, which is commonly regarded as “innovation policy”. National innovation policy aims to create a framework conducive to employment, competitiveness, environment, industry and energy. Against this background, the cognitions of this dissertation might be particularly helpful for the allocation of governmental investments to levers of growth and also for setting focal points within reform agendas. This study contributes the required indicators for comprehensive innovation scoreboards, pinpoints needs for structural adjustments, and notes obstacles to a high innovative capacity in countries.

3. The scientific contribution of this doctoral thesis

This dissertation consists of three articles on the mentioned approach of revisiting the NIC concept. An overview of the articles with regard to authorship, contribution and publication status is provided in Table 1. The first article follows up on Furman (2002) and proposes an alternative model of innovative capacity research on the national level. The second article picks up threads and transfers the methodology to a sectoral innovation system, namely the healthcare sector. With the new model as basis, the third article scrutinizes the determinants of cities' innovation ecosystems as "the fonts of economic innovation" (Shearmur, 2012, 9).

	Article 1	**Article 2**	**Article 3**
Title	Increasing the national innovative capacity: Identifying the pathways to success using a comparative method	National Health Innovation Systems: Clustering the OECD countries by innovative output in healthcare using a multi indicator approach	Increasing the innovative capacity of European cities: Making use of proven concepts from the national level
Joint work with	Dorian Proksch Andreas Pinkwart	Dorian Proksch Julia Busch-Casler Andreas Pinkwart	Andreas Pinkwart
Presentation and double blinded peer review	Global Innovation and Knowledge Academy (GIKA) Conference 2016; Valencia, Spain	The International Society for Professional Innovation Management (ISPIM) Conference 2017; Toronto, Canada	R&D Management Conference 2017; Leuven, Belgium
Awards		Nominated for the Knut Holt Best Paper Award (ISPIM 2017 Forum)	Invited to contribute to the Special Issue 'Understanding Smart Cities: innovation ecosystems, technological advancements and societal challenges' on Technological Forecasting and Social Change (VHB Ranking in 2015: B)
Publication status	Published in *Technological Forecasting & Social Change* 116 (2017) 256–270 (VHB Ranking in 2015: B)	Currently under review at *Research Policy* (VHB Ranking in 2015: A).	Final version to be published in Albach, H. et.al. (Eds.)*: European Cities in Dynamic Competition.* Wiesbaden: Springer/Gabler; forthcoming.

Table 1: Summary of contributions, publications and co-authors of different chapters

3.1 Article 1: Increasing the national innovative capacity: Identifying the pathways to success using a comparative method

- *Study significance:* NIC is an important driver for the long-term economic growth and increasing the innovative capacity is a goal of many nations. Thus, a comparison between countries might uncover the different determinants of national innovative capacity. The resulting knowledge provides new insights for policy makers and helps them to understand the complexity of NIS. In contrast to the rich body of literature dealing with country comparisons against the background of innovative performance rankings, the actual determinants of innovative capacity have received only limited research attention. The few existing studies on this topic point out some rather unstructured determinants for a high capacity, but do not analyze their interconnections, let alone propose comprehensive strategies to increase innovative capacity. Hence, this article provides solid recommendations for achieving improvement on a country level. Moreover, this study is among the first in this research stream to apply a comparative method, thereby overcoming several limitations that characterize the majority of other studies in this field.
- *Methodological approach:* We focus on the European Union (EU), since only a few studies have used a European data set. We collected data for 17 EU member states and constructed a set of 19 variables for the years 2007 to 2011. While data are sufficiently available for most EU countries, Bulgaria, Estonia, Greece, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Slovenia, and Slovakia had to be omitted. We build upon the ICF developed by Furman et al. (2002) and improve the former model in several respects (overcoming linearity, improving data choice as well as data complexity, erasing imbalances within the construct), by creating different fuzzy set Qualitative Comparative Analysis (fsQCA) models to test the determinants of national innovative capacity for the whole timespan. Boolean algebra and fuzzy set theory are used to do derive causal recipes for a specific outcome.
- *Main findings:* We identified different paths leading to a high innovative capacity by combining various determinants. For instance, one set of solutions for high innovative output emphasizes the availability of a high capital base

(measured by GDP, a high share of government expenditure on education, the amount of venture capital and the general capital stock of a country). Another set of solutions highlights the combination of specialization in the high-tech industry and private funding. We were able to show each country's correspondence to either entire or partial success pathways. For example, the UK is strong in all areas except high-tech specialization. The overall knowledge facilitates learning and benefitting from each other.

- *Scientific/practical value:* Analysis of holistic strategies is preferable to focusing on single determinants. Different strategies can produce the same outcome. Countries can select a strategy that is based on a strength they already have. The ICF of Furman et al. (2002) was confirmed. In addition, results shed light on the role of single determinants, such as venture capital, high expenditure on education and high-tech specialization. Using fsQCA enabled us to create a robust model with a rather small data set. As multiple complex antecedent paths with high sufficiency exist, a linear model would have led to information loss.
- *Areas of improvement:* Even though the data availability for EU member states is comparably high, 11 EU member states could not be included in this study owing to lack of data in the 5-year time slice. Thus a replication of this analysis including these 11 countries might be interesting. Further, currently no solution exists for working with panel data sets, even though the results indicate that fsQCA might also be applicable to panel data. This possibility needs intensive study and an empirical comparison of panel regression and fsQCA with multiple data sets. Another disadvantage of fsQCA that needs further discussion is the highly important but difficult assignment of threshold values (data calibration).

3.2 Article 2: National Health Innovation Systems: Clustering the OECD countries by innovative output in healthcare using a multi-indicator approach

- *Study significance:* Sectoral innovation systems are an emerging field of research that complements the concepts of national, regional and technological innovation systems. Despite the high importance of innovation in healthcare for high-quality, cost-effective healthcare provision and, moreover, its prominent role as predominant field of global competition for innovativeness, innovation in healthcare has rarely been considered from a systems perspective. Few studies have examined the innovative output in healthcare innovation systems in the last decade, and literature on the determinants of this output is especially rare. This article provides a first comparison between countries, which facilitates revealing the relevant determinants that may increase the innovative output of the healthcare sub-system in future comparative analysis. In line with the overarching aim of increasing the national innovative capacity, a country comparison will allow for identifying the leading group of countries in healthcare innovation and thus enable policy makers to benchmark their own national health innovation system and draw lessons from the top-performing countries.
- *Methodological approach:* Few investigations have used quantitative data to perform a comprehensive country comparison on a sectoral level, especially in healthcare. We performed a cluster analysis for 30 of 35 OECD nations (not included: Estonia, Iceland, Latvia, Luxembourg and Slovenia, owing to a lack of data in one or more of the output variables). As bases, we collected data for 35 OECD member states, constructing a set of 14 variables for each country, covering a period of twenty years (1995–2014). The analysis is based on data acquired for 2012, as it is the latest year with all variables available for the majority of OECD countries. Although cluster analysis is a common method in the area of national innovation systems and healthcare systems, our study is one of the first to use cluster analysis to group countries by their innovation output in healthcare.
- *Main findings:* The results show a four-cluster solution, with clusters comprising Scandinavian countries, the Netherlands and Switzerland showing

highest innovation output (in terms of knowledge creation and knowledge commercialization). The clusters differ strongly in their innovative output in healthcare. *Cluster D* is the leading cluster in three out of four variables (scientific papers, value added GDP and average trade balance), and ranks third in patents. *Cluster C* ranks first in patents and second in all other variables. *Cluster A* performs worst in patents and third in all other variables. *Cluster B* has the worst performance in three out of four variables but performs second in patents.

- *Scientific/practical value:* Research adds to the current work of both national and sectoral innovation systems as well as innovation in healthcare. We show that innovation output in healthcare differs between countries and that countries can be grouped by this output. In this regard, we discussed potential reasons for those output differences, thereby providing first benchmarking insights for policy makers. Moreover, we have been able to confirm for the healthcare sector that using a multi-indicator approach provides a more comprehensive view on the innovative output compared to only considering patents as the most common proxy.
- *Areas of improvement:* Performing a time series analysis on an extended data set consisting of further countries (OECD and non-OECD) would pay tribute to the dynamic and multifaceted nature of innovation systems. In addition, the factors chosen to measure the healthcare innovational output may not encompass all kinds of innovation, since process innovations are hard to measure and some healthcare innovations may not be patentable or cannot be commercialized easily. In this sense, the chosen descriptive variables may not encompass all relevant aspects, since healthcare systems are complex and use diverse indicators and systems definitions.

3.3 Article 3: Increasing the innovative capacity of European cities: Making use of proven concepts from the national level

- *Study significance:* The highest rates of visible innovation occur in and around cities. Almost all patents and other measures of new products and processes in business are produced in cities. As nations' innovation hubs, cities are the engines of a knowledge-based economy, shaping technological change and economic growth as well as the development of countries. Surprisingly, cities as units of analysis are fairly under-researched from an innovative capacity perspective. A nascent body of academic literature deals with the key elements of innovation in European cities. However, none of these studies draws a holistic picture of the determinants of cities' innovation ecosystems. Thus, significant research opportunities emerge from efforts to form a consolidated view of European cities' or city environments' fragmented characteristics that might foster innovative capacity. Hence, this article proposes a set of variables reflecting European cities' innovation ecosystems and contributes to literature in two ways: first, it sets the scene for respective quantitative analyses, and second, it closes the gap between national and local innovation systems. Policymakers benefit from this research as it aims for the advancement of mostly linear national innovation policies toward becoming more holistic instruments of city-specific state intervention.
- *Methodological approach:* Current literature includes few empirical studies on innovation processes of European cities based on indicators adapted from other cities and regions. In keeping with these approaches, the proposition of this article is that proven concepts on innovative capacity from the national level are also applicable to cities. In the first article of this dissertation, we introduced an innovative comparative methodology to identify the pathways to success for 17 European countries. This article builds the foundation for transferring that framework to European cities. In the course of this, not only the academic work of the past 20 years is scrutinized, including the determinants of innovative capacity of 28 (secondary) capital cities located in the Czech Republic, Denmark, Estonia, Finland, France, Germany, Italy,

Netherlands, Poland, Sweden, Switzerland and UK, but also several practical studies in this field.

- *Main findings:* The results of the investigation of appropriate parameters supposed to reflect European cities' innovation ecosystems indicate differing innovation trajectories for different city types and their preconditions. This observation and the knowledge of 43 relevant city parameters, such as the numbers of new businesses and foreign-born inhabitants or the amount of foreign direct investments, have led to the conclusion that the framework proposed in the first article of this dissertation is transferable to city cases. Taking the proposed 43 parameters as a starting point, further quantitative research is necessary to determine the pathways leading to a high innovative capacity in cities. Useful for both policymakers and all involved actors, these pathways will be critical to successfully transforming the parameters of (all) local innovation ecosystems within a country into institutional arrangements on the upper levels.
- *Scientific/practical value:* As drivers of innovation in the 21st century, contextual factors of innovative capacity are focal points for urban planning and development. Understanding the factors that shape the processes of innovation in cities is helpful in determining the extent to which problems related to city growth may be resolved.
- *Areas of improvement:* The proposed 43 parameters of cities' innovation ecosystems have not yet been tested for their influence on a suitable outcome variable, such as patents. Moreover, not all facets of innovation in cities can be reflected and measured by variables. In this sense, all the issues adhering to patent statistics as measures of innovative capacity have to be considered. Another major challenge for future quantitative research in this field will be finding appropriate data sources.

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Appendix

Article 1: Increasing the national innovative capacity: Identifying the pathways to success using a comparative method. Author rights are with Technological Forecasting and Social Change (Elsevier). Article can be found here: http://dx.doi.org/10.1016/j.techfore.2016.10.009

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National Health Innovation Systems:

Clustering the OECD countries by innovative output in healthcare using a multi indicator approach

Dorian Proksch, Julia Busch-Casler, Marcus Max Haberstroh, Andreas Pinkwart

Abstract:

The importance of innovation in healthcare has increased within the last decades as new challenges like risings costs and an aging demographic have to be solved. The degree of innovativeness in healthcare is strongly influenced by the National Health Innovation System, which encompasses a wide variety of actors and related knowledge. Despite the highly practical relevance of the topic, there are only a few studies that analyze innovation in healthcare on a national level. Thus, this study is a starting point and answers the following questions building on the theoretical framework of national innovation systems: "Can countries be grouped by their innovation output in healthcare and do those groups differ in factors describing the healthcare system?" We compare the healthcare innovation output of 30 OECD countries using a multi-indicator approach and categorize them into four distinct groups using cluster analysis. The cluster consisting of the Scandinavian countries, the Netherlands and Switzerland shows the highest innovation output measured in knowledge and commercial output. Policy makers and researchers might be particularly interested in studying *the healthcare systems of these countries.*

Keywords:

Sectoral Innovation Systems; National Health Innovation Systems; National Innovation Systems; Innovation in Health; Innovative Output in Health

JEL Classification:

I1, O3, O5

1. Introduction

The healthcare system faces the constant challenge of adapting to the newest technology and to changing demands from payers and patients. Thus, innovation is a critical factor in the development and survival of organizations within the healthcare system (Goyen and Debatin, 2009; Hartweg et al., 2015; Janssen and Moors, 2013; Lansisalmi et al., 2006; Thune and Mina, 2016). It is not only a relevant topic for management in healthcare organizations and related companies; it is also a prevalent issue for policy makers. This is especially true in light of increasing healthcare cost throughout the developed countries combined with an aging demographic and continuous technological advancement (Jones, 2002; Thune and Mina, 2016). The relevance of healthcare innovation is for example reflected in the EU initiative Future and Emerging Technologies (FET). It takes on a prevalent role with topics such as, among others, digital health, robotics in healthcare, regenerative medicine, biosensors, and 4D human charting (European Commission, 2017). Additionally, contemporary research largely refers to the fields of NBIC (nanotechnology, biotechnology and life sciences, information and communication technology, cognitive sciences and neurotechnology) as predominant fields of global competition for innovativeness (Islam and Miyazaki, 2009; Wohlmuth, 2013).

Healthcare happens within a very wide context of participants, their relationships, and their contextual knowledge. Creating and implementing innovation in this sector requires bridging the gaps between the actors. Thus, the topic provides significant research opportunities. Surprisingly, the field of innovation in healthcare is fairly under researched from an innovation perspective; however, the number of papers published increased slightly in recent years (Thune and Mina, 2016). Several authors suggest viewing innovation in healthcare through the context of innovation systems (Consoli and Mina, 2009; Larisch et al., 2016; Ramlogan et al., 2007). Current research is mainly concerned with specific single technologies (Consoli and Mina, 2009; Consoli et al., 2016; Metcalfe, 2005; Petersen et al.,

2016) and actors such as physicians (Chatterji et al., 2008), hospitals (Miller and French, 2016) or patients (Oliveira et al., 2015) and rarely provides a systems viewpoint (Larisch et al., 2016).

There is already a great variety of comparisons between the national innovation systems of different countries. However, there is currently no empirical evidence on the output of health innovation systems (HIS), despite the call for further research being conducted in the field of national and regional specifics of HIS and delivery of clinical service (Barnhoorn et al., 2013; Larisch et al., 2016; Schnarr et al., 2015; Thune and Mina, 2016). With innovative capacity as the central focus, our research contributes to revealing the relevant factors that may increase the innovative output of healthcare systems. This first paper sheds light on the innovation output of HIS on a national level to facilitate a first comparison between countries. Empirical comparisons in innovation capacity literature covering sector specific cases are rare so far (Klein and Sauer, 2016; Schrempf et al., 2013). Thus, our work provides an empirical basis for further research into the factors affecting sectoral innovation output and answers the following questions: “Can countries be grouped by their innovation output in healthcare and do those groups differ in factors describing the healthcare system?” Additionally, the results help policy makers to benchmark their own National Health Innovation System (NHIS) and draw lessons from the top-performing countries.

With this, the paper not only contributes to closing the gap between national and sectoral innovation systems in literature, but also to transforming mostly linear (national) innovation policies towards becoming more holistic instruments of (sector specific) state intervention (Edquist, 2016).

2. Theoretical Background

2.1 From National to Sectoral Innovation System

The research on national innovation systems (NIS) traces back to the nineteenth century, when Friedrich List published his main works on economics. List's conviction was that a combination of social and political factors determines the development of an economy. He suggested several recommendations on public policy in order to spur Germany's industrialization and economic growth so it could catch up with England, a highly industrialized and leading economy at the time (List and Colwell, 1856).

Roughly 100 years later, Robert Merton Solow followed up on List's thinking within a wider economic context: exogenous growth theory (Solow, 1956). Broadly speaking, he considers technical progress as external force which primarily drives economic growth. However, this technical progress remains somehow unexplained. Therefore, a group of economists advanced Solow's thoughts towards endogenous growth theory, which encompasses all key determinants of economic growth. Besides investment in human capital and knowledge, investment in innovation is defined as a significant success factor of economic growth (Romer, 1986, 1990). In particular, policy measures, such as setting incentives for innovation in healthcare, are designated as *the* determinants of the long run growth rate of an economy (Romer, 1990). From Romer on, research on innovative capacity and innovation policy has made great progress and provides a rich field of studies (Sun and Grimes, 2016).

Within the last six decades, scholars from all over the world formed a body of NIS literature, combining elements of growth theory and the Schumpeterian school of thought (Schumpeter, 1939) with modern, systemic approaches to innovation (Balzat and Hanusch, 2004). This body of literature consists of several streams which build the foundation of current NIS research. For our reflections on National Health Innovation Systems (NHIS) we stick to these macroeconomic perspectives and add a microeconomic layer (healthcare sector). In summary the logic of our research is structured alongside the following aspects:

1. Economic theory (Freeman, 1989; Freeman, 2001, 2002; Porter, 1998; Romer, 1986, 1990);
2. An explanation of the need for
    a. interaction between the government, science and its actors, industries, clusters and (entrepreneurial) firms, financial institutions (Johnson et al., 2003; Lundvall, 2007; Lundvall, 1998; Lundvall, 2010; Lundvall et al., 2002),
    b. technological change (Bergek et al., 2008; Carlsson and Stankiewicz, 1991);
3. A systemic approach aiming for the translation of NIS "from a conceptual framework to theory that feeds a concrete practice" (Edquist, 2001, 2009, 2013, 2013, 2016);
4. Innovative capacity measurement (Furman et al., 2002; Porter and Stern, 2000; Porter and Stern, 2001, 2004);
5. The advancement and transfer of the NIS concept towards global (Potts, 2016), regional (Acs, 2000; Acs et al., 2002; Acs et al., 2016, 2016; Cooke, 1992, 2002; Cooke et al., 1997; Yoon et al., 2015) and sectoral application cases (Malerba, 2002);
6. The healthcare innovation system (a detailed overview of the most seminal research on this field is presented below);
7. Country comparisons (Nelson, 1992, 1993).

Based on this taxonomy the following deductive definition of national innovation systems is considered as the conceptual basis of our analysis:

The term NIS consists of a political and governmental unit ("nation") and new or better goods/services as well as new ways of producing them – so called product and process "innovation" (Edquist, 2009). The term *system* within NIS determines the innovation process and refers to a set of institutions whose interactions determine the innovative performance of national firms. In addition, the *systems of innovation* approach is clustered along geographical and political aspects into three different dimensions, in literature broadly discussed as regional, sectoral, and national innovation systems (Acs et al., 2016, p. 8).

Naturally, the parameters of innovative capacity differ across these three levels. However, the national context remains most important, since it is the level *“where the ‘rules of the game’ [national policies] are fixed”* (Acs et al., 2016). National policies have to transform sectoral perspectives into institutional arrangements that reflect and aggregate the parameters of a well working innovation system. Institutional changes, changes in economic incentives and the setting of new quantified targets are only a few of the parameters that have to be addressed. *“But how can all relevant policy areas be perfectly matched? How can knowledge demand and supply be optimally organized? Which authorities, companies, and other institutions need to cooperate, and how can they be optimally orchestrated? What weaknesses reside within the linkage of crucial players?”* (Proksch et al., 2016). These questions regarding the healthcare industry can be answered by analyzing the respective sectoral innovation (sub-) system.

The notion of sectoral innovation systems (SIS) complements the concepts of national, regional and technological innovation systems. According to (Malerba, 2002) each innovation system has a particular focus. Whereas national and regional innovation systems regard geopolitical boundaries as static and given, the boundaries of a SIS are rather dynamic, as the *“sectoral as well as the technological innovation system approaches adopt a certain technology (spanning multiple sectors) or the sector in which it is used (including various technologies) as their system boundary.”* (Schrempf et al., 2013) In a broader sense, the following definition can be considered for all SIS and, in a second step, narrowed down to the particularities of the healthcare sector.

"A sectoral system is a set of products and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a specific knowledge base, technologies, inputs and demand. Agents are individuals and organizations at various levels of aggregation. They interact through processes of communication, exchange, co-operation, competition and command, and these interactions are shaped by institutions." (Malerba, 2002)

In current literature, the SIS approach is rather underdeveloped and of limited impact within the systems of innovation research stream. Consequently, HISs have not been covered in-depth either, which is quite surprising, as healthcare plays an important role in all countries (which e.g. is also reflected in the large share of pharmaceutical products at the worldwide high-tech exports). However, slowly but surely research on this particular field gathers momentum and first attempts to explain and examine HISs can be found. True to the "morphological" nature of innovation studies as such, these scientific contributions do not rigorously stick to (Malerba's) theories about SIS, as presented in the next chapter.

2.2 National Health Innovation Systems

The term *health innovation system* was coined by (Ramlogan et al., 2007), who link the healthcare system with existing literature on innovation systems, taking SIS innovation literature into account. They state that the healthcare system encompasses a wide variety of actors (payers, practitioners, providers, patients, researchers etc.) and related knowledge. The knowledge needs to be coordinated in an efficient manner to provide patients with adequate care levels and thus help develop, diffuse and utilize innovation. This constitutes a sectoral innovation system according to the definition of (Malerba, 2002). Following a network analysis approach for glaucoma and cardiovascular disease, (Mina et al., 2007) and (Ramlogan et al., 2007), however, argue, that there is a multitude of "medical micro innovation systems" (Mina et al., 2007). Each of these is linked to specific medical research and spreads across geopolitical boundaries. This definition takes parts of Malerba's definition into account, but breaks it down to a much smaller level of sectoral innovation. (Consoli and Mina, 2009) categorize HIS into a "science and technology system" and a "health delivery system". Both "subsystems" are linked by redistributed knowledge across the specializations (researchers, physicians, etc.) working in the respective systems. This connection enables the spread and further development of knowledge and thus, innovation, through gateways (the actors within the institutions) and pathways (trajectories towards innovation), that may be independent of geopolitical boundaries. (Weigel, 2011) takes another approach and analyzes a very narrow regional health innovation system in the Bern region in Switzerland, closely looking at the role of specific actors in the region. (Larisch et al., 2016) focus on a regional health innovation system evolving around the city of Stockholm, which encompasses all institutions and healthcare fields in the region. They further mention in a side note that this small regional system is part of the national health innovation system of Sweden. (Lawton Smith et al., 2016) state in that regard: "*Within those two [national and regional innovation systems] are sectoral systems, which describe the sectoral specifics of non-linear paths from research to commercialization (value chain) within the local geographic context (micro geographies), which are sustained by the macro (country) and meso (region/state) but also sustain the macro and the meso through feedback loops for sustainable policy development*.".

There is a link between those innovation systems (see also (Asheim and Coenen, 2005; Pombo-Juárez et al., 2016), whereby the sectoral HIS is influenced by the regional and national specifics related to HISs. Thus, health innovation is linked to healthcare systems (Battista et al., 1994; Metcalfe, 2005), especially since innovation diffusion from bench to bedside is often dependent on prevalent conditions for e.g. reimbursement and financing in the healthcare system.

Considering the previous research, measuring the innovation output of a NHIS could provide valuable insights in terms of cross-country benchmarking and the development of policy recommendations. However, none of the previous papers provides empirical evidence on the actual innovation output of such a HIS on a national level. Thus, grouping countries by their innovation output in healthcare and discussing differences among those groups is an apparent gap in current literature.

3. Methodology

3.1 Data collection

We collected data for 35 OECD member states, constructing a set of 14 variables for each country, covering a period of nine years (1997 to 2015). We used the following public databases: OECD Statistics, US National Center for Science and Engineering Statistics, Scimago Journal & Country Rank, World Intellectual Property Organization as well as the World Health Organization Global Health Observatory. All these databases fulfill the statistical requirements (data availability, consistency and reliability) necessary for our research. Ultimately, our analysis is based upon the data acquired for the year 2012, since this was the latest year with all variables available for the majority of OECD countries. Overall, our analysis covers 30 out of 35 OECD member states. Five OECD countries, namely Estonia, Iceland, Latvia, Luxembourg and Slovenia, had to be omitted from the analysis due to a lack of data in one or more of the output variables. This is in line with previous research on OECD countries in the field of healthcare that also suffer from a lack of data availability for some variables and countries (Baltagi et al., 2012; Bohm et al., 2013). An overview of the variables and respective data sources can be found in Appendix A (description of variables) and Appendix B (descriptive statistics on variables).[1]

3.2 Variables

3.2.1. Innovative output variables

While older studies solely focus on the number of patents per year to measure national innovation output (Furman and Hayes, 2004; Furman et al., 2002), scholars argue that not only knowledge production but also commercialization is important for the innovation output (Guan and Chen, 2012; Moon and Lee, 2005). Therefore, we followed the framework of

[1] Detailed information and spreadsheets can be requested from the authors.

(Moon and Lee, 2005)[2] and adapted it to HIS. Consequently, we quantify the innovative output in healthcare through the following pairs of variables per construct:

Knowledge production:

- Total number of patent applications under the category healthcare per 1 million population (WIPO Statistics Database, 2016);
- Number of scientific papers per 1 million population (SCImago, 2015).

Knowledge commercialization:

- Value add in healthcare and pharmaceutical industries as percentage of the GDP (National Science Foundation, 2016);
- Trade balance of the pharmaceutical industries in percentage of GDP (OECD, 2016d).

As current literature does not offer empirical evidence on the innovative output of health innovation systems, there are no similar constructs that could have been taken into account as alternative configurations to measure innovative output in healthcare. In general, the aim of assembling the right set of innovative output variables is capturing a maximum of all innovation produced in a certain context and, while doing so, erasing dissimilarities like differences in local law (Adam, 2014; Carlsson et al., 2002; Schmoch et al., 2006). The proposed construct used in our analysis complies with this demand and is in line with OECD standards for collecting and interpreting innovation data (OECD, 2001, 2005, 2016c). The OECD also provides a consistent taxonomy for healthcare related products and services, consisting of the subsets health and pharma (Hatzichronoglou, 1997; Serve, 2015). We rigorously applied this definition cross databases and only had to cope with minimal divergences, which can be neglected, as they were insignificant.

[2] Moon and Lee propose a composite indicator intending to measure innovative performance on national level. The configuration of this indicator is based on the weighted results of 111 expert interviews carried out in industry (16.2%), academic fields (48.7%; thereof 81.1% natural science or engineering and 18.9% social science) and public institutes (35.1%).

3.2.3. Healthcare systems variables

In order to characterize the healthcare systems underlying the national health innovation output, we look at a set of variables commonly used to describe the healthcare system of a country (Anderson and Hussey, 2001; Baltagi et al., 2012; Battista et al., 1994; Delgado, 2016; Docteur and Oxley, 2003). These include:

- healthcare spending (WHO, 2016);
- doctors and hospital beds (OECD, 2014b, 2015c);
- healthcare personnel per bed (OECD, 2016b);
- percentage of the workforce employed in the hospital sector (OECD, 2014c);
- CT and MRI units (OECD, 2015b, 2015d);
- patients consultations with doctors (OECD, 2015a);
- length of the hospital stay (OECD, 2016a);
- number of elderly people (>65) (OECD, 2014a).

Studying OECD countries provides researchers with certain homogeneity when considering factors regarding public health such as life expectancy or mortality (Anderson and Hussey, 2001). Thus, indicators commonly used to describe the general health of the population, such as life expectancy, neonatal mortality, mortality, level of alcohol consumption or level of immunization (see (Anderson and Hussey, 2001; Globerman, S., Hodges, H., & Vining, A., 2001), are excluded from the analysis. We further excluded qualitative indicators on healthcare systems, as there is currently only limited literature that allows for a comprehensive system comparison among OECD countries (e.g. (Bohm et al., 2013; Wendt et al., 2009).

3.3 Cluster analysis

We used cluster analysis to assess if the OECD countries can be grouped by the innovative output in healthcare. Cluster analysis is a common method in the area of national innovation systems (Gomez et al., 2014; Hollenstein, 2003; Nasierowski and Arcelus, 2003; Samara et al., 2012) and health care systems (Bohm et al., 2013; Borisova, 2011; Wendt, 2009). However, it has not been applied to NHIS for so far.

The goal of cluster analysis is to categorize a number of observations into a restricted number of homogenous clusters. The distance among the clusters should be maximized and the distance between the members of a cluster should be minimized (Hair et al., 2014).

We applied a hierarchical cluster analysis technique using Ward's method with squared Euclidean distances (Hair et al., 2014). We used the four previously described national health innovation output variables as cluster variables. The results showed a two to nine cluster solution. We then evaluated the different solutions. Ultimately, the four-cluster solution showed the most interpretable results. The smallest cluster should at least include 10% of all cases (Hair et al., 2014). A five-cluster classification would result in a cluster with less than 10% of the cases and therefore lead to a result that is difficult to interpret.

To assess the statistical validity of our cluster approach, we applied discriminant analysis. We tested if a set of functions existed that could segment the data set within the respective clusters based on the health innovation outcome variables, thereby following the approach of (Hill and Brennan, 2000). As Table 1 shows, the first discriminant function is significant, the second and third are not. However, the first function explains 96.9% of the variance and is therefore by itself sufficient to create a valid classification. The discriminant functions achieved a classification accuracy of 100 %. Therefore, the maximum chance criterion and the proportional chance criterion are fulfilled. The discriminant analysis showed that the health innovation output variables can be used to segment the four clusters. This means that our clustering approach is valid.

Discriminant function	**Eigenvalue**	**Percentage of variance**	**Canonical correlation**	**Wilks' Lambda**	**Chi-square**	**Sig**
1	12.321	96.9	0.962	0.054	72.983	0.000
2	0.378	3.0	0.528	0.719	8.249	0.220
3	0.02	0.0	0.050	0.998	0.062	0.970

Table 1 - Summary of the four-cluster discriminant analysis

4. Results

Our clustering approach has led to four clusters. Table 2 shows which countries are categorized within which cluster. Cluster A encompasses many of the Central, Western and Southern European countries (Germany, France, Italy, Spain, Portugal, the Czech Republic and Greece). Cluster B consists of the South American (Chile, Mexico), Asian (Japan, South Korea) and Eastern European countries (Hungary, Poland, Slovak Republic) as well as Turkey. Cluster C encompasses the United States, Canada, Australia, New Zealand, the United Kingdom, Austria, Ireland, Belgium, Finland and Israel. It is also the largest cluster with 10 member countries. Cluster D includes the Scandinavian countries (excluding Finland), the Netherlands as well as Switzerland, making up the smallest of the clusters. The clusters are not only based on the health innovation output but also show a slight regional focus. This regional focus can also be seen in Figure 1.

Cluster A	**Cluster B**	**Cluster C**	**Cluster D**
Czech Republic	Japan	Australia	Switzerland
Portugal	South Korea	New Zealand	Denmark
Germany	Hungary	Israel	Norway
France	Poland	United States	Netherlands
Italy	Slovak Republic	Canada	Sweden
Greece	Turkey	Austria	
Spain	Chile	United Kingdom	
	Mexico	Ireland	
		Belgium	
		Finland	

Table 2 - Countries included in each cluster

Fig. 1. Countries according to their cluster affiliation

The average innovation health output of the clusters is shown in Table 3. Cluster A has the weakest output in patents and the second weakest output in papers. It is ranked third in the areas of valued added and trade balance. Cluster B ranks second in patent output and last in all three other areas, thus being the least innovative cluster in this analysis. Cluster C ranks first in patent output and second in the three other areas. Cluster D ranks first in all areas except of patent output. It is thus classified as the most innovative cluster in our analysis. In patent output, however, it only ranks third. We can therefore state that the clusters strongly differ in their innovation health output.

Variable	Type	Cluster A	Cluster B	Cluster C	Cluster D
Average Amount of Health patents per population (HPatents)	Value	8.76	48.07	122.65	15.49
	Rank	4	2	1	3
Average Amount of Health papers per population (HPapers)	Value	626.18	267.12	1,087.78	1,728.82
	Rank	3	4	2	1
Average Value Added divided by GDP (HValueAdd)	Value	6%	3%	8%	13%
	Rank	3	4	2	1
Average Trade Balance divided by GDP (HHigh-Tech Export)	Value	0.49%	0.38%	1.87%	2.54 %
	Rank	3	4	2	1

Table 3 - Average innovation health output per cluster

We further tested if the clusters differ in central health related variables using One-Way ANOVA. Table 4 shows that this is the case for healthcare spending, elderly population, doctors per million, doctor’s visits, percentage of the workforce in healthcare and healthcare personnel per bed.

Variable	df	F-value	Significance
HPatents	29	2.660	**0.069***
HPapers	29	88.621	**0.000*****
HValueAdd	29	24.977	**0.000*****
HHigh-Tech Export	29	1.190	0.333
HSpending	29	5.720	**0.004*****
Elderly Population	28	3.747	**0.024****
Doctors per 1000	25	7.318	**0.001*****
Beds per 1000	27	1.162	0.345
CT per Million	23	0.794	0.511
MRI per Million	21	1.228	0.329
Doctor’s Visits	21	2.501	**0.092***
Length Hospital Stay	25	1.093	0.373
Percent Workforce in HC	29	19.383	**0.000*****
HC Persons per Bed	19	4.422	**0.019****

Table 4 - Results of the ANOVA

(* significant on 90% level, ** significant on 95% level, * significant on 99% level)**

Table 5 shows the averages for the variables describing the healthcare system by cluster. Clusters C and D have higher healthcare spending than the other clusters. The highest numbers of elderly people (over the age of 65) exist in cluster A and D. Both of those clusters also have the highest number of doctors. The annual doctor visits per patient are much higher in cluster A and B than in the other both. The length of the hospital stay is longest in cluster

B. The highest amount of workforce is employed in cluster D, followed by cluster C. Also, both clusters have the highest amount of healthcare personnel per bed.

	Cluster A	**Cluster B**	**Cluster C**	**Cluster D**
HSpending	9.7%	7.3%	10.5%	10.9%
Elderly Population	18.91%	12.91%	14.92%	17.81%
Doctors per 1000	3.67	2.33	3.06	3.67
Beds per 1000	5.09	6.20	4.00	3.80
CT per Million	22.60	15.07	23.29	26.22
MRI per Million	16.73	7.75	14.65	11.82
Doctor’s Visits	7.90	8.96	5.86	4.42
Length Hospital Stay	6.75	8.22	6.13	5.98
Percent Workforce in HC	9.1	5.9	12.6	16.8
HC Persons per Bed	2.57	1.77	4.59	5.15

Table 5 - Average healthcare variable per cluster

5. Discussion

Our research adds to the current work of both national and sectoral innovations systems as well as innovation in healthcare. Innovation output in healthcare differs between countries and they can be grouped by this output. Thus, it may make sense to see which cluster a country belongs to and then further analyze how to advance its healthcare system in order to create a higher innovation output in healthcare. Findings on the overall HIS may not be applicable to specific countries, but rather have to be interpreted within their respective cluster.

The Scandinavian countries (excluding Finland), the Netherlands and Switzerland show the highest innovation output measured in terms of knowledge production and knowledge commercialization in healthcare among the OECD countries. This is in accordance with previous studies showing a high innovativeness of the healthcare system in Switzerland due to a strong interconnection between research and its commercialization aided by a strong industrial engagement, especially in the pharmaceutical sector (Lawton Smith et al., 2016; Marxt and Brunner, 2013). However, there is a need for further research to find out if and why this may also be the case for the Scandinavian countries and the Netherlands, as there is currently no detailed research on those countries' NHIS. A first indicator might be that within this cluster the healthcare spending is the highest and the percentage of workforce employed in health is also the highest. Thus, actors within the NHISs in Scandinavian countries, the Netherlands and Switzerland may have more financial and human resources and thus a higher capacity to innovate. Previous studies already indicated the linkage between healthcare innovation and related resources (Delgado, 2016; Lawton Smith et al., 2016). Surprisingly, the amount of doctor visits per year is the lowest among all clusters. This may be due to the organization of the Scandinavian healthcare system with a focus on primary care centers and nurses as a first contact point (Anell, 2015). This, however, needs further explanation.

Countries in this cluster only ranked third regarding the number of patents in healthcare, which is not in line with the other indicators of national health output. An explanation might be that while these countries focus on the commercialization of their innovations, they do not file patent in their own countries but in other countries with potential bigger markets (Archontakis and Varsakelis, 2016). This might be especially the case as the countries within this cluster have a relative low population (Sweden with around 10 million has the highest population) and therefore a rather small regional market.

Cluster C (encompassing Australia, New Zealand, Israel, United States, Canada, Austria, United Kingdom, Ireland, Belgium, Finland) has the highest patent output but ranks only second in all other categories. A reason for that can be that researchers and doctors are incentivized to protect their knowledge through patents. (Lawton Smith et al., 2016) and (Delgado, 2016) show similar evidence in their analyses of UK's regional respectively national health innovation system. Possibly, the commercialization of these innovations is not fostered in the same way as in cluster D. (Peters et al, 2006) already indicate that healthcare systems are strongly influenced by their institutional arrangements and the social context that they are embedded within. In addition, the infrastructure and incentives to commercialize innovations might not be as strong, as indicated by (Lawton Smith et al., 2016) in the UK example. Another explanation may be the scope of patentable innovation in the respective jurisdictions. Several studies already indicated a patent gap between different countries (Fu and Yang, 2009; Grupp and Schmoch, 1999; Hall and Mairesse, 2006).

Overall, the two most successful clusters have the highest healthcare spending, the biggest workforce employed in healthcare and the highest amount of healthcare personnel per bed. This leads to the proposition that the resource base and its allocation is an important factor for innovation. With this, they may be in a better position to deal with the challenges imposed by demographic change and rising cost, a statement which needs further elaboration.

Interestingly, Cluster D also has the highest percentage of elderly people and thus may have a stronger propensity to innovate in order to cope with the change. This may also lead to a stronger need for using the developed innovations in the markets and thus commercializing them. Overall, this analysis can serve as a starting point for a detailed examination of similarities and differences and related policy benchmarking and recommendations.

Cluster B, consisting of the South American, Asian and Eastern European OECD countries as well as Turkey, showed the worst performance in innovation output. A reason for that might be a comparably low resource base (lowest healthcare spending, lowest amount of doctors per 1,000 population and lowest percentage of the population employed in healthcare). Combining this with a high demand for healthcare services, as indicated by the highest percentage of elderly population as well as the highest number of doctor visits per patient and the longest stays in hospitals creates a rather challenging environment. Possibly, all resources must be used for basic medical care and patient treatment and thus, there may be no more time, resources and room to innovate. This may lead to a lower efficiency in healthcare service provision as indicated by a long hospital stay (OECD, 2016a). Another explanation could lie in the nature of the policies related to innovation. (Delgado, 2016) describes e.g. the Japanese healthcare industry as rather “innovation-shy” and more focused on reverse engineering.

Finally, Cluster A (encompassing Germany, France, Italy, Spain, Portugal, the Czech Republic and Greece) performs poorly regarding the innovation output. Again, there is a combination of the highest percentage of elderly people (18.9%) together with a comparatively low resource base when considering healthcare spending and percentage of workforce employed in the healthcare sector. However, the cluster shows a high number of doctors and a comparably lower number of beds and a length of hospital stays being much closer to the top group, indicating a higher level of efficiency (OECD, 2016a). This could indicate that the focus within the healthcare system lies more in gaining efficiency through incremental improvements. (Delgado, 2016) suggests that due to the somewhat fragmented nature of the German healthcare system, there might be a disconnection between the healthcare system and its related policies on the one hand and the industry and research organizations producing innovation on the other hand.

6. Limitations, implications and further researchers

Limitations

Rating the innovativeness of countries is challenging. Measuring the innovation output in healthcare along the previously described four factors may not encompass all innovations. Process innovations are especially hard to measure. Further, patents and scientific articles may not always lead to new products and services. Additionally, certain healthcare innovations (e.g. medical process innovation or innovation relating to more efficient patient pathways) may not be patentable depending on different jurisdictions and may be thus (partially) excluded from our analysis. However, we used the (Moon and Lee, 2005) indicator for our research and believe that the combination of its factors leads to a maximum coverage of innovations.

Additionally, this research would have benefitted from one data source offering the required data for both the innovative output variables and also the healthcare system variables. This would have erased even slightest divergences in data taxonomy and definitions.

Further, only 30 out of the 35 OECD countries could be included in the study due to data availability issues. However, the sample includes most of the economically stronger countries with established healthcare systems. Therefore, we believe that the sample is large enough to derive comprehensive conclusions, which can also serve as benchmarks for emerging health systems in non-OECD countries.

The descriptive variables show the major variables characterizing healthcare systems and serve as a first indicator for characterizing the NHIS clusters. However, they may not encompass all relevant variables, especially since healthcare, related regulations and healthcare financing are complex systems with diverse indicators and systems definitions. We believe that we can provide substantive insights into the clusters with the chosen variables, as we used common indicators to describe the systems.

Implications

This research might be of great interest for policy makers as healthcare systems are an important issue in political discussions. Raising the national innovation output within the healthcare system may lead to cost savings and better patient care. Therefore, nations can create policies that foster more innovation within the healthcare systems. For this, it is important to know which countries have a high innovation output in healthcare to derive best-practices. This research shows that policy makers might be particularly interested in studying the healthcare systems of the Scandinavian countries, the Netherlands and Switzerland and taking them into account when considering new political reforms.

Further research

We showed that the Scandinavian countries, the Netherlands and Switzerland have the highest innovation output in healthcare among OECD countries. However, it is currently not clear why this seems to be the case. Possible reasons can include national policies, the national infrastructure and the resource base. A comprehensive analysis of determinants of the NHISs can lead to a better understanding of the phenomenon.

Further, this research was performed with a limited data set. Extending the data set to all OECD countries as well as non-OECD countries with emerging healthcare systems such as China, Brazil or India (as already indicated by (Delgado, 2016) would extend the findings and provide further insights into NHIS. Also, a broader data set may enable researchers to include a time series analysis. Covering more than one year may lead to more robust results and pays the necessary academic tribute to the dynamics and multifaceted nature of the NHIS as subset of a country’s NIS.

Finally, extending the descriptors of the underlying healthcare system to qualitative data describing the healthcare systems and their governance may lead to an even more comprehensive picture of NHIS. Detailed case studies and case comparisons of countries within the mentioned clusters as well as between clusters would also lead to interesting insights.

7. Conclusion

Within this paper we discuss the innovative output in healthcare of 30 OECD countries using a multi indicator approach. Despite the high relevance of the topic, there are only few empirical studies on the NHIS. We are one of the first who use a cluster analysis to group countries by their innovation output in healthcare and scrutinize obvious differences based on the certain factors that describe the national healthcare systems. We found four distinct clusters, whereby the cluster comprising of Scandinavian countries, the Netherlands and Switzerland shows the highest innovation output measured in terms of knowledge creation and knowledge commercialization. We discussed potential reasons for the outcome and provided first benchmarking insights for policy makers. With this, we contributed to the scientific discourse on national as well as sectoral innovation systems research as well as the literature on NHIS.

Appendix A: Description of variables

Variable	Scale	Full variable name	Definition in our model	Source	Based on
Innovative Output – Dependent Variable					
HPatents $_{j, 2012}$	Number, total count by filing office; Health patent applications per 1 mn population	Total health patent applications (direct and PCT national phase entries)	Health definition used: **Medical Technology IPC Codes** (WIPO, 1979)**:** A61B; A61B 8/12; A61B 10/04; A61B 17/00; A61B 18/22; A61B 3/00 [2006.01] **Pharmaceuticals IPC Codes** (WIPO, 1979): A61K; A61J 3/00; A61L; A61P	World Intellectual Property Organisation	Moon and Lee, 2005
HPapers $_{j, 2012}$	Number, Total count of Health documents; per 1 mn population	Health documents	Health definition used: Dentistry, Health Professions, Medicine, Neuroscience, Nursing, Pharmacology, Toxicology and Pharmaceutics	Scopus® database	(Moon and Lee, 2005)
HValueAdd $_{j, 2012}$	Percentage of GDP (purchasing power parity)	Value added of health and pharma industries	Health definition used: Value added of pharmaceuticals industry, by region/country/economy; Value added of health and social	National Center for Science and Engineering	(Moon and Lee, 2005)

			services, by region/country/economy. (Value added is the amount contributed by a country, firm, or other entity to the value of a good or service and excludes purchases of domestic and imported materials and inputs.)	Statistics	
HHigh-Tech Export $_{j, 2012}$	Percentage of GDP (purchasing power parity)	Trade Balance: Pharmaceutical industries (current prices)	Health definition used: Pharmacy SITC Revision 3 (Hatzichronoglou, 1997); Medical/ optical instruments are not included	OECD Stats	(Moon and Lee, 2005)
Healthcare systems - independent variables					
HSpending $_{j, 2012}$	Percentage of GDP (purchasing power parity)	Total expenditure on health as a percentage of gross domestic product	Total expenditure on health expressed as a percentage of gross domestic product	WHO - Global Health Observatory	Docteur & Oxley (2003), see also Anderson & Hussey (2001), Globerman et al (2001), Delgado (2016)
Elderly Population $_{j, 2012}$	Total percentage of population	Eelderly population	people aged 65 and over	OECD Data	Battista (1994), see also Arah et al (2003)

Appendix A: Description of variables

Doctors Per 1000 $_{j,\,2012}$	Total, per 1.000 inhabitants	Doctors	"Practicing" doctors providing direct care to patients (exemption: Canada, Finland, France, Ireland, Italy, the Netherlands, Slovakia and Turkey: "professionally active" doctors)	OECD Data	Battista (1994), see also Anderson & Hussey (2001), Globerman et al (2001), Delgado (2016)
Beds Per 1000 $_{j,\,2012}$	Total, per 1.000 inhabitants	Hospital beds	Number of beds that are maintained, staffed and immediately available for use (acute care beds, psychiatric care beds, long-term care beds and other beds in hospitals)	OECD Data	Battista (1994), see also Anderson & Hussey (2001), Globerman et al (2001), Delgado (2016)
CT Per Million $_{j,\,2012}$	Total, per 1 mn population	Computed tomography (CT) machines	CT scanners	OECD Data	Battista (1994), see also Globerman et al (2001)
MRI Per Million $_{j,\,2012}$	Total, per 1 mn population	Magnetic resonance imaging (MRI) units	MRI units	OECD Data	Battista (1994), see also Globerman et al (2001)
Doctor's Visits $_{j,\,2012}$	Total, per capita	Doctors' consultations	Number of patients consultations with doctors (generalists and specialists) in various settings (e.g. hospitals)	OECD Data	Battista (1994), see also Anderson & Hussey (2001)

Appendix A: Description of variables

Length Hospital Stay $_{j, 2012}$	Days	Length of hospital stay (acute care)	Average number of days that patients spend in hospital (excluding day cases)	OECD Stats	Battista (1994), see also Anderson & Hussey (2001)
Percent Workforce In HC $_{j, 2012}$	Density per 1.000 population	Total health and social employment as % of civilian workforce	Human health and social work activities (ISIC Rev.4 – Section Q 851, 86, 852,87, 853, 88)	OECD Stats	Battista (1994)
HC Person Per Bed $_{j, 2012}$	Hospital-employment-to-bed ratio (head counts)	Total hospital beds	Number of beds that are maintained, staffed and immediately available for use (acute care beds, psychiatric care beds, long-term care beds and other beds in hospitals)	OECD Stats	Battista (1994)

Appendix B: Descriptive statistics on variables

Variable	Min	Max	Med	Average	Std. Dev.
Innovative Output – Dependent Variable					
HPatents $_{j, 2012}$	0.72	426.49	11.43	58.33	100.36
HScientific Papers $_{j, 2012}$	43.33	2,194.49	789.90	868.07	532.33
HValue Add $_{j, 2012}$	1.10%	15.00%	7.20%	7.07%	3.93%
HHigh-Tech Export $_{j, 2012}$	0.12%	12.06%	0.44%	1.26%	2.52%
Healthcare systems – independent variables					
HSpending $_{j, 2012}$	5.24%	17.02%	9.38%	9.52%	2.27%
Elderly Population $_{j, 2012}$	6.41%	24.15%	16.60%	15.79%	4.06%
Doctors per 1000 $_{j, 2012}$	1.69	4.80	3.18	3.10	0.77
Beds Per 1000 $_{j, 2012}$	1.57	13.36	3.86	4.88	2.73
CT per Million $_{j, 2012}$	5.10	50.51	15.48	21.12	12.58
MRI per Million $_{j, 2012}$	2.17	34.43	10.35	12.80	8.98
Doctor's Visits $_{j, 2012}$	2.90	14.30	6.75	7.03	3.46
Length Hospital Stay $_{j, 2012}$	3.90	17.50	6.15	6.73	2.43
Percent Workforce In HC $_{j, 2012}$	3.05%	21.11%	10.88%	10.70%	4.57%
HC Person Per Bed $_{j, 2012}$	0.49	7.56	3.25	3.52	1.87

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Increasing the Innovative Capacity of European Cities:

Making Use of Proven Concepts from the National Level

Marcus Max Haberstroh, Andreas Pinkwart

Abstract

Besides facing challenges like globalization, agglomeration, digitalization, and demographical change, a nation finds its growth and development to be strongly influenced by its innovativeness. Innovation emanates from interaction and knowledge flows, and countries' systems of innovation shape the manifold innovation processes. Cities are the focal point of these processes, as they serve as regional hubs that facilitate the interplay between all involved actors and the exchange of related knowledge. Consequently, cities as fonts of innovation are central to policy makers' concerns. Despite cities' high value as a unit of analysis, few studies have investigated strategies leading to a high innovative capacity in cities. However, much research has occurred at the national level. Among this, one study introduces an innovative methodology to identify so called pathways to success for European member states using a comparative method. As the national level is an aggregate of the lower levels, the authors assume that such proven concepts from the national level also apply to cities and claim that different innovation strategies with the same outcome exist, thus allowing cities to define appropriate policies in line with their specific preconditions. The few academic works on the determinants of innovative capacity of European (secondary) capital cities, as well as several practical studies in this field, provide first evidence of the truth of this theory. Drawing on these fragmented sources, the authors propose a consolidated set of 43 variables reflecting a local innovation ecosystem, thus setting the scene for a quantitative proof of the concept in the future.

Keywords:

Regional Innovation Systems; Local Innovation Systems; Innovation in European Cities; Innovative capacity; Innovation Policy

JEL Classification:

P25, O3, O5

1 Introduction

Innovation has been critical for the long-term competitiveness of nations since the Industrialization Revolution (Romer 1986, 1990). In recent decades a scientific field has emerged, aiming to explain, forecast, and modify this essential of economic success (Acs et al. 2016; Atkinson 2013; Albach 2006), with elements of growth theory, the "Schumpeterian school of thought" (Schumpeter 1939), and modern, systemic approaches to innovation forming the foundation of research. This literature is dedicated to studying the production and use of formal and informal knowledge regarding the creation and adoption of new products and services, improved processes, organizational forms, and business models (Fagerberg 2016; Lundvall 2010). Regardless of whether the application area is country comparison, R&D forecasting, or analysis of technological systems, the doctrine of innovation systems is centered on the triad of innovative capacity, innovation strategy, and innovation policy.

Innovative capacity makes the difference between countries' prosperity or stagnation (Marceau 2008b; Furman and Hayes 2004; Porter 1990) as it reflects the level of invention and the potential for innovation in any nation, geographical area, or economic activity (Villa 1990; Furman et al. 2002). Studies of innovative capacity have focused mainly on the national level and provide a "conceptual framework to theory that feeds [the] concrete practice" (Edquist 2009, p. 182) of generating useful insights about the focal points of *innovation strategy* (Sun and Grimes 2016; Porter and Stern 2001, 2000, 2004). Innovation strategies build upon the availability, intensity, and combination of certain economic elements, such as GDP or production factors like capital and labor, which on the whole reflect a country's innovation ecosystem (Edquist 2016). Together with organizational and institutional arrangements these elements naturally differ in terms of levels, and *innovation policies* aim to create respective regional, local and sectoral innovation areas (Couchman et al. 2008). In this regard, "sub-national entities, such as provinces, industrial districts, cities or 'Silicon Valleys' are becoming, or have already become, more important than the nation-state" (Freeman 1998). This importance especially holds true in view of the fact that the highest rates of visible innovation are found in and around cities (Athey et al. 2008). However, in an effort to aggregate the complexity of the various ecosystems at lower levels, innovation policies are largely set on the national level.

As drivers of innovation in the 21st century, the contextual factors of innovative capacity are focal points for urban planning and development (Kourtit and Nijkamp 2012; Dameri 2017; Briggs 2009). Surprisingly, cities as units of analysis are fairly under-researched from an innovative capacity perspective (Martin and Simmie 2008). Although research in this particular field is gathering momentum and a small body of academic literature deals with the key elements of innovation in European cities, no study presents a holistic picture of the determinants of cities' innovation ecosystems. Thus, condensing the fragmented characteristics of European cities or city environments that might foster a consolidated view of innovative capacity provides significant research opportunities (McCann 2004). Moreover, understanding the factors that shape the processes of innovation in cities might also be helpful in determining the extent to which problems related to city growth may be resolved (Johnson 2008). Hence, this article contributes to literature in two ways, first by setting the scene for quantitative analyses by proposing a consolidated set of variables reflecting European cities' innovation ecosystems, and second by closing the gap between national and local innovation systems. Policymakers also benefit from this research as it aims to advance the mostly linear national innovation policies toward becoming more holistic instruments of city-specific state intervention (Edquist 2016).

2 Theoretical Foundation: About Innovation Systems and Cities

Research on innovation systems emerged primarily from the theory of political economy. Early attempts to explain the development and performance of nations trace back to the forefathers of the German school of economics, among them especially Friedrich List. Roughly 200 years ago, he paved the way for a lively scientific discourse (List and Colwell 1856), in literature now recognized under the notion of exogenous (Solow 1956) and endogenous growth theory (Romer 1990, 1986). From Romer on, the question of the determinants of the long-run growth rate of an economy and in particular the contribution of innovation began to dominate this field of research (Acs et al. 2016).

2.1 The Purpose of Innovation Systems Research

Motivated by high practical relevance for policy makers, innovation scholars from all over the world are producing a rich body of literature consisting of various strands (Sun and Grimes 2016). At the beginning, a four-pronged taxonomy prevailed, with its foci on national, regional, and sectoral innovation systems and, as an overarching analytic perspective, the innovative capacity view, which emerged in parallel, closely attached to the mentioned geographies (Teixeira 2014). What today is called the innovative capacity framework was initially "proposed as an index that could provide regular diagnostics of national performance in invention over time" (Villa 1990, p. 290) with the intention to show the influence of technological change on economical growth.

Meanwhile, a new plurality of studies evolved, introducing new dimensions along with new notions like "global," "local" and "technical" innovation systems (Klein and Sauer 2016). Nevertheless, the methodology behind innovation systems research and also the research questions remains largely the same, demanding suitable answers on both the "DNA" of a certain country-level or industry innovation ecosystem as well as the respective measures to maximize the outcome of innovation endeavors (Edquist 2013, 2009, 2001).

However, rather than merely creating innovation systems in literature, scholars try to understand them in order to improve them (Acs et al. 2016). In that regard, within all strands of innovation system research various studies propose certain strategies that might lead to high innovative capacity. Even though the determinants of innovative capacity differ across levels, "the 'rules of the game' are fixed" (Acs et al. 2016, p. 1) on the national level with policy measures. These measures are, for instance, institutional changes, changes in economic incentives, or the setting of new quantified targets. Their purpose is to transform sub-national perspectives into institutional arrangements that reflect and aggregate the parameters of a smoothly working innovation system — from the bottom (local level) to the top (supra-/national level) (Edquist 2016). To identify the right parameters, regional systems and the local sub-systems have to be analyzed.

2.2 Regional Innovation Systems

As part of a national innovation system, regional innovation systems describe the interaction of different sectors with regional governance, innovation support infrastructures, and the national-level system (Teixeira 2014). In this regard, the regional innovation system concept complements the national innovation system concept by adding an additional layer that heavily emphasizes institutions (Parto and Doloreux 2004) and focuses on aspects like the proximity between firms (Klein and Sauer 2016). Even though views are conflicting, some scholars consider the regional level to be the "preferred spatial level for regulatory intervention…, rather than the central state" (Klein and Sauer 2016, p. 14). This claim is predominantly promoted by Philip Cooke, the widely recognized pioneer and seminal author in this strand of literature (Cooke 1992, 2002; Cooke et al. 1997, 1998). Along with other scholars in fields of innovation, he justified the necessity and importance of a regional dimension within innovation systems research. Nijkamp (2016) recently contributed another landmark work in the context of regional innovation, presenting a novel framework intended to help low performers catch up. At its core, his theory builds upon regions' unique portfolios of development possibilities and shows how to optimize the combination of available resources and capabilities. Zitek and Klimova (2016) propose a slightly different framework that highlights and builds upon knowledge flows within and between organizations. The study aims to identify appropriate indicators as well as a methodology for determining the knowledge base of a region. In line with Nijkamp's conviction, Zitek and Klimova recommend considering the unique characteristics of the given region when implementing regional innovation policies. In summary, the strand of literature on regional innovation systems discusses a more or less independent and complex analytical framework generating the empirical foundation for innovation policy making (Parto and Doloreux 2004). In this regard, the special role of cities within regional innovation systems constitutes an important factor.

Freeman, well known in the context of innovation research (Freeman 2002, 2001, 1989) , stressed the importance of cities within regional innovation systems based on his far-reaching studies on the root causes of catching up and falling behind in Eastern and Central Europe (Freeman 1998). Further analyses on the role of cities for economic growth and development of countries has been done by Johnson (2008), whose research also tackles the question of which factors might shape the processes of innovation in cities and thereby pursues a systemic approach to analyze institutional, political, and technical innovation in cities. In this context he is among the first to apply the rarely used notion of local innovation systems. Later on, Capello et al. (2012) and Breschi (2001) headed in the same direction and strengthened the link between the presence of cities in the region and innovative performance, finding a notably high degree of innovation in regions hosting large urban areas and so-called dynamic agglomeration economies[1] as well as knowledge spillovers generated by cities. The most recent contribution of Viitanen (2016) follows up on this and draws on the case of Cambridge to identify "the key ecosystem elements that are necessary for building up a solid foundation for the innovative regions" (p. 6). On the basis of these key elements he presents a holistic approach to managing the innovation ecosystem of the Cambridge region under the notion of the "innovation hub framework."

2.3 Local Innovation Systems

As noted earlier, the local innovation systems approach is somewhat underdeveloped and of limited impact within the systems of the innovation research stream. The fact that the notion of local innovation systems (LIS) is almost never found independent from regional innovation systems (RIS) is evidence of this gap in literature.

The LIS strand is still in its infancy. Mainly, current LIS literature is promoted by a handful of experts who have contributed the few fundamental works to date (Martin and Simmie 2008; Marceau 2008a, 2008b; Breschi 2001; Simmie 2001). However, not only academic literature addresses LIS. Large-scale international field studies, such as the Local Innovation Systems Project or the Regional Entrepreneurship Acceleration Program hosted by the Massachusetts Institute of Technology, also contribute valuable knowledge (Regional Entrepreneurship Acceleration Program 2017; Local Innovations Systems Project 2005).

The notion of LIS complements the concepts of national, regional, and technological innovation systems. According to Martin and Simmie (2008), each innovation system has a particular focus. LIS research aims to increase the understanding of how localized technological innovation operates in a global economy—that is, the dynamics of the global–local relationship and the different ways they interconnect (Kosonen 2005). In this context, LIS scholars attempt to determine the conditions associated with the development of a sustainable

[1] See European Commission (2016b, p. 62) for a detailed explanation of urban and dynamic agglomeration economies.

local innovation system, or the transition from one kind of system to another, as well as the role, behavior, and performance of local innovation systems during a period of increasing globalization (Sotarauta et al. 2004).

In a broader sense, LISs can be defined as spatial concentrations of businesses (firms of all industries) and associated non-businesses (institutions like education and science, authorities, specialist associations) that collaborate to generate new practical knowledge, including new products or services, and to commercialize this knowledge (Martin and Simmie 2008). Furthermore, the LIS literature argues that "local innovation systems are the key driving mechanism underlying change in spatial economies because they are the primary source of new commercially valuable knowledge" (Martin and Simmie 2008, p. 194).

True to the "morphological" nature of innovation studies, the notions of LIS, RIS, and sectoral innovation systems (SIS) are not always rigorously applied, which creates a further barrier to the emergence of a clear-cut LIS strand in innovation systems literature.

2.4 Cities

Cities are comprehensive local innovation systems, "composed of the same elements as regional or national systems but geographically much more concentrated" (Marceau 2008b, p. 137). Cities' innovation ecosystems and innovative capacity, as pivotal points within LISs, have also not been covered from academia in a satisfactory manner, an omission that is quite surprising since cities play an enormous economic role in countries' prosperity (Kogler et al. 2016). In the EU, 271 metro regions hold 59% of the population, create 62% of all employment, and generate 68% of GDP (European Commission 2016b). However, cities are far more than mere centers of population, economic activity, and employment. Almost all patents and other measures of new products and processes in business are produced in cities (Marceau 2008b). As nations' innovation hubs, cities are the engines of a knowledge-based economy, shaping technological change and economic growth (Johnson 2008; Kogler et al. 2016).

Besides elaborating on the economic role of cities and the "plain connection" between innovation and cities (Shearmur 2012), the vast part of current research is concerned mainly with the "smart city" and focuses on the entire economic role of cities. In this broader context, innovation is perceived as one of the three levers of cities' competitiveness (Sáez and Periáñez 2015) and therefore a main aspect of so-called "smart economies" (Dameri 2017). The smart economy concept and theory are the result of knowledge-intensive and creative strategies aimed at enhancing the effectiveness, environmental considerations, and innovative capacity of cities

(Vinod Kumar and Dahiya 2017). In this regard, only a few studies have tested the isolated influence of single factors on the innovative capacity of cities. Predominantly, although not exclusively, these factors are:

- Globalization (Eger 2012);
- Agglomeration (Simmie 2001);
- Urbanization (Vinod Kumar 2017; Vinod Kumar and Dahiya 2017);
- Social dynamics of city regions and migrant and ethnic diversity (Andrew 2014);
- Availability of "hard” production factors and non-material production factors (Caragliu et al. 2016);
- Knowledge base of a city (Kogler et al. 2016; Zitek and Klimova 2016; Makkonen and Weidenfeld 2016);
- Creation, availability, and distribution of human capital (Cowling and Lee 2017; Kiuru and Inkinen 2017);
- Contribution of risk-loving and innovative individuals (Caragliu et al. 2016);
- University–industry–government relations (Couchman et al. 2008);
- Attractiveness for new businesses and investments (Sáez and Periáñez 2015);
- Innovation platforms (Anttiroiko 2016);
- Benefits from partnerships (Atkinson 2013);
- Specialization patterns of inventive activities (Kogler et al. 2016);
- Relevance of marketing systems (Briggs 2009).

In addition, further studies attempt to test the influence of various city characteristics on the innovative capacity of cities in the form of so-called innovation indexes. Wang and Gong (2016), for instance, propose an innovation evaluation index for Shenyang, a Chinese national innovation-oriented city. Derived from the European innovative scoreboard and the Silicon Valley index, it is composed of three interlinked dimensions (innovation system, innovation input, and innovation performance), with several so-called “third-level indicators” underlying each dimension. Sáez and Periáñez (2015) propose another index, the urban competitiveness index that benchmarks the competitiveness of European cities as locations for businesses and in terms of their ability to attract investment. This index also consists of three dimensions not exclusively dedicated to innovation measurement, although one dimension focuses on an innovation construct consisting of ten indicators.

Besides these “academically perceptible” indexes, some rather practical indexes are to be found throughout the internet, such as the Regional Innovation Index calculated by the European Commission. Its aim is to help European cities learn from each other by comparing the performance of cities based on 12 indicators taken from the Regional Innovation Scoreboard (European Commission 2016a). Another example of measuring the impact of regional innovation policy is the Innovation Report 2009 of the German federal state of North Rhine-Westphalia (Fertig et al. 2010). Starting from the set of indicators of innovation formerly introduced in the innovation reports 2006–2008, the Innovations Report 2009, in a first step, selected key indicators as subject for update and reinterpretation. The position of North Rhine-Westphalia was analyzed in comparison with the federal average as well as with the federal states of Bavaria and Baden-Wuerttemberg. The goal was to consolidate the whole collection of indicators into a manageable set of core indicators, for which contemporary data were indeed available, so that an updated summary and assessment of the genuine potential for innovation in North Rhine-Westphalia became possible. In so doing, North Rhine-Westphalia was engaging in an approach to regional innovation policy measurement not previously used in Germany.

3 Making Use of Proven Concepts from the National Level

However, all of these innovation evaluation indexes propose a calculation method for the innovative capacity of cities only. They do not provide the theoretical basis for setting the right innovation parameters within innovation policies. This step explaining the results on the basis of the knowledge gained from the theory of path dependence is rarely to be found in LIS literature. The research work done by Martin and Simmie (2008) tends in this direction and, in the first instance, helps in understanding the different historical economic trajectories followed by different cities. The authors hold that path-dependent development of new technologies or industrial sectors within urban economies happens in four phases, each of which depends on the nature and interactions of a city's local innovation system combined with the capacity to absorb new knowledge.

In keeping with the wish for understanding the factors that shape the processes of innovation in cities, we propose the transition of proven concepts on innovative capacity from the national level to cities, as they have already reached a high level of sophistication (Acs et al. 2016).

3.1 Framework: Underpinnings of the Proposition

Proksch et al. (2017) have proposed an innovative methodology for identifying the pathways to success for 17 European countries using a comparative method. As a result of their analysis, those authors identified different paths leading to a high innovative capacity on the national level. These paths were translated into innovation strategies. Rather than a single strategy, different strategies with the same outcome exist, thus allowing countries to choose the appropriate strategies on the basis of their preconditions. The framework of Proksch et al. (2017) might be a good fit to city cases for the following reasons:

- It is a novel framework that does not focus on showing the significance of single determinants on innovative capacity but instead analyzes the combination of different factors.
- The framework is based on the Furman et al. (2002) model of innovative capacity and its applicability has been successfully proven within various innovation studies (Sun and Grimes 2016).
- On the basis of the results (different strategies) recommendations for policy improvement can be expediently derived.
- It overcomes the limitations of regression analysis, which most of the empirical innovation capacity

studies have to cope with.[2]

- It brings the advantages of fuzzy set qualitative comparative analysis (fsQCA) (Ragin 1987, 2000, 2008) to city studies.[3]

Thus, the article at hand builds the foundation for transferring the methodology used by Proksch et al. (2017) to European cities. For this purpose, understanding the fundamentals of the underlying Furman et al. (2002) model is crucial.

According to Furman et al. (2002), the innovation ecosystem of countries can be reflected and measured by determinants that can be grouped into three categories: the common innovation infrastructure, the cluster-specific environment for innovation, and the quality of their linkage. The authors hold that the interplay among the three categories reflects the overall innovative performance of an economy. Taking into account the so-called Porterian Cluster (Porter 1990) and also the Idea Production Function (Porter and Stern 2000), they define these categories as follows (Furman et al. 2002, pp. 905–907):

- *The Common Innovation Infrastructure* reflects the cumulative technological sophistication, human capital, and financial resources available for R&D activity, resource commitments, and policy choices (e.g., investments in education and training, intellectual property protection, openness to international trade, R&D tax policies).
- *The Cluster-Specific Environment for Innovation* focuses on the microeconomic environment present in a nation's industrial clusters, comprising cluster-specific circumstances, investments, and policies (e.g. R&D expenditures funded by industry; relative concentration of innovative output in high-tech patent classes).
- *The Quality of Linkage* represents the relationship between the common innovation infrastructure and industrial clusters (e.g., R&D expenditures performed by universities, venture capital investments). "The strength of linkages influences the extent to which the potential for innovation induced by the common innovation infrastructure is translated into specific innovative outputs in a nation's industrial clusters, thus shaping the realized rate of national R&D productivity" (Furman et al. 2002, p. 907).

[2] As laid out in detail in Proksch et al. (2016, p. 4).

According to Stern (2014, p. 47),

> clusters are the fulcrum around which a region [and its cities in the center of local innovation systems] realize the potential from its innovative and entrepreneurial capacity. Clusters shape the potential to develop and commercialize new technology and scale new businesses for global impact.

In this sense, clusters and linkages allow regions and cities to focus and prioritize innovation in terms of their comparative advantage. Hence, on that basis the validity of this taxonomy for city cases, notwithstanding the fact that it was formerly introduced by Furman et al. (2002) in a national context, can be considered as given.

The outcome of the whole construct is measured on the basis of patents as a consistent country-specific indicator of the level of commercially valuable innovative output. However, measuring the output of innovation on the basis of patent statistics has been quite controversially discussed in innovation science for decades (Acs et al. 2002; Griliches 1990; Pavitt 1988; Roper and Hewitt-Dundas 2015). Nevertheless, the suitability of patents as a valid measure of cities' innovation outcome has been tested and confirmed. According to Kogler et al. (2016, p. 1), "patents provide a wealth of information to analyse the knowledge specialization at specific places, such as technological details and information on inventors and entities involved …." The European City Report argues along similar lines, stating that "the innovative capacity of cities is underlined by the number of patents per inhabitant" (European Commission 2016b, p. 61). Hence, we rely on patents as outcome measure and thereby ensure closeness to the original model and its transferability.

However, Proksch et al. (2017) and the original model differ regarding the *Contributing and Related Outcome Factors*. These were initially introduced to the model as "alternative output measures…that are less comparable across countries and likely to be less closely linked to the level of…innovative output" (Furman et al. 2002, pp. 912–913). In contrast to this approach, Proksch et al. (2017) consider these indicators as proxy-determinants within a quasi-fourth category, complementing individual determinants of the other three categories which capture contexts that are partially difficult to measure. For instance, the economic success of a city can be measured by the amount of GDP, a variable that is not in itself directly relevant but that serves in place of this hardly graspable condition. These complementing determinants (e.g., real GDP, number of scientific publications, non-residential capital stock) thus become part of the modeled innovation ecosystem, which is a far more constructive approach than using them as sensitivity measures against the outcome variable (patents). The proposed approach is in line with OECD standards for collecting and interpreting innovation data (OECD 2005).[3] Transferring the entire taxonomy to city cases results in the generic model depicted in Figure 1.

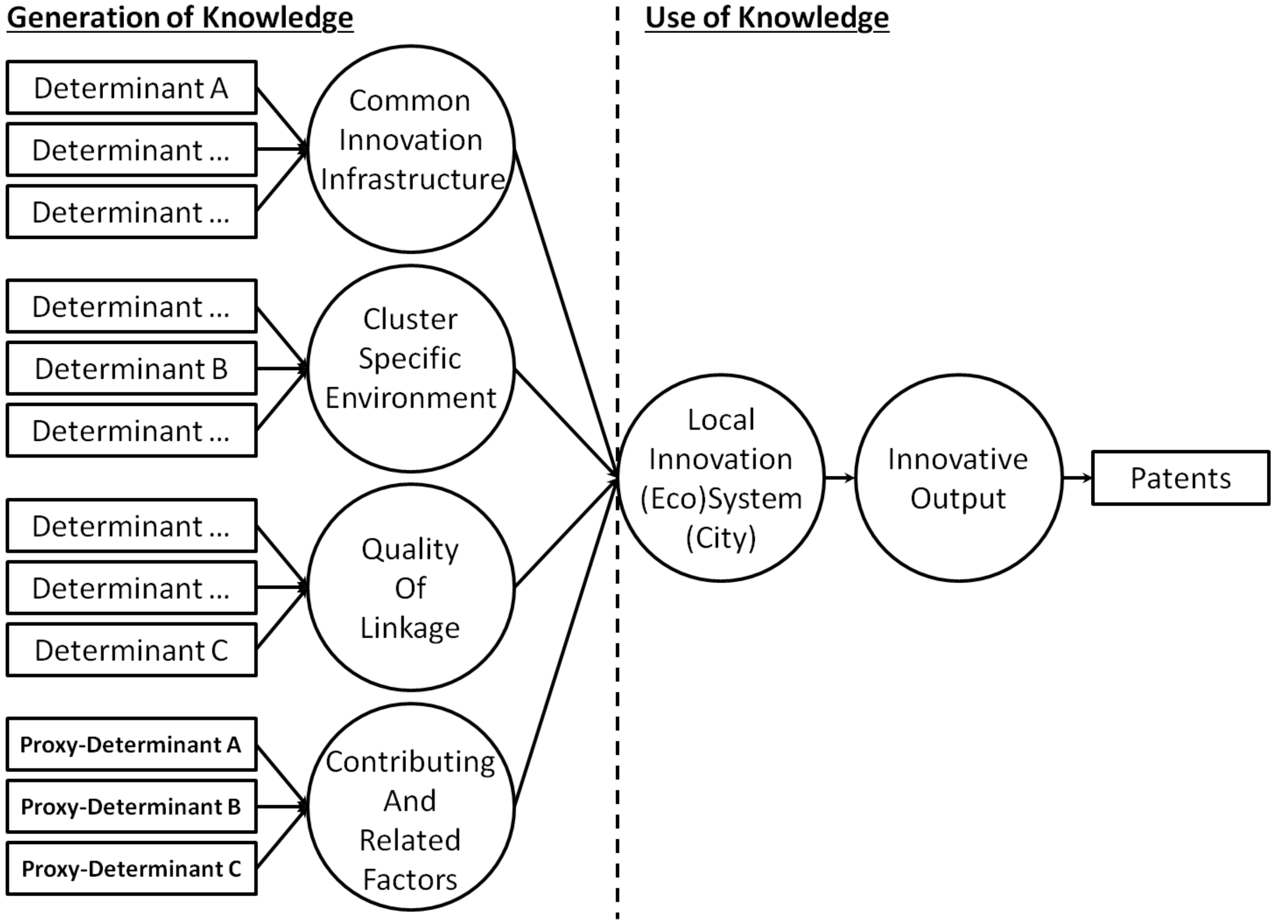

Fig. 1. Generic model: The innovative capacity framework transferred to cities (Furman et al. 2002).

3.2 Method and Data: The Search for Appropriate Determinants

Validating and enhancing the determinants per category from a city perspective is the critical criterion for the transferability of the innovative comparative methodology to identify the pathways to success. In this undertaking, not only the academic work of the past 20 years is scrutinized, but also several practical studies in this field. Table 1 depicts the in scope European (secondary) capital cities and the respective academic articles which, at least to a certain extent, deal with the determinants of innovative capacity.[4]

[3] The applicability of the Oslo Manual is not limited to OECD member states, as it was jointly developed with Eurostats.
[4] The scoping constraint was whether at least some studies on the respective city's innovation ecosystem were available, regardless of their academic or practical backgrounds.

Country	City/Region	Articles
Czech Rep.	Various	Zitek and Klimova (2016)
Denmark	Copenhagen	Makkonen and Weidenfeld (2016)
Estonia	Tallinn	Makkonen and Weidenfeld (2016)
Finland	Helsinki	Anttiroiko (2016); Makkonen and Weidenfeld (2016)
	Oulo	Anttiroiko (2016)
	Tampere	Anttiroiko (2016)
France	Grenoble	Kogler et al. (2016)
	Marseille	Kogler et al. (2016)
	Paris	Pin and Galimberti (2016); Kogler et al. (2016); Simmie (2001)
	Toulouse	Kogler et al. (2016)
Germany	Dortmund	Athey et al. (2008)
	Stuttgart	Simmie (2001)
Italy	Genoa	Dameri (2017)
	Milan	Pin and Galimberti (2016); Simmie (2001)
Netherlands	Amsterdam	Dameri (2017); Simmie (2001); Kogler et al. (2016)
	Eindhoven	Kogler et al. (2016)
	Rotterdam	Kogler et al.(2016)
	The Hague	Mayer et al. (2016)
	Wagenigen	Kogler et al. (2016)
Poland	Various	Nijkamp (2016)
Sweden	Malmö	Makkonen and Weidenfeld (2016)
Switzerland	Bern	Mayer et al. (2016)
United Kingdom	100 largest (ex. London)	Cowling and Lee (2017)
	Cambridge	Viitanen (2016)
	Coventry	Athey et al. (2008)
	Dundee	Athey et al. (2008)
	Leeds	Devins et al. (2016)
	London	Athey et al. (2008); Simmie (2001)
	Newcastle	Couchman et al. (2008)
	Reading	Athey et al. (2008)
Various	Various	Capello et al. (2012); Sáez and Periáñez (2015)

Table 1 European (secondary) capital cities, country assignments, and coverage included within articles.

In addition to these academic works, two practical studies are considered to be further knowledge sources with respect to the determinants of the national innovative capacity of the above-mentioned cities. These are the Regional Innovation Scoreboard (European Commission 2016a) and the European City Report (European Commission 2016b). These two studies provide a rich source of information based on time series and longitudinal data. Besides the comparison of certain variables, these reports also offer examples of policies that have worked. To this extent, all articles and reports together provide considerable information on cities' innovation ecosystems in general and, in more detail, on the economic and political dynamics as well as the policy regime inside the systems. Combining all these perspectives into an analysis allows for identification of the particular urban factors that support or impede innovative activity of cities, as they are critical to determining the pathways leading to a high innovative capacity.

4 Results

On the basis of the aforementioned sources, we propose a consolidated set of 43 determinants reflecting cities' local innovation ecosystems. All determinants of this set are classified and categorized along the taxonomy of Proksch et al. (2017). Overall, these variables illustrate the interplay of firms, markets, assets, institutions, and networks within a systemic architecture designed for knowledge production, consumption, and commercialization. In this sense, most of the established determinants introduced by Furman et al. (2002), extended and updated by Proksch et al. (2017), are also valid for cities' innovation ecosystems. Only the *intellectual strength of protection for IP* and *openness to international trade* indicators seem to be conditions attributed solely to the country level and therefore not transferable to the city level.

Further determinants have been added to create an image as holistic as possible of cities' innovation ecosystems. At its core, the enhancement builds on both the basic characteristics of cities (spatial concentration and agglomeration) and major trends influencing a city's development (globalization, digitalization, and demographical change). Appendix 1, Table 1 offers a list of the proposed city-level determinants together with an in-depth explanation for each item. The influence of these determinants on the outcome variable (patents) needs to be tested, regardless of their treatment within other studies of national or sub-national innovation systems. The suggested comparative method (fsQCA) would provide such a test, as the resulting pathways consist of only those antecedent conditions that have had a measurable impact on the outcome condition (patents). In this context, respective data sources per determinant have to be identified. Even though data availability is a well known issue in innovation system research, scholars should exclude variables sparingly, as exclusion might lead to an undervaluation of the respective category within the whole construct.

4. 1 Discussion and Implications

Although certain determinants can be used to reflect and understand a city's innovation ecosystem, the process of innovation in cities remains a complex phenomenon. Naturally, cities have evolved differently, and thus have different preconditions for future growth. However, regardless of their developmental trajectories, competitiveness and innovative capacity are somehow comparable among cities. Various benchmarking studies offer an elevated view of the innovative performance of cities, assigning them to well known groups such as innovation leaders, innovation followers, moderate innovators, and modest innovators (see, for example, European Commission 2016a; 2thinknow 2017). Consequently, development, or indeed nondevelopment, is path-dependent. Different innovation strategies with the same outcome exist, allowing cities to define appropriate policies in line with their specific preconditions. Evolutionary economics argues that international knowledge exchange and the oligopolistic power exercised by firms are the cornerstones for unleashing innovative activity for the first time and defending innovation ecosystems from becoming locked into entrenched paths in the long run, thus maintaining the preconditions for a steady growth of all factors concerned with innovative capacity (Simmie 2001). In this sense, path dependence can be understood as means of explanation for different levels of innovative capacity. Following Porter (1990), one approach would be to "focus on the attributes that lead to the establishment of competitive industrial production clusters" (Simmie 2001, p. 42). Another approach, recommended by Krugman (2002), would be to emphasize "the importance of trade in producing external economies and agglomeration" (Simmie 2001, p. 42). In the end, no particular approach is right or wrong. Innovation emanates from both endogenous and exogenous factors, whose effect on innovative capacity is either increasing (e.g., the presence of key technologies) or decreasing (e.g., a lack of specialists owing to demographic change as well as unresolved questions of business succession). Innovative ecosystems of cities cannot be treated and analyzed hermetically, since no clear-cut innovation ecosystem exists in cities. As we know today, innovative capacity and entrepreneurial capacity are inextricably linked. Hence, the system's boundaries are dynamic rather than static. The objective, however, is to understand innovation in cities as a crucial economic power promoting countries' economic growth and development. Ultimately, institutional innovation, political innovation, and technical innovation are of equal relevance. To this end, partnerships between local places and the national government are critical prerequisites to inform the development of innovation policy from different perspectives, giving consideration to innovative inputs such as the concentration of knowledge workers as well as outputs such as new products, services, or even firms.

Fixing certain determinants to reflect a city's innovation ecosystem, even if they are broadly selected to capture the above-mentioned links, inevitably leads to the analysis of a *closed* system. However imperfect, such a system at least illustrates urban planning and evaluation processes attributed to innovative capacity and reveals the connections between different types of innovation. The results of a pathway analysis would enable policymakers responsible for urban development and sub-regional stakeholders involved in strategy implementation to identify promising areas of further knowledge development and smart specialization. Knowledge regarding the innovation trajectories for different city types (capital-metro, other-metro, nonmetro) is critical to successfully transforming the parameters of all local innovation ecosystems within a country into institutional arrangements on the upper levels.

4.2 Limitations and Future Research

The above observations and the knowledge about the right city parameters lead to the conclusion that the framework proposed by Proksch et al. (2017) is transferable to city cases. Taking the proposed 43 parameters as a starting point, further quantitative research, ideally based on a comparative method, could determine the pathways leading to a high innovative capacity in cities. However, not all facets of innovation in cities can be reflected by variables. The well-known issues regarding patent statistics as a measure of innovative capacity are just the tip of the iceberg. Few studies offer fully tested determinants, and the academic quality of these works differs. Datasets largely build on estimations and algorithms, which from a methodical perspective do not result in reliable real-world observations. Hence, a major challenge for future quantitative research in this field will be finding appropriate data sources. A source comparable to Eurostats (Eurostats 2017) on the country level is not presently available for cities. However, the European Union has recently launched an internet-based Urban Data Platform (European Commission 2017) offering a rich load of determinants attributed to city comparison that might be a promising foundation for future research in this field. As similar resources may become available before long, covering different geographies (e.g., cities within OECD countries), the intelligence of this article might be expandable to pan-European settings soon.

Appendix 1

Table 1. List of the proposed city level determinants together with explanations

Variable Name	Numerator	Denominator	Rationale	Included in Proksch et al. (2016)	Based on
Outcome variable					
International patents (per million inhabitants)	Patent applications to the European Patent Office by priority year, i.e. the year of the first international filing of a patent	Inhabitants (millions)	The capacity of firms to develop new products determines their competitive advantage. One indicator of the rate of new product innovation is the number of patents (European Commission 2016a). The innovative capacity of cities is underlined by the number of patents per inhabitant (European Commission 2016b).	Yes	(Kogler et al. 2016; European Commission 2016b, 2016a)
Quality of the common innovation infrastructure					
GDP (per capita)	Gross domestic product (purchasing power parity)	Inhabitants	This is indicator denotes whether a city is more or less economically successful (Sáez and Periáñez 2015).	Yes	(Makkonen and Weidenfeld 2016; Sáez and Periáñez 2015)
Stock of international patents	Cumulative patents	Time period	This indicator reflects the state of the cities' knowledge economy and relatedly the intensity of knowledge linkages and networks within regions (Makkonen and Weidenfeld 2016).	Yes	(Makkonen and Weidenfeld 2016; Kogler et al. 2016)
Population	Total inhabitants per 1 January	Per year	Population is an attractor of company head offices and generally has important historical and cultural legacies that may affect an individuals' locational decision (Cowling and Lee 2017).	Yes	(Cowling and Lee 2017)
People born abroad (%)	Share of people born abroad (another country)	Inhabitants	This is a measurement of diversity and independency as part of socio-cultural (or societal) development (Makkonen and Weidenfeld 2016). Diversity is important in attracting talented workers who might prefer tolerant areas (Cowling and Lee 2017).	No	(Makkonen and Weidenfeld 2016; Cowling and Lee 2017)

Educational attainment rate (%)	Share of inhabitants with tertiary educational attainment	Inhabitants	This is a general indicator of the supply of advanced skills. It is not limited to science and technical fields, because the adoption of innovations in many areas, in particular in the service sectors, depends on a wide range of skills (European Commission 2016a)**.** The basic talent measure is simply the proportion of the adult population with an undergraduate degree and above (Cowling and Lee 2017)**.**	No	(Makkonen and Weidenfeld 2016; European Commission 2016a; Cowling and Lee 2017; Sáez and Periáñez 2015)
Students	Number of enrolled students	Annual average	Additional measure of talent. Included are students across all types of tertiary education.	No	(Cowling and Lee 2017; Sáez and Periáñez 2015)
Public institutions that support innovation	Number of public institutions including science parks	-/-	A number of public institutions and actors support innovation—notably universities, individual change agents and some economic development agencies (Athey et al. 2008). As with science parks, there may be templates and exemplars that are promoted by policymakers, academics, and consultants but specific local configurations of institutions and governance relations lead to different outcomes (Couchman et al. 2008).	No	(Athey et al. 2008; Couchman et al. 2008)
Employment in medium-high and high-tech manufacturing and knowledge-intensive services (%)	Share of employed persons in the medium-high and high tech manufacturing sectors	Total workforce including all manufacturing and service sectors	The share of employment in high technology manufacturing sectors is an indicator of the manufacturing economy that is based on continual innovation through creative, inventive activity. The use of total employment gives a better indicator than using the share of manufacturing employment alone, since the latter will be affected by the relative decline of manufacturing in some countries. Knowledge-intensive services can be provided directly to consumers, such as telecommunications, and provide inputs to the innovative activities of other firms in all sectors of the economy. The latter can increase productivity throughout the economy and support the diffusion of a range of innovations, in particular those based on ICT. (European Commission 2016a)	Yes	(Zitek and Klimova 2016; European Commission 2016a; Sáez and Periáñez 2015)

Aggregate R&D expenditures (%)	Share of R&D expenditures, cross-sectors (government, higher education, business sector)	Gross Domestic Product	See *Private R&D Funding* and *Percentage of R&D performed by universities.*	Yes	(Zitek and Klimova 2016; Makkonen and Weidenfeld 2016; European Commission 2016a; Sáez and Periáñez 2015)
Non-R&D innovation expenditures (%)	Share of total innovation expenditure, excluding intramural and extramural R&D expenditures	Total turnover (both innovators and non-innovators)	This indicator measures non-R&D innovation expenditure as percentage of total turnover. Several of the components of innovation expenditure, such as investment in equipment and machinery and the acquisition of patents and licenses, measure the diffusion of new production technology and ideas (European Commission 2016a).	No	(European Commission 2016a)
Number of firms	Number of registered businesses	Annual net number	Firms are the key innovators, and cities support innovation by firms in a number of ways (Athey et al. 2008).	No	(Athey et al. 2008)
Locational policy	Strength of locational policy	Score value based on survey	Strength of locational policy environment to support innovation, with regard to: • adapting national policy frameworks; • attracting funding (incl. council tax bill); • inducing cross-sectoral clusters; • incentivizing collaboration.	No	(Mayer et al. 2016; Cowling and Lee 2017; Viitanen 2016)
Higher education share (%)	Share of public spending on higher education	Gross Domestic Product	Measure of the intensity of human capital investment. A high level of *higher education share* creates a base of highly skilled personnel upon which ficre and other institutions across the economy can draw, both for formal R&D activities as well as other innovation-related activities (Furman et al. 2002).	Yes	(Makkonen and Weidenfeld 2016)
Cluster-specific innovation environment					
Private R&D Funding (%)	Share of R&D expenditures in the business sector	Gross Domestic Product	This indicator captures the formal creation of new knowledge within firms. It is particularly important in the science-based sector (pharmaceuticals, chemicals and some areas of electronics) where most new knowledge is created in or near R&D laboratories (European Commission 2016a).	Yes	(Zitek and Klimova 2016; European Commission 2016a)

Specialization degree (%)	Share of high-tech patent applications to the EPO by priority year	Total patent applications to the EPO by priority year	An essentially positive relationship exists between specialization in high-tech sectors and innovation performance (Capello et al. 2012). Furthermore, specialization degree is a measure capturing an important consequence of cluster dynamics, the relative specialization of an economy in specific technologies fields (Furman et al. 2002).	Yes	(Kogler et al. 2016; Capello et al. 2012)
Head offices (%)	Share of company headquarters	Number of registered businesses	The presence of company headquarters can be a lever of innovation, not only because of R&D departments but also because the filing address of patents is generally a company's head office, regardless patents' point of origin.	No	(Sáez and Periáñez 2015)
Firms innovating in-house (%)	Share of firms with in-house innovation activities	Number of registered businesses	This indicator measures the degree to which firms that have introduced any new or significantly improved products or production processes have innovated in-house. Innovative firms with in-house innovation activities have introduced a new product or new process either in-house or in combination with other firms. The indicator does not include new products or processes developed by other firms (European Commission 2016a).	No	(European Commission 2016a; Viitanen 2016)
Marketing or organizational innovators (%)	Share of firms that introduced a new marketing innovation and/or organizational innovation to one of their markets	Number of registered businesses	The Community Innovation Survey mainly asks enterprises about their technological innovation. Many enterprises, in particular in the services sectors, innovate through other non-technological forms of innovation. Examples of these are marketing and organizational innovations. This indicator captures the extent that firms innovate through non-technological innovation (European Commission 2016a).	No	(European Commission 2016a)
Product or process innovators (%)	Share of firms that introduced a new product or a new process to one of their markets	Number of registered businesses	Technological innovation, as measured by the introduction of new products (goods or services) and processes, is a key ingredient to innovation in manufacturing activities. Higher shares of technological innovators should reflect a higher level of innovation activities (European Commission 2016a).	No	(European Commission 2016a)

Specialization in technology (advanced manufacturing and knowledge intensive services) (%)	Proportion of the total business stock that can be classified as operating in knowledge based industries	Number of registered businesses	Regions hosting large urban areas are the most innovative, and this statement is reinforced in regions characterized by specialization in knowledge-intensive services. The simultaneous presence of advanced manufacturing and knowledge-intensive service activities generates synergic effects, fostering innovative performance (Capello et al. 2012).	No	(Cowling and Lee 2017; Capello et al. 2012)
Commercial premises occupation (%)	Occupancy rate of commercial premises	Area of commercial premises (sqm)	Business space is a critical urban asset in supporting innovation. Both underutilization and full utilization are important indicators with regard to factor availability and suitability.	No	(Simmie 2001; Athey et al. 2008)
Quality of linkages					
R&D performed by universities (%)	Share of R&D expenditures in the higher education sector	Gross Domestic Product	R&D expenditure represents one of the major drivers of economic growth in a knowledge-based economy. Trends in the R&D expenditure indicator provide key indications of the future competitiveness and wealth of a region. Research and development spending is essential for making the transition to a knowledge-based economy as well as for improving production technologies and stimulating growth.	Yes	(Zitek and Klimova 2016)
Venture capital Performance	Volume of venture capital investments	-/-	A given common innovation infrastructure results in a more productive flow of innovative output when there are mechanisms or institutions, such as … established funding sources for new ventures, which encourage the commercialization of new technologies in particular clusters. (Furman et al. 2002) Included are private equity transactions across these development phases: acquisition, preparation, founding and post-formation.	Yes	(Simmie 2001)
New businesses registered (%)	Proportion of new firms	Number of registered businesses	One measure of openness and vibrancy is the inflow of new entrepreneurial businesses as entrepreneurs start new firms to take advantage of perceived new market opportunities and gaps in the provision of goods and services (Cowling and Lee 2017).	Yes	(Cowling and Lee 2017)

Incubation environments per startup (%)	Number of incubation environments (accelerators, incubators, idea labs, co-working spaces, brain trusts, etc.)	Number of new businesses registered	Another innovation ecosystem element is in the incubation environments, which provide essential, professional growth services for startups and growing SMEs. These incubation environments are physical locations where a selected group of young companies receive professional support for their management concerns. Included are all accelerators, incubators, idea labs, co-working spaces and brain trusts.	No	Own interpretation based on: (Viitanen 2016)
Collaborative networks	Number of collaborative projects, programs or platforms (either digital or analogue)	-/-	Projects, programs or platforms promoting collaborative user-driven methods and tools for improving the real world development of products and services. Typical examples of these platforms include interconnected parts of user-driven cities, real-life experimentation sites on streets, open system platforms for developing mobile applications (with users), and internet-based, end-user beta-testing environments to engage users in an early-stage R&D process. (Viitanen 2016)	No	(Anttiroiko 2016; Athey et al. 2008; Viitanen 2016)
Internet users (%)	Share of people who regular use internet	Population	The internet is a ubiquitous access point to innovation and creativity platforms as well as to economic opportunities.	No	(Sáez and Periáñez 2015)
Public-private partnerships	Number of institutionalized innovation partnerships	-/-	These partnerships reflect the shared public/private interest of planning innovation activities to support the creation of intellectual property and cross-sectoral collaboration together (Viitanen 2016).	No	(Viitanen 2016)
Innovative firms collaborating with others (%)	Share of firms with innovation co-operation activities.	Number of registered businesses	This indicator measures the degree to which firms are involved in innovation co-operation. Complex innovations often depend on companies' ability to draw on diverse sources of information and knowledge, or to collaborate on the development of an innovation. This indicator measures the flow of knowledge between public research institutions and firms, and between firms and other firms. Firms with co-operation activities are those that have had any co-operation agreements on innovation activities with other enterprises or institutions.	No	(European Commission 2016a; Athey et al. 2008)

Contributing and related outcome factors					
Publications in academic journals	Number of scientific publications	Inhabitants (Million)	Complement to *stock of international patents.* Scientific publications indicate the knowledge infrastructure (science base) of a city.	Yes	(Makkonen and Weidenfeld 2016; Pin and Galimberti 2016)
High ranked universities	Number of high ranked tertiary education institutions	-/-	Complement to *educational attainment rate (%).* Research has highlighted considerable difference in labor markets between university and non-university cities. Some cities have universities that were founded hundreds of years ago and are woven into the culture of a city as well as being a major actor in the socio-economic system of a city (Cowling and Lee 2017). Especially cities hosting universities that enjoy a strong reputation in the offered scientific disciplines might be relevant for the acquisition of both new talent and high qualified labor (Makkonen and Weidenfeld 2016).	No	(Makkonen and Weidenfeld 2016; Cowling and Lee 2017)
Spoken languages	Number of foreign languages spoken	-/-	Complement to *educational attainment rate (%).* Language barriers restrict international labor mobility.	No	(Simmie 2001)
Total workforce including all manufacturing and service sectors	Number of persons engaged	Annual average	Complement to *employment in medium-high and high-tech manufacturing and knowledge-intensive services*. Innovative capacity depends in part on the labor force of an economy.	Yes	(Sáez and Periáñez 2015)
Job change rate	Mean length of stay in the same job	Time period	Complement to *firms innovating in-house (%).* This indicator measures the duration of transferring exclusive knowledge among firms and organizations driven by job changes (i.e. the “rotation” of labor).	No	Own interpretation based on: (Simmie 2001)
Gross Domestic Product	Real GDP (purchasing power parity)	-/-	Complement to *GDP per capita.* Measure of economic development.	Yes	(Makkonen and Weidenfeld 2016)
Foreign direct investments	Non-residential capital stock	-/-	Complement to *GDP per capita.* Measure of economic development.	No	(Makkonen and Weidenfeld 2016)
Daily commuters (%)	Share of daily commuters (inbound and outbound)	Total workforce including all sectors	Complement to *head offices (%).* This indicator signals how well the labor markets of the cities and regions are integrated.	No	Own interpretation based on: (Makkonen and Weidenfeld 2016)

Dependency ratio (%)	Share of people in age groups 0-14 and 65+	Population in the working age groups 15-64	Complement to *population*. This indicator is used to measure the pressure on productive population.	No	(Makkonen and Weidenfeld 2016)
Satisfaction	Level of inhabitants' satisfaction	Score value based on survey	Complement to *population.* Quality of life and place, aggregated measure consisting of the following sub-categories: • Agglomeration economies (e.g., population density) • Attractive environments (e.g., CO_2 emissions) • High quality facilities (e.g., public transport) • Cultural diversity (e.g., arts, cuisine, religion) • Welfare (cost of living) • Safety (crimes involving life and death) • Healthcare infrastructure (e.g., hospitals)	No	(Simmie 2001; Makkonen and Weidenfeld 2016; Cowling and Lee 2017; Sáez and Periáñez 2015)
Ethnic groups	Number of different ethno-linguistic groups		Complement to *share of people born abroad (%).* The measure of diversity refers to the ethnic diversity of the population. (Cowling and Lee 2017)	No	(Cowling and Lee 2017)
Market share (%)	Share of exports in medium-high and high-tech manufacturing industries	Total exports	Complement to *specialization degree (%).* The indicator measures the technological competitiveness of a region, i.e., its ability to commercialize the results of research and development (R&D) and innovation in the international markets. It also reflects product specialization. Creating, exploiting and commercializing new technologies are vital for the competitiveness of a region in the modern economy. Medium and high technology products are key drivers of economic growth, productivity and welfare, and are generally a source of high value added and well paid employment (European Commission 2016a).	Yes	(European Commission 2016a)

Sales of new-to-market and new-to-firm innovations (%)	Share of total turnover of new or significantly improved products	Total turnover of firms (both innovators and non-innovators)	Complement to *specialization in technology (advanced manufacturing and knowledge intensive services)(%.)* This indicator measures the turnover of new or significantly improved products to the firm as a percentage of total turnover. These products are not new to the market. Sales of new-to-the-firm but not new-to-the-market products are a proxy of the use or implementation of products (or technologies) already introduced elsewhere. This indicator is a proxy for the degree of diffusion of state-of-the-art technologies.	No	(European Commission 2016a)
Capital	Capital stock based on total financial assets	-/-	Complement to *VC performance* (funding sources).	Yes	(Simmie 2001)

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