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INNOVATION IN EUROPE

A Comparative Study

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Abstract

Innovation is one of the major factors of the country's development and wealth. It is generally accepted that economically strong countries can afford to dedicate more funds to research and development, and as such, the economy and innovation are highly interconnected. In addition, while a strong economy allows for more innovation, innovation is recognized as a driver of the economy. In the past decades, many attempts have been pursued to develop the best innovation measures and apply them to identify the most innovative states. The task proved to be difficult, mainly because of the complexity of the topic and a vast number of factors that can potentially contribute to the country's innovation performance.

Moreover, there is an ongoing discussion among experts regarding what innovation is, how to measure it, and what factors should be included in the evaluation framework. The aim of the current study looks at three main innovation indices and attempts to position all 28 European Union member countries in terms of innovation performance. Further, the study also attempts to compare the results of all three indices and discuss similarities and discrepancies which position the same country differently depending on the applied framework. The study is based on existing innovation performances such as the Global Innovation Index, the Bloomberg Innovation Index, or the Global Competitiveness Report. Bivariate analysis and simple data visualization techniques have been applied to reveal differences and similarities and to draw conclusions.

The study revealed that the European Union is generally very innovative, which is confirmed by high ranking positions of each of the European Union member states within all three innovation rankings. Further, performed bivariate analysis and data visualization show significant methodological discrepancies of all three frameworks, which result in different ranking outcomes. These innovation indices often play an essential role in national policy developments and are an indication of the country's status and prestige; as such achieving uniform or similar results despite applied framework is of high importance.

Keywords: innovation, comparison, Europe

Content

Abbreviations

et al.	et alii, Latin for “*and others*”
EU	European Union
GCI	Global Competitiveness Index
GDP	Gross domestic product
i.e.	id est, Latin for “*that is*”
IBM	International Business Machines
INSEAD	Institut Européen d'Administration des Affaires, French for "*European Institute of Business Administration*”
IQ	Intelligence quotient
L.P.	Limited partnership
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
Ph.D.	Doctor of philosophy
R&D	Research and development
SPSS	Statistical Package for the Social Sciences
U.S.	United States [of America]
USD	United States Dollar
WEF	World Economic Forum
WIPO	World Intellectual Property Organization

Definitions

Innovation	implementation of new products or services which result in socio-economic gains
Index / Quotient	a degree or amount of a specified quality or characteristic
Intellectual property	intangible property that is the result of creativity, such as trademarks, patents, trade secrets, copyrights, etc.

Introduction

Competition arises when at least two parties strive for a goal that cannot be shared. Just like companies compete with each other to be a market leader, nations compete to provide the best possible business environment and become economic leaders. Innovation is a vital component in a country's competitiveness globally. Traditionally, for centuries, Europe used to be a leader in innovation and trends development (Ciocanel and Pavelescu, 2015, Taalbi, 2017, Mokyr, 2018). However, with the emergence of the U.S. as a global leader and superpower in the late 19^{th} century, the innovation leadership shifted across the Atlantic. The creation of Silicon Valley in the 1970s only strengthened the U.S. position as an innovation leader (Mervis, 2013, Wonglimpiyarat, 2006, Ooms et al., 2015). While the U.S. and Europe continued their innovation lead race, other economies emerged and joined the competition (Hu et al., 2017).

Japan was and continues to be one of the leading innovation economies on a global scale. While Japan has a strong tradition in innovation, this strengthened during and after World War II, (Luo and Triulzi, 2018, Huff and Angeles, 2011), other Asian economies joined only recently. Innovation in Singapore, South Korea, Taiwan, and Malaysia emerged mainly due to the shift of manufacturing power from the West to the East and was driven initially by cheap labour (Huff and Angeles, 2011). However, profits from immense manufacturing activities allowed the governments of those countries to divert some of the revenue and invest it into innovation, education, and generally improve the state of the country's competitiveness, this in return, allowed for the enhancement of the quality of life and wellbeing. Whether directly or indirectly, innovation was a driving force for many Asian economies (National Research Council, 1988).

In the last decade or two, China underwent a similar transformation. From a country that faced food security issues and massive poverty, China rapidly became a global manufacturing super house, mainly due to cheap labour and the availability of the workforce (McKinsey & Company, 2015). New revenue streams allowed China to follow a similar path as other regional leaders and divert and diversify its economy into more innovative and technology-oriented industry sectors.

The growth of innovation in Asia and existing competition from the U.S., quickly dethronized many European economies from their innovation leadership positions. Since Europe has been putting a lot of effort and resources to keep and improve its innovation performance.

Innovation is one of the key interests of the European Commission (European Commission, 2018). The Commission acknowledges the role of innovation in the overall competitiveness and is implementing policies, frameworks, and programs that support innovation and increase investment in research and development. Significant focus is also given to converting research into novel products, goods, services, or processes that will benefit the region and future generations.

Innovation is often linked to boosting job numbers and revenue, and as such, innovation became a goal for many governments and businesses. Countries that show innovation track records can attract more talent and new business ventures, which results in further innovation. Because of this, it is important to measure, and rank countries based on their innovation performance. Such a measure allows talents, companies, and investors to make a choice when selecting their next business destination. Becoming the most innovative nation or at least achieving high rankings is high on the agenda for many governments. Innovation, however, is difficult to measure, partly because it means different things to different groups, but also because assessing innovation at a country level is a difficult task by itself (Anadon et al., 2016, Edler and Fagerberg, 2017).

Over the last decade or so, several indices have been developed that aim to measure a country's innovation. Similarly, several prestigious innovation rankings have also been produced annually. The most referred rankings include the Global Innovation Index by INSEAD and the World Intellectual

Property Organization (WIPO), the Bloomberg Innovation Index by Bloomberg L.P., or the Global Competitiveness Report by the World Economic Forum (WEF). These three innovation rankings are the only global rankings that are produced annually. The credibility of authors and publishing organizations, as well as common references in media and literature, make these rankings mainstream.

Methodologies used by each of the rankings are different, and as such, the country's position in the ranking can differ significantly. Many scholars have tried to establish the best or most reliable way of measuring a country's innovation and predict future trends (OECD, 2010, OECD and Eurostat, 2018). However, a more uniform and systematic approach is required to measure, evaluate, and compare innovation performance, especially when dealing with complex and multivariable systems such as country (Blankley et al., 2006, OECD and Eurostat, 2018). The three rankings studied in the study tend to use different methodologies and give different results, and their methodologies often evolve and change over the years, which makes it difficult to compare innovation performance over a certain period of time.

The current research compares the three above mentioned innovation metrics and evaluates how innovation rankings position European Union member countries. Based on this initial evaluation and comparison, the study also shows that different indices and methodologies give different results, and as such, these innovation rankings may be inaccurate or only one of the rankings accurate. As such, the reader should consider them as a guiding measure and not the ultimate country's innovation position, since a '*true*' ranking does not exist. The study uses comparative methodologies and bivariate analysis to identify, quantify, and evaluate discrepancies between all three studied metrics. The study is relative since the results are not compared to the gold standard or baseline because such standards and benchmarks do not exist. As shown in later chapters of the thesis, the rankings do not convey inherent information about the country's innovation performance and are so to say relative.

The results of the thesis can not only contribute to our implications and problems of measuring innovation when it comes to large and multi-variate systems, such as states but can serve as a source of recommendations when shaping the directionality of the public policy and country's innovation roadmaps. Thus, the findings of the thesis are relevant from both policy and academic perspective. The outcomes of the work are also of relevance to the general public since these innovation measures are often followed annually by European citizens and are either a source of pride or disappointment of one's country position in the ranking. The thesis aimed at educating the general public that the innovation measures used to evaluate a country's innovation performance is not bulletproof; neither provide reliable outcomes. Instead, these measures are somewhat incomplete and flawed, and as such, the public should consider them as indicators or estimates rather than the ultimate innovation performance index.

The remainder of the thesis is organized as follows. Chapter 3 describes the methodological approach to answer research question based on the previous literature. The chapter also discusses the research gap. Chapter 4 provides an overview of results based on collected and visualized data with a brief description to further explain the meaning and relevance of the presented results. Chapter 5 is a discussion derived from the results presented in chapter 4. In the chapter, further meaning and relationships are identified, evaluated and critically discussed. Chapter 6 provides a summary of the research and links results with the research question, same time concluding the work. Chapter 7 discusses the potential for future considerations and for the continuation of this research beyond the scope and time limitations of the current study.

The reader should be aware that words ranking, metrics, framework, and index are considered synonymous in the context and are used interchangeably throughout the thesis text.

Previous research

The European Union Industrial Policy highlights the importance the industry plays for the European Union's competitiveness and innovation. According to data provided by the European Union, industry accounts for 80% of Europe's exports, while about 65% of private-sector research and development investment comes from manufacturing (European Committee of the Regions, 2017). Therefore, the EU strongly supports and encourages industrial modernisation, including the commercialisation of innovative products and services, industrial-scale application of innovative manufacturing schemes and technologies, and innovative business models.

Further, the study performed within the European Union showed that 79% of companies that introduced at least one innovation since 2011 experienced a turnover increase of over 25% by 2014. About 63% of companies with up to nine employees declared having introduced at least one innovation since 2011, in comparison to 85% of companies with 500 employees or more (European Commission, 2015).

A critical theory that directly relates to this current study is the concept of endogenous growth (Romer, 1994). Endogenous growth theory argues that economic growth is primarily the result of endogenous and not exogenous factors. Endogenous growth theory maintains that factors such as innovation, knowledge, development of new technologies, efficient and effective means of production, and investment in human capital are essential contributors to economic growth.

Endogenous growth proponents believe that improvements in productivity can be linked directly to enhanced innovation and more human capital investments. As such, proponents of endogenous growth theory advocate for government and private sector to nurture and invest in innovation initiatives as well as to offer various incentives and grant schemes for businesses and individuals to enhance innovation and creativity, leading to the development of new products and services and creation of intellectual property. (Howitt, 2010) The central argument of the endogenous growth theory is that in a knowledge-based economy, the spillover effects from investment in technology and people generate economic, social, and other benefits.

Nelson (1985) provides a wider scope on innovation in terms of product knowledge and organizational routines and their linkages to growth. Schumpeter's theory of creative destruction lends to the narrative of innovation-led booms (Emami-Langroodi, 2017).

Innovation as a process should be applied from a long-term perspective (Anadon et al., 2016, Edler and Fagerberg, 2017). Generally, innovation is not necessarily measured in time increments, i.e., weeks, months, years, but instead by the completion of assumed goals and milestones. Measuring innovation is never easy; there is always a number of factors to consider. Besides, innovation and its success can be seen differently by different stakeholders. Measuring innovation becomes even harder when weighing and measuring innovation of the entire country as opposed to measuring innovation of a firm. This is mainly because of data availability and data collection protocols, which may differ between different sources. Measuring a country's innovation requires the collection of information from various sources, institutions, government agencies, etc. Ensuring uniformity and comparability of such datasets is challenging by itself. For countries with hundreds of research organizations, data collection is very time consuming and requires entire teams to organize it. Multiple attempts have been pursued by scholars and economists to develop and apply as precise measures to quantify a country's innovation as possible.

Measuring innovation becomes even harder when the definition of innovation is not clearly set and defined. Multiple competing definitions of innovation exist and based on each of the interpretations the outcomes and objectives of the innovative process as well as measurable goals change (Gault, 2018). For the purpose of the study, innovation is defined as the implementation of new products or services that result in socio-economic gains.

While companies tend to use different key performance indicators for measuring innovation performance (Banu, 2018, Sawang, 2011), such as the Innovation Sales Rate (Song et al., 2015), which is a measure of the percentage of sales that are sales of new products. These cannot be applied directly to measuring complex systems such as a country's innovation performance because a single measure of this kind does not capture the true complexity of innovation. Data for sales distinguishing sales of new products or services is also often not available or incomplete. Many of the key performance indicators are also questionable as they tend to be too simplistic to emulate real innovation performance. For example, R&D expenditure, which is often used as an innovation indicator does not tell much about innovation performance by itself; it is also relative since costs associated with R&D will differ in different countries. Some other companies measure innovation as a number of new ideas generated by employees per month (Dziallas and Blind, 2018). This measure could be adapted to capture the country's perspective by summing all invention disclosures submitted within a specific year to the country's intellectual property offices. However, when thinking about it, would this method give a precise idea about innovation performance? It is highly doubtful. While patents have been frequently used to study innovation, patents are only one of the indicators of innovation and should be considered together with other relevant indicators. Research institutions in one country can be efficient in producing patents, but not effective in translating them to achieve meaningful results. Also, it could be argued that the number of invention disclosures is a more precise indicator of innovation than patents. Not all invention disclosures result in patents, yet they often carry important and innovative breakthroughs. More on this is described in the Brookings Institution article (Kolodziejczyk, 2018).

To develop frameworks for measuring innovation performance, it is necessary to understand innovation as a process. One iconic work that deserves mention is the so-called chain-linked model or Kline model of innovation. The model was initially introduced by mechanical engineer Kline and further developed by Kline and economist Rosenberg in 1986 (National Research Council, 1986). The chain-linked model is an attempt to describe stages and complexities in the innovation process.

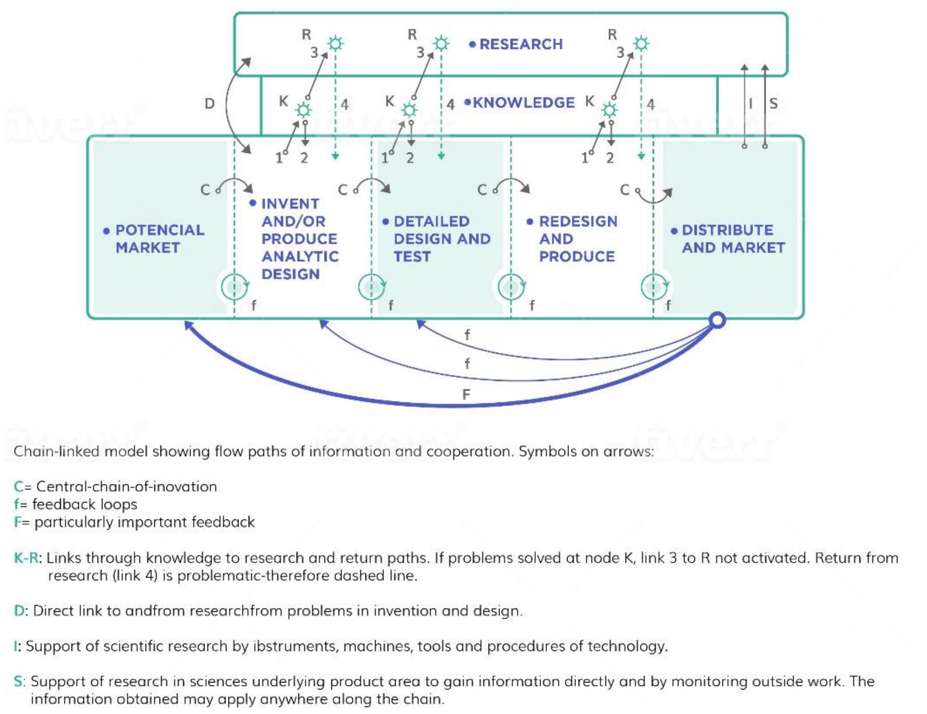


Figure 1 The chain-linked model. Reproduced from Kline and Rosenberg (National Research Council, 1986).

The initiation process in the chain-linked model is not necessarily knowledge-driven; instead, the framework begins with the identification of market potential, which subsequently enables research and design, product optimization and production, and finally, marketing and distribution (Micaëlli et al., 2014). Each of the process stages is linked by complex feedback loops. In case there is any problem or unknown at any stage of the process, feedback loops direct the user to research and knowledge to conduct new studies or gather additional information to fill in the gaps.

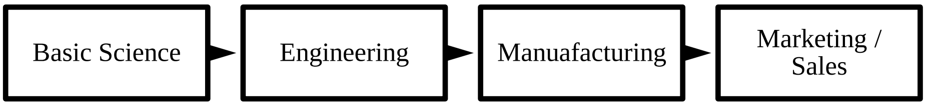


Figure 2 The linear model. Reproduced from Rothwell (Roy, 1995).

The chain-linked model is contrasted with the so-called linear model of innovation (Micaëlli et al., 2014, Oliveira, 2014), in which the innovation process is performed in iterative steps starting with primary research which then leads to applied development, engineering, and manufacturing to conclude at marketing and distribution. The chain-linked model has been broadly applied in various industries, and multiple researchers have described extensions and variations to the initial work by Kline and Rosenberg (Micaëlli et al., 2014, Kline, 1995, Kameoka et al., 2001).

Some other innovation performance measures include measuring translation of deliverables to goals, completing activities that enhance the brand image, production of intellectual property (i.e., patents, trademarks, trade secrets, etc.), and some like to measure innovation by speed to market, or a number of new products or services launches (Anadon et al., 2016, OECD, 2010). However, again, the above is seem too simplistic to apply even for a single company and are utterly inapplicable for measuring a country’s innovation performance. The researcher’s personal conclusion is drawn mainly from the fact that measuring complex phenomena such as innovation, and multivariate evaluation is needed. The above measures often use single or several variables only.

Most of the multi-parameter innovation indices recognize scientific publications and patents as one of the factors indicating innovation. However, the practice is against the definition of innovation assumed in the study. These sophisticated metrics count the overall number of country’s scientific publications and patents, including patents and publications that never find commercial use. This only shows how inaccurate these metrics can be. To solve the problem, an appealing yet straightforward way to measure innovation performance by comparing the ratio of start-up or spin-off companies formed to the number of invention disclosures in a specific year (Kolodziejczyk, 2018). While there are still numerous drawbacks with the approach; for example, companies are less like to be formed in the same year as the invention disclosure was filed; the ratio rewards countries for the number of invention disclosures that have been turned into commercial entities, at the same time punishing them for the number of invention disclosures that have failed to be commercialized.

In his World Economic Forum write up Chakravorti, the Senior Associate Dean of International Business and Finance at The Fletcher School at Tufts University (Chakravorti, 2015), assumed a broad definition of innovation, “as the creation of extraordinary new value in extraordinary new ways,” and shared three general, but relevant observations on the topic. Chakravorti concluded that people have been chasing the wrong measures. Instead of pumping money into technology, patents, and start-ups, they should use an innovation index that measures their progress on closing the economic development gap. Different countries see innovation differently, and as such measuring innovation globally becomes a difficult task.

The current study focused mainly on innovation in developed European Union countries; however, it also is essential to realize how innovation indices that are designed to serve the developed world may not be applicable to measure innovation in developing countries, at the same time rendering the rankings irrelevant.

In 2012, Sutz published a paper on measuring innovation in developing countries (Sutz, 2012), in which she argued that current metrics are inapplicable in the developing world and suggesting more accurate and useful indicators. The study emphasised that it has to be understood as a learning process and that innovation indices need to incorporate the learning aspects. The author also argued that innovation surveys could give misleading results, for example, by assuming that innovation is a value-free concept, which, in option on the author, is not the case. Similarly, Ghazinoory et al. believed that common innovation performance measures are not relevant to dominant innovation behaviours in developing countries (Ghazinoory et al., 2014). Ghazinoory, just like Sutz, argued that innovation in developing countries relies on learning processes and catching-up with the Western nations. The authors claimed that the innovation system of developing countries relies on capturing, imitation, learning by doing, and diffusion of knowledge to reduce technological gaps created by developed countries. As such, the purpose of measuring innovation performance in developing states should be the evaluation on the success in closing the technological gaps.

Another study concerning developing countries by Bogliacino et al. (Bogliacino et al., 2009) described two problems that emerge when applying innovation metrics in the developing world. First, developing countries tend to focus on the domestic generation of knowledge and capabilities, the knowledge and skill gap in developing countries is often so large that states and companies lack resources, skills, abilities, and knowledge to exploit knowledge generated externally. As such, the authors emphasized the need for including facts such as training activities, technology acquisition, and organizational innovations as the innovation measurement factors. According to the authors, the second important issue of measuring innovation in developing countries is concerned with the methodology and sample design. Bias towards larger firms and corporations in developing countries and discrediting smaller firms, which in developing countries represent the majority of the industry, which prevents them from getting reliable results and discrediting developing countries compared to fast forward developed economies.

Many more studies have been performed to evaluate measures and frameworks for innovation performance. In 2010, OECD published an extensive 128-page long report measuring innovation performance titled '*Measuring Innovation: A New Perspective*' (OECD, 2010). The report presents new measures and fresh views on traditional innovation indicators. The report goes beyond indicators focused purely around research and development to describe experimental indicators and the broader context in which innovation thrives to provide insights and influence on new areas of policy. Building upon OECD's 50 years of indicator development and evaluation, the publication points out gaps in the innovation measurement processes and addresses these gaps by proposing effective directions for improving the innovation measurement agenda.

The Measuring Innovation report acknowledges the role of evidence-based innovation policymaking by complementing traditional innovation indicators with new ones that link innovation and policy. The report also recognises that innovation indices must evolve and adapt to changing market and innovation landscape, at the same time describing measurement challenges that will often require consolidated approaches by policymakers, researchers, innovators, and other stakeholders to be addressed. The publication is an important contribution to the field of measuring innovation performance as it identifies factors that drive innovation in firms, and how the scientific and research landscape must adapt to interdisciplinarity, convergence, new trends and technologies, and emerging innovation leaders. The authors believed that the human capital is at the center of innovation, and as such, they include factors related to education systems or capacity of the companies in transforming skills and knowledge of their employers into innovative outcomes in the innovation measurement frameworks. Finally, the publication explains the role of private and public investment in fostering innovation.

While '*Measuring Innovation: A New Perspective*' provided new, fresh and critical perspectives on measuring innovation, it was not OECD's first attempt to address the issue of measuring innovation to provide evidence and guidance to policy-making processes. First published in 1992, OECD's Oslo Manual is the foremost international reference guide for collecting and using data on innovation activities in the industry (OECD et al., 1997). The Manual was an attempt at answering some of the field's most important questions, such as what innovation is and how to measure it. It explains in detail the scale of innovation activities and the characteristics of innovative companies, later focus on systemic and internal factors and parameters that influence innovation. The essential advantage of the Oslo Manual is that it acknowledges the changing landscapes, and together with the emergence of new trends and challenges, the manual adapts and evolves to address changing reality. For example, the manual's third edition (OECD and Communities, 2005), published in October 2005, considers the progress made in understanding innovation processes and the economic impact of innovation. For the first time, the third edition acknowledges the impact of non-technological innovation and defines linkages between different innovation types. This edition also acknowledged innovation differences between developed and developing nations and included an annex on measuring innovation in the developing world. Whereas the manual's most recent fourth edition published in October 2018 (OECD and Eurostat, 2018), has updates on a broader range of innovation-related phenomena and practical experience gained from recent rounds of innovation surveys; this edition contains improved guidance reflecting evolving user interests, as well as new guidelines on the measurement of innovation outside the business sector. The Oslo Manual is, in a way evolving and adapting work in progress which aims at closing the gap of knowledge. To better understand, it attempts a timeline of the Oslo Manual will be explained in more detail.

Generally, the OECD's Oslo Manual is the foremost international reference for measuring innovation performance. It is also considered to be the best adapted to changing nature and landscape of innovation thanks to continuous updates that attempt to address new reality and changing innovation trends. Comparing different editions of the Oslo Manual, it becomes evident that the indicators and tools for measuring innovation performance have changed over time, and as such, the Oslo Manual is central to addressing these changes by developing better measures of innovation. Because of the changing innovation landscape, the knowledge gap is naturally becoming broader, and as such statisticians, researchers, policymakers and other stakeholders need to ensure that they are up to date to provide viable methods and new knowledge to be able to follow those regularly occurring changes and to close the gap between innovation and approaches to measure it. This is the central aim of the Oslo Manual.

A considerable body of work was undertaken during the 1980s and 1990s to develop analytical models and frameworks to study and better understand innovation phenomena (Edler and Fagerberg, 2017, Anderson et al., 2014). The early experimentation with innovation surveys as a viable tool for measuring innovation, as well as the need for a universal set of tools and concepts led to the first edition of the Oslo Manual in 1992, which cantered around the concepts of technological product and process innovation, specifically, in the manufacturing industry. Initial results from surveys that applied the approaches described in the Oslo Manual allowed for a better understanding of the complexity of measuring innovation performance and lead to further refinement of the strategies presented in the second edition of Oslo Manual published in 1997. Because of the further need for better understanding of the innovation concepts and its changing landscape as well as growing agreement among stakeholders that, for example, most of innovation related to the service sectors is not captured by technological product and process concept, as such the third revision of the Manual further refined the various concepts, theories, tools, and definitions and expanded the scope of the framework to address non-technological innovation and provide feasible and practical tools to measuring it. The Oslo Manual has expanded the scope and understanding of innovation to cover aspects such as marketing and organisational innovation. The Manual's consecutive editions also provided continuous and ongoing governance in terms of data collection methods or refinements to methodological issues such as the measurement of innovation inputs and outcomes as well as the systemic dimension of innovation by focusing on innovation linkages.

The Oslo Manual was one of the first publications of its type to acknowledge geographic discrepancies and systemic differences between developed and developing nations and include best practices to apply the Oslo Manual in emerging economies (OECD and Eurostat, 2018). The development of these guidelines for the developing world was a learning process and was possible thanks to best case practices learned by applying recommendations and methodologies of the Oslo Manual in countries in Latin America, Eastern Europe, Asia, and Africa. Developing countries have begun undertaking surveys based on the Oslo Manual. However, quickly, it became apparent that practices designed to work in leading economies do not always comply with the standards of the developing world. As such, many surveys have adapted the Oslo Manual methodology to consider specific user needs and the characteristics of countries with different economic and social backgrounds. The main overarching methodological difference and adaptation of the Oslo Manual in most developing countries accept that the diffusion and incremental changes to innovation account for much of the innovation occurring in non-OECD countries. The approach is in agreement with the challenges described by innovation researchers from developing countries and previously mentioned in this current study (Sutz, 2012, Ghazinoory et al., 2014, Bogliacino et al., 2009). These numerous case studies and experiences from non-OECD countries have resulted in the best practices and are now included in the Oslo Manual, providing further guidance for innovation surveys in non-OECD countries. It is most likely these practices will result in additional surveys that will give even more feedback and input for future editions of the Oslo Manual and further refinement of these guidelines.

Other similar guidelines have been developed over the years. The Oslo Manual together with the Frascati Manual (OECD, 2015) cover innovation topics related specifically to research and development, and the Canberra Manual (OECD and Communities, 1995) focuses on measuring globalisation, human resources in science and technology, and indicators related to the information society are altogether a family of continuously evolving guidelines and handbooks devoted to measurement and interpretation of innovation, science and technology related data.

The Oslo Manual, together with similar publications, provides internationally recognized guidelines for collecting and interpreting innovation measures. Moreover, the manual strives to be universally applicable and comparable, which often requires finding consensus. Each guideline has its drawbacks and limitations; however, as long as the research is aware of these fundamental issues, the Oslo Manual can serve as a source of valuable information and practices. This ongoing and incremental learning process and aim for achieving ultimate excellence have allowed each edition of the Oslo Manual to be better than before. The Oslo Manual is constantly decreasing the knowledge gap in the innovation-related fields and effectively moves forward to addressing it (OECD and Eurostat, 2018).

Beyond the above, The European Union publishes an annual Innovation Union Scoreboard (previously the European Innovation Scoreboard), which provides a comparative analysis of innovation performance in the European Union countries, select other European countries, as well as regional neighbours. The Innovation Union Scoreboard evaluates relative strengths and weaknesses of national innovation systems within the European Union and identify areas to be addressed.

The best metric does not exist. Further, there is a certain paradox as a single measurement process can sometimes negatively impact the innovation processes they are attempting to measure. As such, more complex, multi-parameter frameworks should be considered when measuring a country's performance. Such a suite of metrics allows for the mitigation of the negative impact and increases the value of the innovation measurement process.

The study is not trying to develop new or evaluate existing frameworks to measure innovation; it merely provides an overview and comparison of existing frameworks and compares the results.

Research aim

According to the innovation rankings, global innovation leadership changes annually. The cause for this can be either the country's progress or inaccuracy of data or the measurement framework. A significant, several place position increase or decrease in the innovation ranking by a country within only one year is unlikely to be caused by rapid change in the country's innovation landscape in such a short period of time. As such, these instant ranking position increases, or drops are more likely to be due to available input information that the rankings are based on. The current research evaluates previous attempts to measure innovation and based on data from the prestigious rankings, such as the Global Innovation Index, the Bloomberg Innovation Index or the Global Competitiveness Report, evaluates the reliability of innovation measures with each other, as well as future innovation trends for the European Union states. The study relies on existing data and simple statistical analysis to answer research question.

The aim of the thesis is to shed light on the innovation performance within the European Union, as seen by different rankings. The study relies on a comparative approach of three leading innovation rankings. This aim is fulfilled by identifying and evaluating discrepancies and differences between various rankings to establish whether these rankings favored or undermined European Union member states role as leading innovators. The research focused on only 28 European Union member states; however, a similar methodology could be applied to extend the study's scope beyond the European Union.

Research question

Based on the previous sections, one main research question can be asked to relate to the aims of this work. The research question is:

Which are the most innovative European Union member states?

By analysing outcomes of three selected innovation indices over several years, the study will examine the position of each of 28 European Union member states in each of the rankings and discuss how this position was shaped over the years. Moreover, the discussion will explain what factors influenced this position. In cases where significant discrepancies between the country's position in all three rankings are identified, the thesis will also aim at explaining the source of these differences. Thus, by comparing the three rankings, the thesis will analyse whether there are different messages conveyed concerning the country's innovation performance. The comparison may also reveal certain trends and relationships between all three rankings, and as such, it may indicate the best-performing nations within all three measurement frameworks. Finally, based on all three rankings conclusions is drawn to identify the most innovative European Union member states.

This comparison will be followed by discussion attempting to explain identified discrepancies. This discussion will be based on quantitative analysis, i.e., bivariate analysis, and will be supported by data visualization. This will lead to the evaluation of the current innovation measurement frameworks and their subjective appropriateness to measure a country's innovation performance. The subjective correctness will be based on a comparison of the three indices between each other. Since there is no golden standard for measuring innovation performance, the study has to rely on comparison and identifying differences between the three rankings. The quantitative analysis will lead to revealing some potential innovation trends, which could potentially be extrapolated into the future to reveal with a degree of uncertainty how the country's innovation will shape in the following years.

Answering the research comparison of the country's position in three innovation rankings as well as discussion of similarities and discrepancies between three rankings will allow deriving an answer to the research question, and at the same time, conclude this work.

Methodology

The methodology used in the study involved four steps. First, data was collected from existing rankings and transcribed in Microsoft Excel; second, transcribed data was processed to unify the ranking scale. Some of the earlier innovation reports used a scale different from the 0-100 scale. Third, processed data was exported to Microsoft Excel to perform bivariate analysis. Microsoft Excel was used to visualize transcribed data in the form of plots. Finally, based on the results, the discussion and conclusions followed. The methodology used in the work is shown in Figure 3.

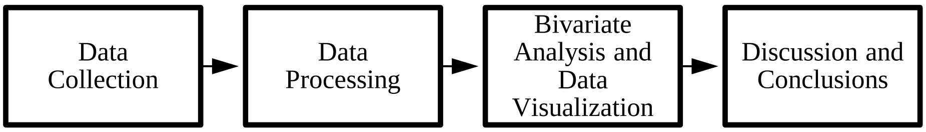


Figure 3 The research methodology used in the current work.

The study was initiated before Brexit. The United Kingdom is listed as one of the European Union member states and is included in this evaluation.

Data collection

A suite metrics of multi-parameter frameworks have been developed to measure most innovative countries and position them in accordance with the level of innovation they exhibit. Three most prestigious of the measures or indices include Global Innovation Index by INSEAD and the World Intellectual Property Organization, the Bloomberg Innovation Index by Bloomberg L.P., and the Global Competitiveness Report by the World Economic Forum. These three rankings have been used as a data source for the current work. There is also the International Innovation Index 2009 by the Boston Consulting Group and the National Association of Manufacturers. However, this report had only one edition published in 2009, and as such, it was not included in the study.

Global Innovation Index

As stated in the Global Innovation Index, it is an annual ranking of countries by their capacity for, and success in, innovation. This innovation index is published annually by the World Intellectual Property Organization, INSEAD, and Cornell University, in partnership with other organisations and institutions. The Global Innovation Index is based on both subjective and objective data derived from several sources, including the International Telecommunication Union, the World Bank, and the World Economic Forum. The Index first appeared in 2007 and was published by INSEAD and World Business (Cornell University, 2018).

The methodology used by the Global Innovation Index relies on the computation of scores in two sub-indices), the Innovation Input Index and Innovation Output Index) composed of five and two pillars, respectively. Each of these innovation pillars describes a specific attribute of innovation and comprises up to five indicators. The overall score of each pillar, as well as the overall Global Innovation Index score, is calculated by the weighted average method. The overall Global Innovation Index score is a simple average of the Input and Output Sub-Index scores, each of which has assigned own weights (Cornell University, 2018). More on the methodology used in the Global Innovation Index reports can be found in the reports themselves. The reader should be aware that the methodology used in different years may differ.

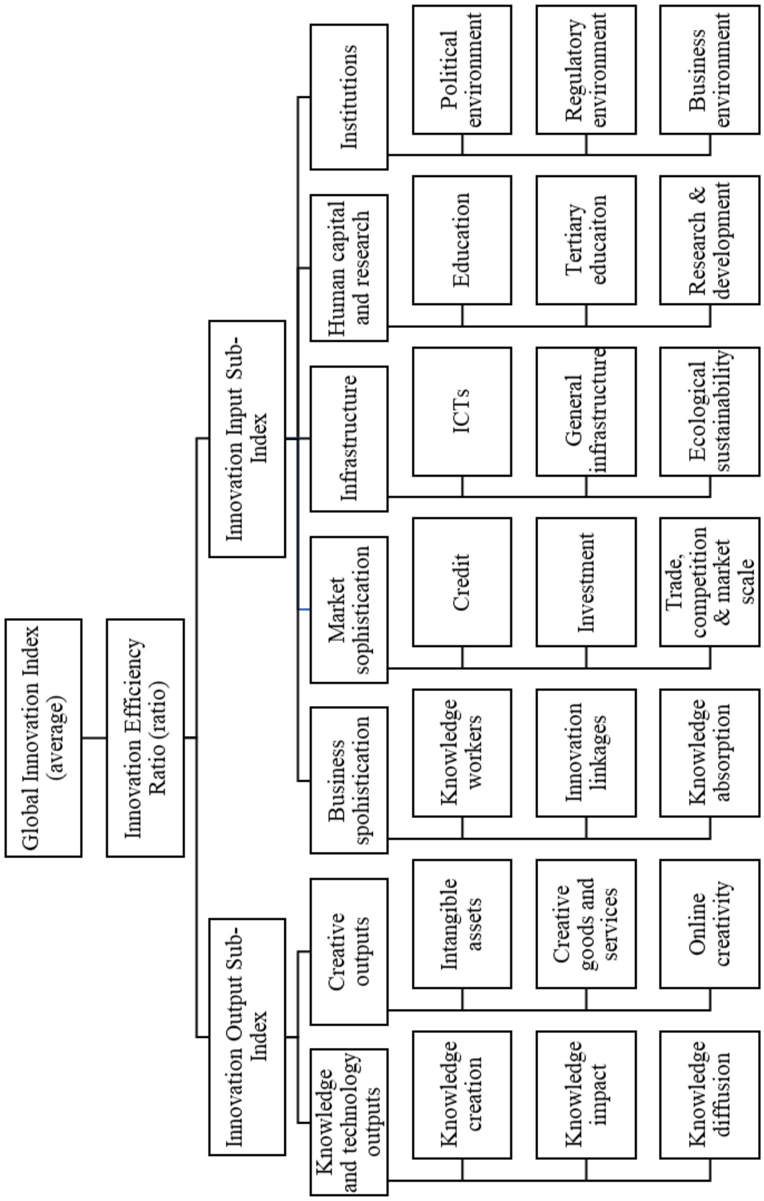


Figure 4 Framework of the Global Innovation Index 2018. Framework used in the previous editions may differ. Reproduced from Cornell, INSEAD, and WIPO (Cornell University, 2018).

The overall score and rank values have been extracted from the Global Innovation Index for all years between 2007 and 2019 because other indices do not have data available until 2014, for the purpose of the comparative study, only Global Innovation Index data between the years 2014 and 2019 was used. Only values for the 28 European Union member states are considered in the current work.

Bloomberg Innovation Index

The methodology used in the Bloomberg Innovation Index relies on ranking countries based on their overall ability to innovate. Bloomberg Innovation Index identifies the top 50 to 60 most innovative countries annually. The methodology used in the Bloomberg Innovation Index relies on examining six equally weighted metrics, where the overall score and corresponding ranking position is a combination of all six metrics for each country on the scale from zero to 100 (Michelle Jamrisko, 2019). The six metrics used in the Bloomberg Innovation Index are:

- *Research & Development*: Research and development expenditure as a percentage of GDP;
- *Manufacturing*: Manufacturing value-added per capita;
- *High-tech companies*: Number of domestically domiciled high-tech public companies—such as aerospace and defence, biotechnology, hardware, software, semiconductors, Internet software and services, and renewable energy companies - as a share of world's total high-tech public companies;
- *Postsecondary education*: Number of secondary graduates enrolled in postsecondary institutions as a percentage of the cohort; a percentage of the labor force with tertiary degrees; annual science and engineering graduates as a percentage of the labor force and as a percentage of total tertiary graduates;
- *Research personnel*: Professionals, including Ph.D. students, engaged in R&D per 1 million population; and
- *Patents*: Resident utility patent filings per 1 million population and per 1 million USD of R&D spent; utility patents granted as a percentage of the world total.

Postsecondary education and patent activity consist of multiple factors that are weighted equally. Weights are rescaled for countries void of some but not all the factors. The top 50 and more recently top 60 countries in the ranking are displayed by Bloomberg. Bloomberg Innovation Index uses the most recent data available from sources such as Bloomberg, International Monetary Fund, World Bank, Organisation for Economic Co-operation and Development, World Intellectual Property Organization, United Nations Educational, Scientific, and Cultural Organization. Some other ranking sources include Samsung, Swiss Federal Statistical Office, and Unified Patents (Michelle Jamrisko, 2019).

The reader must be aware that the methodology may differ slightly between the years, and the methodology used in a specific year can be found in the respective Bloomberg Innovation Index. Table 1 shows how weights have differed between the editions.

Table 1 Weights assigned to the factors of the Bloomberg Innovation Index over the years.

<table>
<tr><th>Factor</th><th>2012</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td>R&D Intensity</td><td>0.2</td><td>0.2</td><td colspan="5" rowspan="7">Factor names may differ between editions.
The number of factors was reduced to six.
All metrics are equally weighted.</td></tr>
<tr><td>Manufacturing Capability</td><td>0.2</td><td>0.1</td></tr>
<tr><td>Productivity</td><td>0.1</td><td>0.2</td></tr>
<tr><td>High-tech Density</td><td>0.1</td><td>0.2</td></tr>
<tr><td>Tertiary Efficiency</td><td>0.1</td><td>0.05</td></tr>
<tr><td>Researcher Concentration</td><td>0.2</td><td>0.2</td></tr>
<tr><td>Patent Activity</td><td>0.1</td><td>0.05</td></tr>
</table>

The score values for the 2012 Bloomberg Innovation Index are on a different scale and as such, cannot be used in the study. An attempt to recalculate the total scores for this year based on the weights above have failed due to a lack of values for specific factors. In this year, Bloomberg's meteorology was to report Bloomberg Innovation Quotient, where countries were ranked on a scale from 0 to 100. The Bloomberg Innovation Quotient was modelled after IQ scales, assigning a score of 140 to the top-ranked country and a rating of 100 to the 81st country. Detail methodology and factors used in a specific edition of the Bloomberg Innovation Index can be found in the report itself.

The overall score and rank values have been extracted from Bloomberg Innovation Index. Extracted data from Bloomberg Innovation Index reports include years between 2014 and 2019. Data from prior years were not available, or scale differences prevent its use. For the purpose of the thesis, only the score and rank values of European Union countries are used.

Global Competitiveness Report

The Global Competitiveness Report aims at measuring a country's competitiveness rather than innovation. However, the metrics used by the World Economic Forum to measure the competitiveness include indicators of innovation. The innovation index in the Global Competitiveness Report has its own ranking. The innovation pillar, as it is called in the report, consists of factors such as the capacity for innovation, quality of scientific research institutions, company spending on research and development, university-industry collaboration in research and development, government procurement of advanced technology products, availability of scientists and engineers, or PCT patent applications. However, some previous versions of the report included solely PCT patent applications as the only measure of innovation. The data was extracted from reports between 2005 and 2019, but because of the lack of earlier data for the Bloomberg Innovation Index, only data between 2014 and 2019 was used for the purpose of the study.

Table 2 Factors and their description used in innovation pillar of the Global Competitiveness Index over the years. Framework used in the previous editions may differ. Reproduced from World Economic Forum (World Economic Forum, 2018).

12th pillar: Innovation capacity	
12.A: Interaction and diversity	
12.01	**Urbanization rate** Share of urban population to total population. Urban population refers to people living in urban areas as defined by national statistical offices.
12.02	**Diversity of workforce** *weighted average* In your country, to what extent do companies have a diverse workforce (e.g., in terms of ethnicity, religion, sexual orientation, gender)? [1 = not at all; 7 = to a great extent]
12.03	**State of clusters development** *weighted average* In your country, how widespread are well-developed and deep clusters (geographic concentrations of firms, suppliers, producers of related products and services, and specialized institutions in a particular field)? [1 = non-existent; 7 = widespread in many fields]
12.04	**International co-inventions** *moving average* Number of patent families with co-inventors located abroad, filed in at least two of the major five offices in the World: the European Patent Office, the Japan Patent Office, the Korean Intellectual Property Office, the State Intellectual Property Office of the People's Republic of China, and the United States Patent and Trademark Office.
12.05	**Multi-stakeholder collaboration** *weighted average* Average score of the three following questions: In your country, to what extent do people collaborate and share ideas within a company? [1 = not at all; 7 = to a great extent]; In your country, to what extent do companies collaborate in sharing ideas and innovating? [1 = not at all; 7 = to a great extent]; In your country, to what extent do business and universities collaborate on research and development? [1 = not at all; 7 = to a great extent]
12.B: Research and development	
12.06	**Citable publications** *moving average* Number of citable documents published by a journal in the three previous years (selected year documents are excluded). Exclusively articles, reviews, and conference papers are considered. The documents universe is defined by the documents tracked by Scopus, the largest abstract and citation database of peer-reviewed literature: scientific journals, books, and conference proceedings.
12.07	**Patent applications** *moving average* Total number of patent families filed in at least two of the major five offices in the World: the European Patent Office, the Japan Patent Office, the Korean Intellectual Property Office, the State Intellectual Property Office of the People's Republic of China, and the United States Patent and Trademark Office.
12.08	**R&D expenditures** Expenditure on research and development as a percentage of GDP. Expenditures for research and development are current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development.
12.09	**Quality of research institutions**

	This indicator assesses the prevalence and standing of private and public research institutions. It is calculated as the sum of the inverse ranks of all research institutions of a country included in the SCImago Institutions Rankings.
12.C: Commercialization	
12.10	**Buyer sophistication** *weighted average* In your country, on what basis do buyers make purchasing decisions? [1 = based solely on the lowest price; 7 = based on sophisticated performance attributes]
12.11	**Trademark applications** *moving average* Number of international trademark applications issued directly or through the Madrid System by country of origin per 1,000 population.

The Global Competitiveness Report has been published since 2004, ranking the world's nations according to the Global Competitiveness Index. As stated in the report, the ranking is based on the latest theoretical and empirical research. However, the current methodology differs from the methodology that was used in the early editions. The current rankings are based on the Global Competitiveness Index methodology developed by Sala-i-Martin and Artadi. Whereas previous editions used macroeconomic ranks based on the Growth Development Index developed by Sachs and microeconomic ranks using the Business Competitiveness Index methodology by Porter (World Economic Forum, 2018, E Porter et al., 2004).

Currently, the report is made up of over 110 variables organized into twelve pillars, where each of the pillars represents a critical determinant of competitiveness. In the Global Competitiveness Index, countries are divided into three distinct stages, including factor-driven, efficiency-driven, and innovation-driven stage. In the innovation-driven stage, states can sustain a high standard of living and high wages by providing new products. As such, companies must compete by producing new, different, and unique goods, products, and services through sophisticated production processes and through innovation, illustrated by pillar 11 and pillar 12, respectively. For the purpose of the study, the researcher only focused on the pillar related to innovation.

The calculation of the overall Global Competitiveness Index relies on assigning different weights to the pillars depending on the per capita income of the nation (World Economic Forum, 2018). The weight values are selected to explain the country’s growth in recent years best. For example, the business sophistication and innovation pillars are assigned a 0.1 weight in factor and efficiency-driven economies, but the same pillars in innovation-driven economies are given a 0.3 weight. Further methodological approaches used to derive innovation pillar in the World Economic Forum’s report can be found directly in the report (World Economic Forum, 2018).

Data extracted from the Global Competitiveness Index includes the score and rank of pillar 12, which relates to the country’s innovation capacity. Only the score and rank values of European Union countries have been used for the purpose of the study.

Innovation Union Scoreboard

While briefly introduced before Innovation Union Scoreboard published annually by the European Commission is a solid innovation ranking, it was not considered for the purpose of this study because it focuses on a limited number of states, mainly European Union member countries. In contrast, three other rankings used in this work compare countries globally. Further, Innovation Union Scoreboard is less known outside of the European Union and innovation researchers. Finally, due to the time limitation of this work, only three rankings have been selected. Future work could expand this current study by adding the Innovation Union Scoreboard as the fourth ranking for comparative analysis.

Data processing

Extracted and transcribed data from three different sources was then used in Microsoft Excel. Transcribed data was then processed and rescaled to obtain a uniform scale for all the rankings. For example, the Global Competitiveness Report measures all indicators on a 1–7 scale, whereas two other rankings use a 0-100 scale. Rescaling of all the values to 0-100 helps at the later stage with plotting values in ternary plots, where all three variables should be on the same scale for better data visualisation and direct comparison of the results.

The rescaling of the values in the Global Competitiveness Report to 0-100 scale has been done using

$$x_{0-100} = (x_{1-7} - \min s_{1-7}) \cdot \frac{\max(s_{0-100}) - \min(s_{0-100})}{\max(s_{1-7}) - \min(s_{1-7})}$$

Equation *1*.

$$x_{0-100} = (x_{1-7} - \min s_{1-7}) \cdot \frac{\max(s_{0-100}) - \min(s_{0-100})}{\max(s_{1-7}) - \min(s_{1-7})}$$

Equation 1 The formula for rescaling values from a 1-7 scale to 0-100 scale.

Where x_{0-100} stands for new rescaled value, x_{1-7} is a value on the 1-7 scale, which is being rescaled, $\max(s_{0-100})$, and $\min(s_{0-100})$ are maximum and minimum values on the 0-100 scale respectively. In this case, the $\max(s_{0-100})$ and $\min(s_{0-100})$ are 100 and 0, respectively. The $\max(s_{1-7})$ and $\min(s_{1-7})$ are maximum and minimum values on the 1-7 scale, respectively. In this case, the $\max(s_{1-7})$ and $\min(s_{1-7})$ are 7 and 1, respectively. In the specific case,

$$x_{0-100} = (x_{1-7} - \min s_{1-7}) \cdot \frac{\max(s_{0-100}) - \min(s_{0-100})}{\max(s_{1-7}) - \min(s_{1-7})}$$

Equation *1* can be simplified to:

$$x_{0-100} = (x_{1-7} - 1) \cdot \frac{100}{6}$$

Equation 2 Simplified formula for rescaling values from a 1-7 scale to 0-100 scale.

The rescaled scores have been rounded to two decimal places to keep the same data standards as two other rankings. Score values of the Global Competitiveness Report 2018 were already on a 0-100 scale, and as such, rescaling was omitted in this case.

In addition, most of the Global Competitiveness Report editions have two years in the title, meaning that the data used in the report was collected from two years, i.e., the Global Competitiveness Report 2017 – 18. Because two other rankings have assigned a specific year, it becomes confusing when comparing those rankings. The latest Global Competitiveness Report has already changed the nomenclature and was published as the Global Competitiveness Report 2018. As such, the data from previous Global Competitiveness Reports is assigned a single year. For example, the Global Competitiveness Report 2017 – 18 was assigned the year 2017, the Global Competitiveness Report 2016 – 17 was assigned 2016, and so on.

Bivariate analysis and data visualisation

The adequately prepared and rescaled innovation data has then been used to perform bivariate analysis and to plot the variables in ternary plots. Both methodologies are described below.

Bivariate analysis

Bivariate analysis is a set of statistical processes for evaluating the relationships between variables. Bivariate analysis may include several different techniques for modeling. The general methodology for bivariate analysis focuses on evaluating the relationship two variables. (Montgomery et al., 2015, Faraway, 2005).

In the current study, bivariate analysis was performed separately for each of the 28 European Union member states for ranking scores between 2014 and 2019. Bivariate analysis was selected because if the three rankings are consistent in terms of scores, they should follow a linear relationship. Microsoft Excel software was used to perform bivariate analysis. In Microsoft Excel, bivariate analysis was performed using Excel's embedded packages. Performing bivariate analysis in Microsoft Excel is straightforward and involves using the Regression function from the Data Analysis Toolbox in the Data tab. Bivariate analysis was done by selecting datasets or columns with respective variables. Excel created a regression model that calculates the relationships between variables and returns the coefficients of determination (R^2) among other outputs. The coefficient of determination, denoted R^2, is the proportion of the variance in the dependent variable that is predictable from the variables.

Bivariate analysis is performed at two of the rankings at the time. To ensure that all possible combinations are tested, bivariate analysis is performed on three pairs of rankings. In addition, two different bivariate analysis tests have been performed. In the first case, bivariate analysis was performed by looking at the relationship between all 28 European Union member states each year. In the second case, bivariate analysis was applied to establish a relationship between different years for one given country at a time. Performing bivariate analysis for each of the ranking pairs, ranking scores, and ranking position as well as for countries and years of the ranking resulted in Table 3, Table 4, Table 5, and Table 6 presented in Chapter 4. The bivariate analysis was performed without the use of any control variables.

Plots

The Microsoft Excel package provides a flexible and reliable environment for graphical presentation of calculated results. All graphs presented in the study were plotted in Microsoft Excel which allows for a high degree of reproducibility and uniformity of the results. The study outputs have been presented using Excel's scatter plot function and consist of two different types of plots. Three bivariate plots where for each of the ranking pairs have been plotted where different color points correspond to a specific year of the ranking. Moreover, trendlines lines are plotted, and their position and slope can be compared with a dashed line (guideline), which is there to show one-to-one relation between the values and serves as a visual guide.

In addition, a series of small plots have been generated. Each of the plots corresponds to a specific country where three different colors correspond to values for different rankings over a period of time. These plots are generated to help directly and see how different rankings score and rank specific countries as well as what are the differences of these rankings for a particular country over a period of time from 2014 until 2019. Bivariate and time plots have been generated for both the overall ranking score and ranking position.

Results

Results based on the country's scores are shown below. Further results based on the country rank are shown in the appendices. The results are discussed in detail in the next chapter.

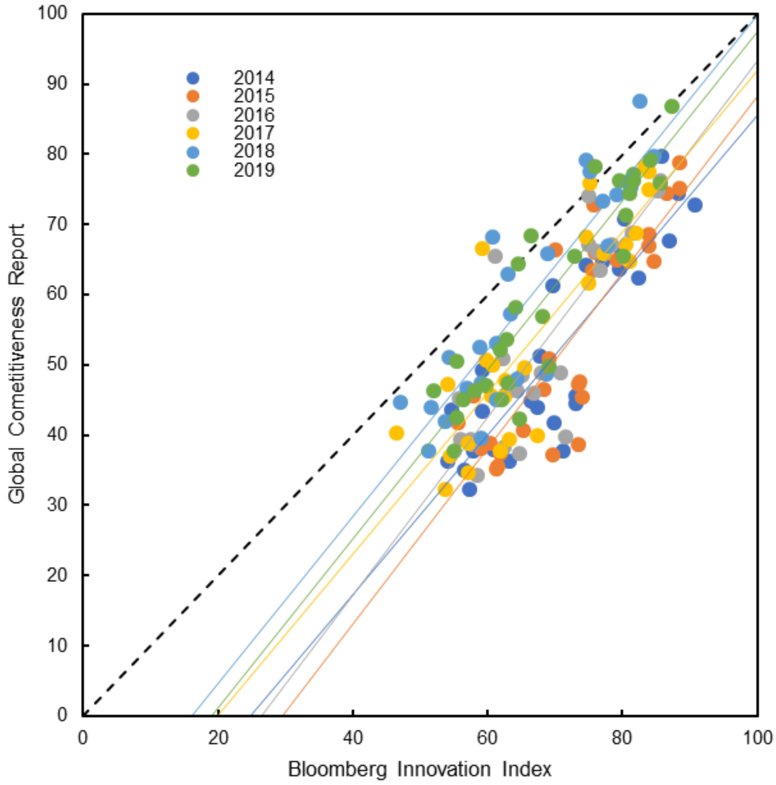


Figure 5 Relationship between score values of 28 European Union countries as seen by Bloomberg innovation Index versus Global Competitiveness Report. The dashed line is plotted to help guide the reader. Different colors correspond to various years.

Figure 5 shows two distinct and disconnected '*islands.*' Further examination reveals that countries forming the first group, which have higher ranking scores, are the old European Union member states. The countries of the second group, with generally lower score values, are new European Union members. The values are generally below the guideline, meaning that Global Competitiveness Report scored these countries less preferably. This claim is further supported by the parallelity of yearly trendlines versus the guideline.

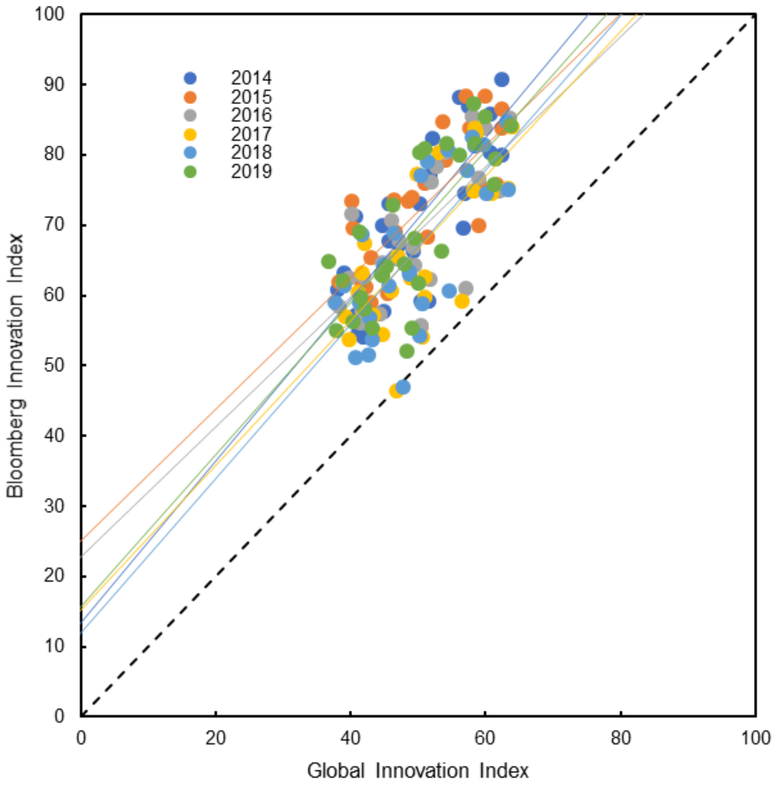


Figure 6 Relationship between score values of 28 European Union countries as seen by Global Innovation Index versus Bloomberg innovation Index. The dashed line is plotted to help guide the reader. Different colors correspond to various years.

The case shown in Figure 6 is more uniform. The division between old and new members is not as evident. The points are more densely packed and form nearly a uniform patch of points. The majority of the points are above the dashed guideline, which indicates that the Bloomberg Innovation Index scored 28 European Union countries more preferably compared to scores derived from the Global Innovation Index.

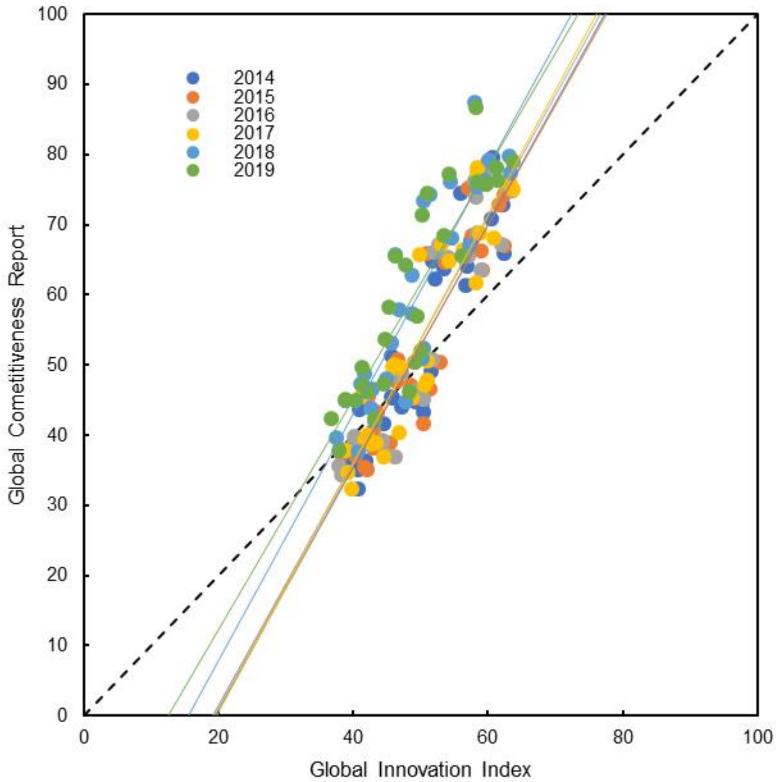
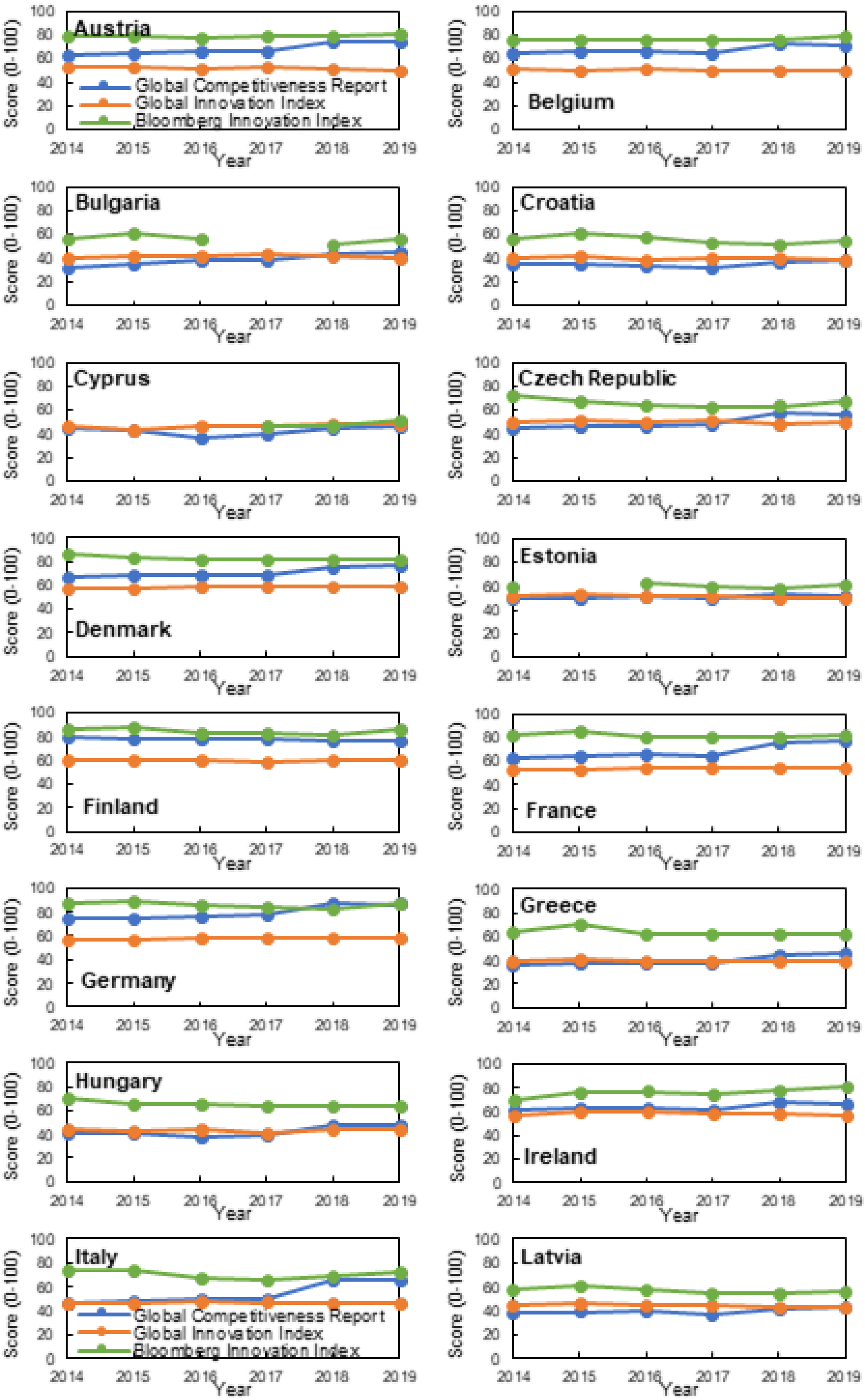


Figure 7 Relationship between score values of 28 European Union countries as seen by Global Innovation Index versus Global Competitiveness Report. The dashed line is plotted to help guide the reader. Different colors correspond to various years.

Figure 7 is an interesting case because there are again two, if not three, evident groups of countries. While lower scored countries are positioned around the dashed guideline, which would indicate that both rankings gave them similar scores, the countries with higher ranking scores tend to diverge from this relation and are positioned above the guideline, meaning that the Global Competitiveness Report scored them higher. The yearly trendline crosses the guideline, which would indicate that the score range of the Global Competitiveness Index for 28 European Union member states is broader compared to the score range of the Global Innovation Index. Yearly lines are parallel to each other which indicates consistency of the rankings and their methodologies over the years.


Austria
Belgium
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Latvia
Global Competitiveness Report
Global Innovation Index
Bloomberg Innovation Index
Score (0-100)
Year
0
20
40
60
80
100
2014
2015
2016
2017
2018
2019

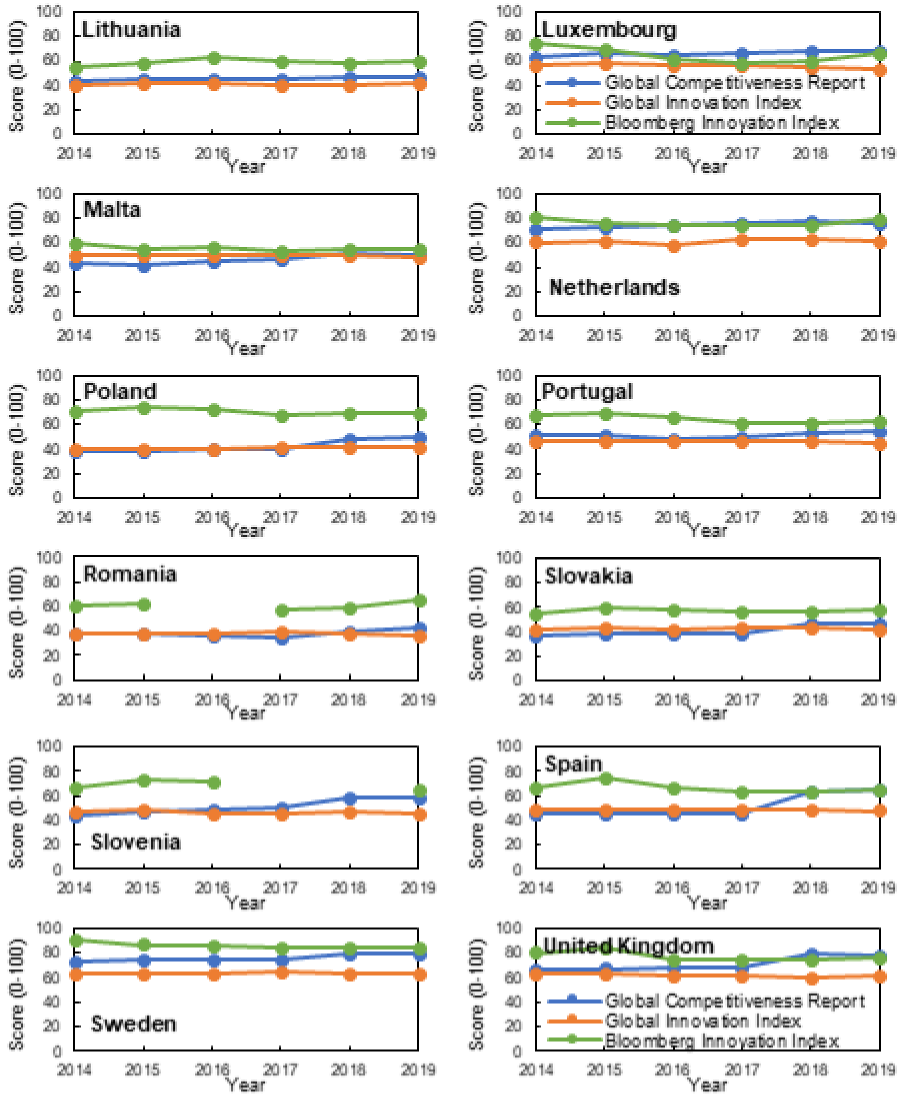


Figure 8 Score values of three rankings for each of 28 European Union countries plotted as a function of time. Green trace corresponds to the Bloomberg Innovation Index, blue to the Global Innovation Index, and read to the Global Competitiveness Report.

The examination of each European Union member state separately reveals a number of interesting relationships. First, all three ranking traces for all 28 European Union states seem to be very flat, which means that in terms of rankings scores, they remain relatively constant over the years. Second, traces for the Global Innovation Index and the Global Competitiveness Report are relatively uniform and often nearly overlap each other. However, in many cases, the Bloomberg Innovation Index shows a discrepancy from two other rankings, positioning a given country higher than the two other rankings.

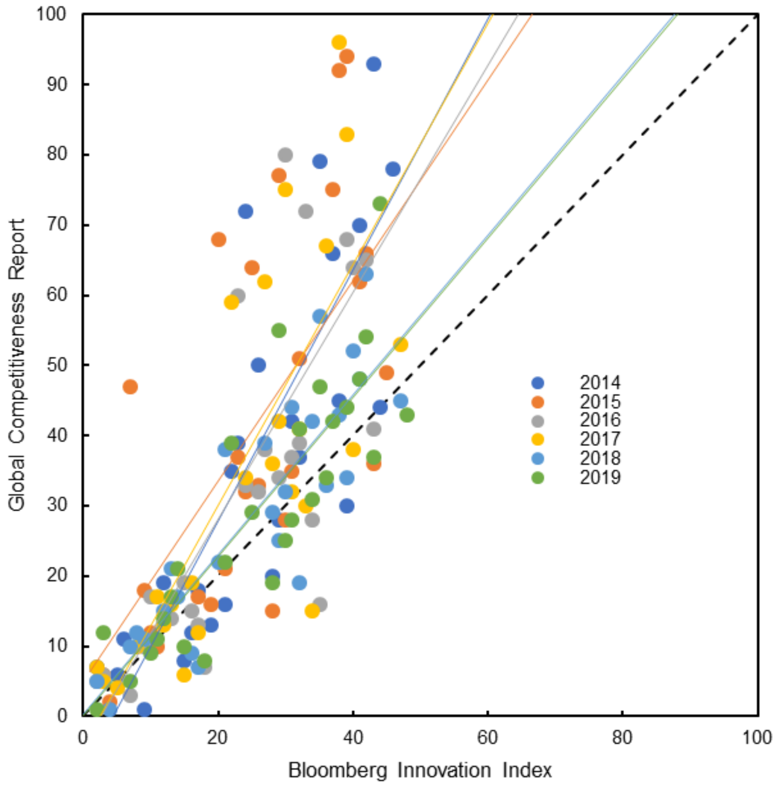


Figure 9 Relationship between rank values of 28 European Union countries as seen by Bloomberg innovation Index versus Global Competitiveness Report. The dashed line is plotted to help guide the reader. Different colors correspond to various years.

The relationship between the Bloomberg innovation Index and Global Competitiveness Report (Figure 9) seems to follow a previously seen trend with two distinct groups of European Union countries, to later diverge from the trend and become somehow random. This can be potentially caused by the fact that Bloomberg lists only the 50 most innovative countries in the ranking, whereas the Global Competitiveness Report has global coverage. In Bloomberg, all 28 European Union states are always nearly covered within the 50 position list, where some countries in the Global Competitiveness Report are often listed in positions beyond 50, within certain years Croatia and Bulgaria scoring ranking position of over 100. This, however, does not explain the methodological discrepancies in establishing these ranking positions.

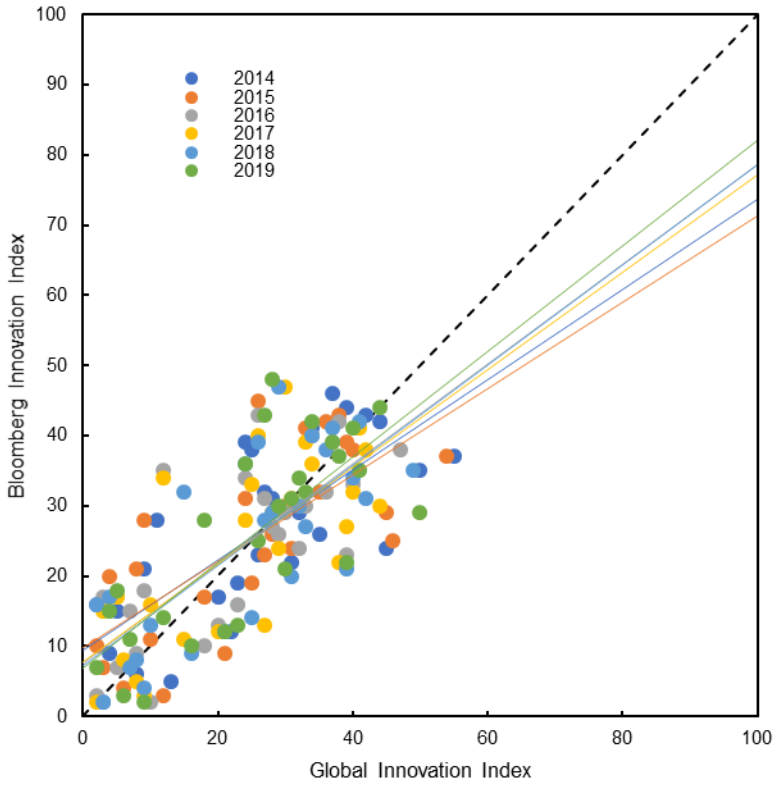


Figure 10 Relationship between rank values of 28 European Union countries as seen by Global Innovation Index versus Bloomberg innovation Index. The dashed line is plotted to help guide the reader. Different colors correspond to various years.

Figure 10, which examines the relationship of rank values in the Global Innovation Index and the Bloomberg Innovation Index, is another interesting case. These numbers tend to align along with the guideline, which would mean that there is some relationship between ranking values in both reports. However, yearly trend lines are significantly skewed towards the Global Innovation Index. This means that, on average, the Global Innovation Index assigns higher rank numbers to countries. The higher rank value the less innovative country is. To some extent there seem to be again two groups of countries as well as countries in transition.

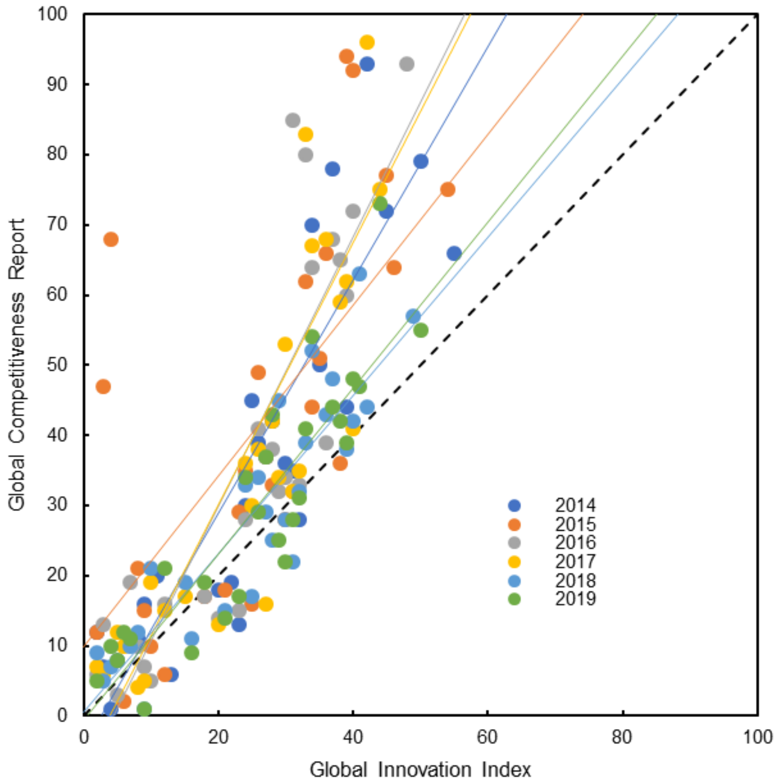
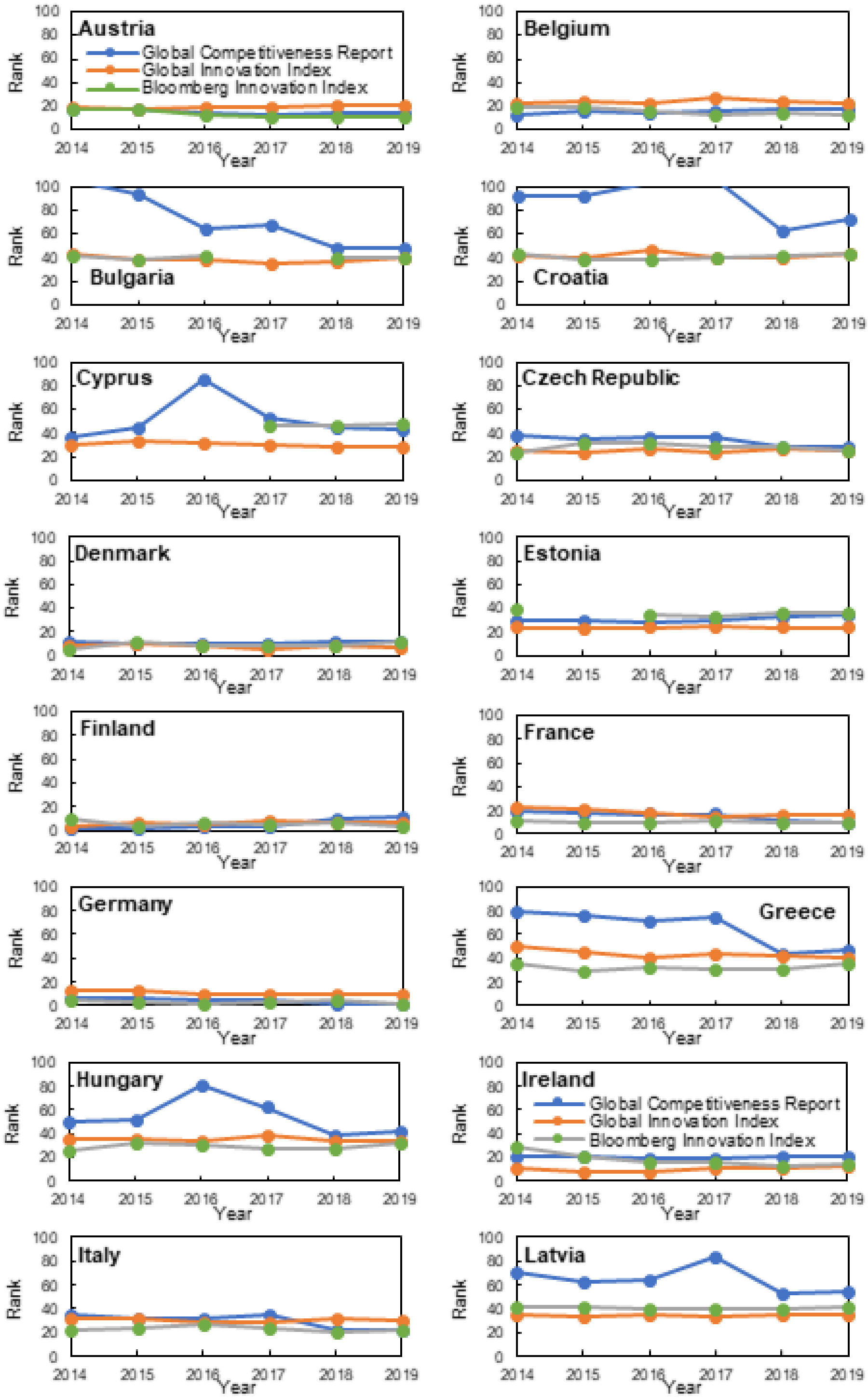


Figure 11 Relationship between rank values of 28 European Union countries as seen by Global Innovation Index versus Global Competitiveness Report. The dashed line is plotted to help guide the reader. Different colors correspond to various years.

Figure 11 seems to show similar relation to the one in Figure 9, where there is a certain trend that tends to diverge with an increase in rank values. These outlier values correspond to Sweden and the Netherlands in the 2015 year. Other years seem to be more consistent and with less significant discrepancies.


Austria
Global Competitiveness Report
Global Innovation Index
Bloomberg Innovation Index
Belgium
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Latvia
Rank
Year
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20
40
60
80
100
2014
2015
2016
2017
2018
2019

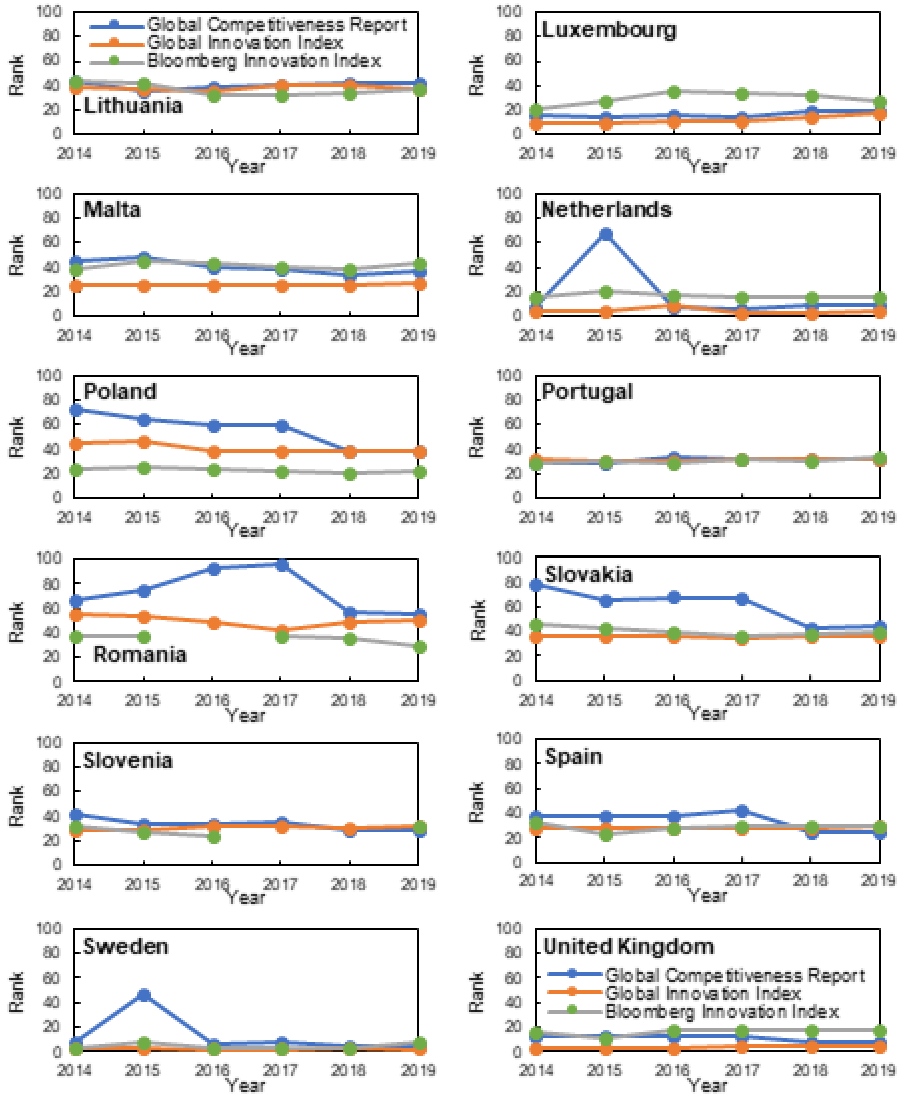

Figure 12 Rank values of three rankings for each of 28 European Union countries plotted as a function of time. Green trace corresponds to the Bloomberg Innovation Index, blue to the Global Innovation Index, and red to Global Competitiveness Report.

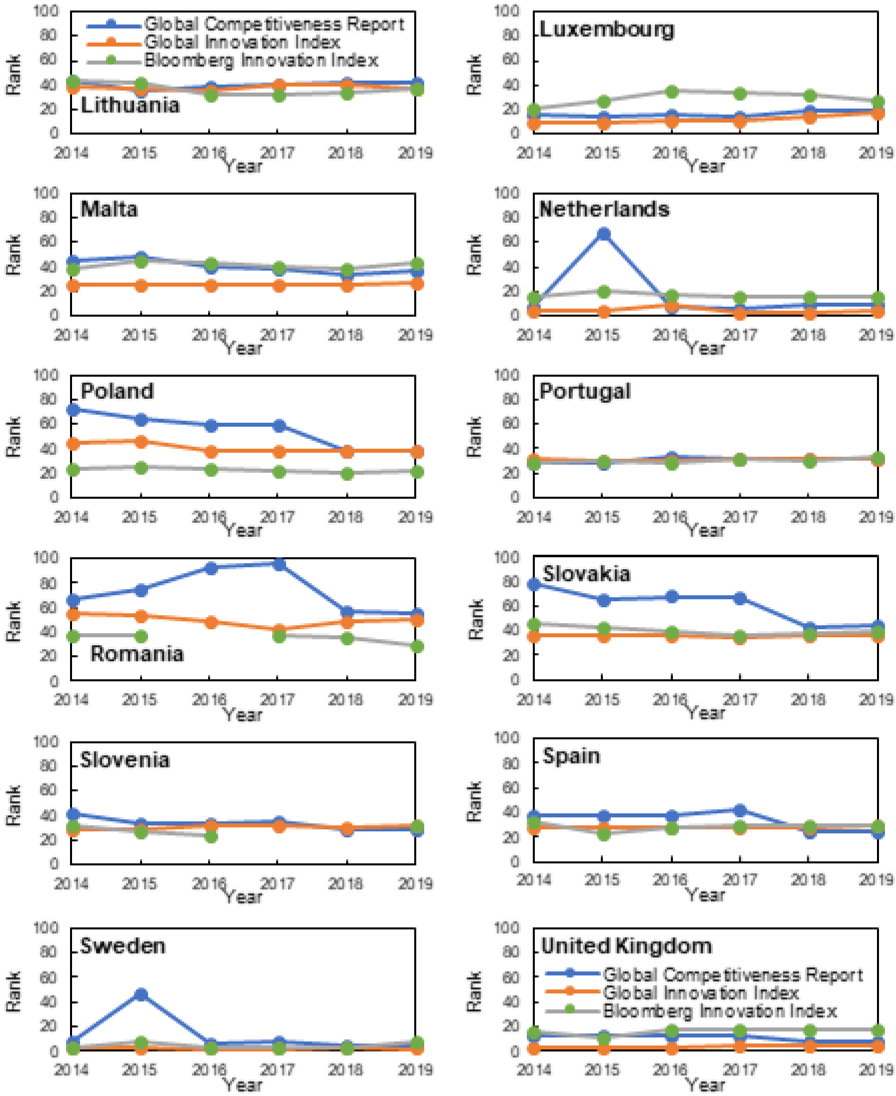
Global Competitiveness Report
Global Innovation Index
Bloomberg Innovation Index
Lithuania
Luxembourg
Malta
Netherlands
Poland
Portugal
Romania
Slovakia
Slovenia
Spain
Sweden
United Kingdom
Rank
Year

Figure 12 county plots are unlike those in Figure 8. Country plots in

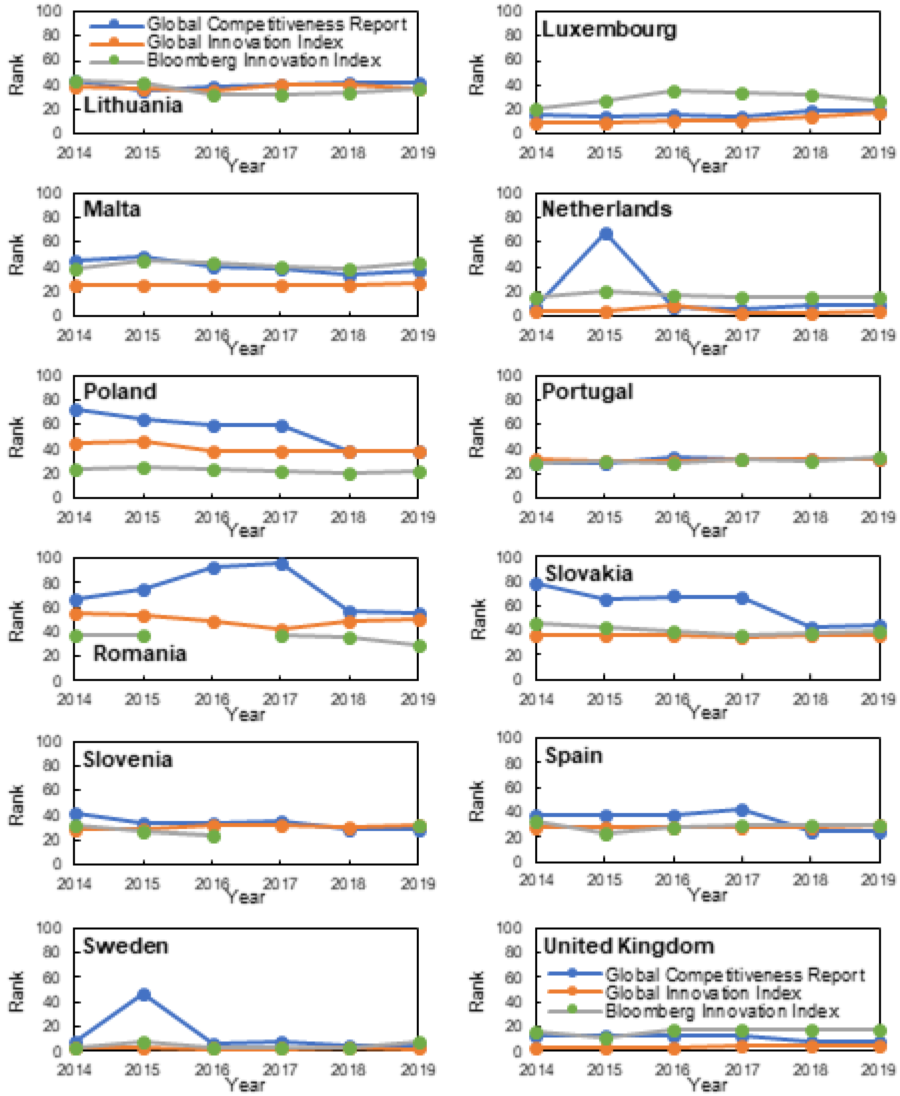

Figure 12 tend to be less consistent. These plots tend to be more dynamic with often significant ranking shifts over the years. There are significant outliers in the Global Competitiveness Report, in which values tend to significantly increase in one year to get back to the previous position the following year. It seems like the methodology used in the Global Competitiveness Report has some flaws. Other than a few specific cases, all three rankings tend to have quite uniform values.

Table 3 Bivariate analysis of ranking score values. R^2 coefficients are calculated for each pair of rankings per year.

	Year					
	2019	*2018*	*2017*	*2016*	*2015*	*2014*
Global Innovation Index / Bloomberg Innovation Index	0.595	0.545	0.510	0.536	0.538	0.623

Global Innovation Index / Global Competitiveness Report	0.792	0.790	0.848	0.844	0.831	0.836
Bloomberg Innovation Index / Global Competitiveness Report	0.831	0.797	0.733	0.721	0.714	0.768

Bivariate analysis was performed on raw data, and the R^2 coefficient of determination for score values of ranking pairs for years between 2014 and 2019 has been evaluated in Table 3. Looking at the numbers rather than graphs allows evaluating the relationships in a more quantitative way. The table shows that the pair of Global Innovation Index and the Global Competitiveness Report is most closely related because their R^2 coefficient are most of the time closest to the value of '*1*', followed by the Bloomberg Innovation Index and Global Competitiveness Report. None of the values in Table 3 is lower than 0.5 but not higher than 0.9. This means that variation of these data sets is significant, but a certain relationship exists.

Table 4 Bivariate analysis of ranking score values. R^2 coefficients are calculated for each pair of rankings per country for datasets between 2014 and 2019.

Country	Global Innovation Index / Bloomberg Innovation Index	Global Innovation Index / Global Competitiveness Report	Bloomberg Innovation Index / Global Competitiveness Report
Austria	0.116	0.910	0.123
Belgium	0.266	0.210	0.296
Bulgaria	0.049	0.001	0.412
Croatia	0.033	0.006	0.050
Cyprus	0.675	0.035	0.599
Czech Republic	0.047	0.438	0.111
Denmark	0.796	0.193	0.321
Estonia	0.002	0.400	0.015
Finland	0.220	0.084	0.220
France	0.201	0.398	0.105
Germany	0.460	0.332	0.230
Greece	0.701	0.187	0.212
Hungary	0.098	0.201	0.034
Ireland	0.002	0.067	0.635
Italy	0.561	0.007	0.000
Latvia	0.619	0.682	0.129
Lithuania	0.079	0.016	0.323
Luxembourg	0.101	0.475	0.239
Malta	0.004	0.333	0.301
Netherlands	0.021	0.294	0.173
Poland	0.933	0.285	0.284
Portugal	0.156	0.635	0.066
Romania	0.649	0.813	0.618
Slovakia	0.099	0.004	0.086
Slovenia	0.553	0.249	0.358
Spain	0.160	0.696	0.196
Sweden	0.689	0.196	0.437
United Kingdom	0.575	0.571	0.231

When looking at bivariate analysis for ranking score values (Table 4), it becomes clear that there is very little relationship between rankings. Even when one ranking pair achieves high R^2 values for a specific country, the two other pairs score much lower. Surprisingly only Romania scores R^2 values higher than

0.5 for all three ranking pairs. This indicates very little relationship between all three rankings. Further, looking vertically, R^2 values change significantly depending on the country. For example, the pair of Global Innovation Index and Bloomberg Innovation Index show R^2 value for Poland of 0.933, which is the highest value in the entire table. However, the same pair goes as low as 0.002 in the R^2 coefficient for Ireland.

Table 5 Bivariate analysis of ranking rank values. R^2 coefficients are calculated for each pair of rankings per year.

	Year					
	2019	*2018*	*2017*	*2016*	*2015*	*2014*
Global Innovation Index / Bloomberg Innovation Index	0.565	0.541	0.521	0.564	0.517	0.559
Global Innovation Index / Global Competitiveness Report	0.793	0.800	0.731	0.772	0.448	0.751
Bloomberg Innovation Index / Global Competitiveness Report	0.729	0.758	0.568	0.556	0.449	0.637

Coefficients of determination for rank values (Table 5) show a similar trend to what has been seen in Table 3 but are significantly lower. None of the values goes beyond 0.8, and the lowest R^2 value in the table is 0.488. This means that rank-wise variance of the ranking values is lesser than the variance of the score value.

Table 6 Bivariate analysis of ranking rank values. R^2 coefficients are calculated for each pair of rankings per country for datasets between 2014 and 2019.

Country	Global Innovation Index / Bloomberg Innovation Index	Global Innovation Index / Global Competitiveness Report	Bloomberg Innovation Index / Global Competitiveness Report
Austria	0.541	0.221	0.846
Belgium	0.103	0.144	0.483
Bulgaria	0.091	0.388	0.019
Croatia	0.015	0.038	0.297
Cyprus	0.750	0.024	0.429
Czech Republic	0.028	0.071	0.001
Denmark	0.088	0.004	0.087
Estonia	0.399	0.018	0.071
Finland	0.258	0.164	0.200
France	0.056	0.427	0.202
Germany	0.306	0.524	0.047
Greece	0.009	0.334	0.040
Hungary	0.146	0.040	0.000
Ireland	0.008	0.133	0.001
Italy	0.389	0.050	0.496
Latvia	0.136	0.323	0.355
Lithuania	0.001	0.221	0.001
Luxembourg	0.096	0.735	0.000
Malta	0.335	0.209	0.154
Netherlands	0.114	0.014	0.669
Poland	0.788	0.416	0.639
Portugal	0.145	0.024	0.004
Romania	0.006	0.320	0.494
Slovakia	0.340	0.004	0.286
Slovenia	0.101	0.162	0.037
Spain	0.083	0.305	0.055

Sweden	0.005	0.199	0.360
United Kingdom	0.448	0.272	0.132

Finally, evaluation of the coefficients of determination of ranks per country reveals that there is no single country that gets an R^2 of more than 0.5 for all three ranking pairs. The lowest R^2 value is less than 0.001, which indicates that both rankings are completely different and random. The largest value in Table 6 is 0.846 for Austria and the Bloomberg Innovation Index and Global Competitiveness Report ranking pair. This indicates a relatively strong relationship between two rakings. But this is only true for Austria, coefficients of determination for this ranking pair for other countries are significantly lower. coefficients of determination for rank values are significantly lower than coefficients of determination for score values. This indicates that there is more variance between ranks than there is between ranking scores.

Discussion

The bivariate analysis and respective plots show some trends. Generally, the score values of all three rankings follow a certain relationship. However, the relationship is not very strong, meaning the rankings are clearly related but not the same. Preferably all points should lay on the dashed line or in close approximation to the dashed line. Instead, the discrepancies are quite pronounced. These discrepancies in ranking position and ranking score make it difficult to answer the research question and identify the most innovative countries within the European Union. Based on the rank values Sweden, Finland, and Germany are the most innovative European Union economies irrespective of ranking type. This result is also in agreement with the findings of the Innovation Union Scoreboard, which lists Sweden and Finland as 'Innovation Leaders,' while Germany is considered to be a 'Strong Innovator.' It becomes difficult to identify the most innovative economies based on the ranking score values. The discrepancies between score values of all three rankings are too significant to allow for a clear answer.

The points on the graph showing the relationship between the Bloomberg Innovation Index and Global Competitiveness Report (Figure 5) are quite far away from the dashed line, which corresponds to the exact match for both rankings. In addition, most of the points are shifted below the dashed line. This figure indicates that there is a strong relationship between two rankings. However, the values for the same county are lower in the Global Competitiveness Index compared to the same countries in the Bloomberg Innovation Index.

Figure 6, which shows the relation between the Bloomberg Innovation Index and the Global Innovation Index, resembles the same relationship as the previous graph. The score values of the Global Innovation Index are significantly lower compared to the score values of the Bloomberg Innovation Index, which results in the points being generally below the dashed line. The spatial distribution of the points is also quite diverse. The points do not resemble a strict linear trend, although some trends can be seen.

Figure 7 showing the relation between the Global Innovation index versus Global Competitiveness Report shows the closest relationship out of all three graphs. The points are tightly packed, resembling a sort of linear trend. Most of the points are also in close approximation to the dashed line, which means that the score values for the selected 28 European Union member states are not too far away from each other. However, it must be noted that the situation may change when considering other non-EU countries. The slope of the closest linear relation between the values shows significantly different values compared to the dashed line. Which means that the European Union member states which are generally higher in these two rankings show slightly higher score values in the Global Competitiveness report compared to the Global Innovation Index, and vice versa the European Union countries that are generally lower in the innovation rankings are show significantly lower score values in the Global Competitiveness Report compared to Global Innovation Index score values. It might also be that the score interval in Global Innovation Index might be smaller compared to the interval in the other ranking effectively, resulting in a tilted slope.

Interestingly, Figure 5, Figure 6, and Figure 7 show two separate point clouds meaning that there are two distinct groups of countries in the European Union in terms of innovation. Looking at these two graphs in more detail, it becomes evident that the countries with higher scores are the countries that have been members for a longer period of time, whereas the group of countries with lower scores is a group of countries that joined the European Union relatively recently. This is likely caused by several factors. European Union was initially formed by wealthier and more developed countries and later joined by European countries that were less fortunate. These new European Union members are often latecomers when it comes to innovation capacity. Having a large and common market as well as freedom of talent flow across the borders is also likely contributor. Finally, the European Union has developed a number of policies and programs to support innovation, i.e., Seventh Framework Programme and more recently Horizon 2020, to support and enable innovation. Old European Union member states have been benefiting from these mechanisms for a long time, while new members take advantage of it only in the last several years. Figure 6 does not show a distinct separation between old and new European Union members. The scores on the graph are more uniform and show continuity.

The relationship between rankings looks very different when considering the rank position of the 28 European Union member states. The graphs are shown in Figure 9, Figure 10, Figure 11, and Figure 12. The predominant difference is how loosely packed the points representing the countries are when ranks are compared. Loose packing of the countries means that there is a more substantial discrepancy in terms of the rank position. However, the points are more closely following the dashed line, which would mean that even the discrepancies are more significant; they still more closely follow some relation. However, the relationship between rank values of 28 European Union countries as seen by Bloomberg innovation Index versus Global Competitiveness Report (Figure 9) and Global innovation Index versus Global Competitiveness Report (Figure 11) initially follows the trend along the dashed line to at the later stage show significant divergence from the pattern and go completely off the dashed line. This clearly illustrates that the countries on top of the ranking tend to follow similar trends despite used methodology, whereas countries that are considered less innovative are also more prone to be differently ranked depending on the ranking used. These two graphs also show some significant outliers which are belied to be caused by the discrepancies of the values in the Global Competitiveness Report, which is the common nominator between two graphs, and both cases happen in 2015. This can be caused by the different methodologies used this year.

Moving to Figure 8, which illustrates the ranking score change over a period of years where green trace corresponds to the Bloomberg Innovation Index, blue to the Global Innovation Index, and red to Global Competitiveness Report. Score and rank records for Bulgaria in 2017, Cyprus in 2014, 2015, and 2016, Estonia in 2015, Romania in 2016, and Slovenia in 2017 and 2018 are missing from the Bloomberg report. While certain values are missing from the Bloomberg Innovation Index, it is still quite apparent that the score values for the Bloomberg Innovation Index are generally significantly higher than the scores of two remaining rankings, whereas the score values of the Global Competitiveness Index are either slightly higher or very similar to the values of the Global Innovation Index. Additionally, the values of all three rankings are quite uniform and do not change significantly over the period from 2014 to 2019. The ranking that is the most dynamic over the studied period is the Bloomberg Innovation Index, in which values can oscillate quite a bit for specific European Union countries (Figure 12). The Global Innovation Index and the Bloomberg Innovation Index are relatively constant for most of the countries, whereas the Global Competitiveness Report ranking values change significantly. For example, Sweden experiences a significant ranking drop in 2015 by over 40 positions. The Global Competitiveness Report 2015-16 claims that '*Since an update in 2007, the methodology has remained largely unchanged* (Klaus Schwab, 2015),' until more recent 2018 and 2019 editions which rely on the so-called GCI 4.0 methodology. The reason for the sudden decrease in Sweden's position is unknown but may likely be related to input data availability. Hungary and Romania initially decrease their ranking position in the Global Competitiveness Report to be among some of the most innovative economies quickly. Croatia and Bulgaria have also been effectively becoming major innovators within only a period of six years. This is highly unusual and shows that relatively insufficient change in the score can immensely affect the rank position of a country. The effect is so visible, pronounced, and significant that maybe the ranking positions from such metrics should be abolished, and the only overall score of the country should be reported to illustrate the country's innovation capacity as assigning a specific ranking position to a country can be highly misleading.

Bivariate analysis and quantitative evaluation based on R^2 coefficient reveal some relationship in certain cases between rankings. However, in terms of score and rank values, the majority of rankings are uncorrelated. This further means that trends shown in these rankings are very different when compared with each other. The highest coefficient of determination does not go beyond 0.9, whereas the lowest one is less than 0.001. The majority of the cases show R^2 values of less than 0.5 which indicates a low relationship between two rankings. Tables with coefficients of determination support findings shown in figures.

It is worth noting that ranking plots and score plots show very different relationships. Ranks are stricter because only one country is allowed to be rank 1, one country with rank 2, etc. Whereas score plots are in a way, more organic. The scoring system accommodates not only a broader ranking scale but also non-uniform distribution intervals. For example, countries with ranks 1 and 2 can have very similar score values, but countries ranked 27 and 28 can be far away from each other on the score scale.

Conclusions

The results and discussion presented in the previous chapters showed that the current innovation metrics are not consistent with each other, as each of them provides slightly, and often completely different results. The discrepancies in the country's ranking positions are generally significant. Having this in mind, from the above discussion, it becomes evident that the three rankings considered in the study are very different methodologically and, as such, result in different outcomes, which are, in the majority of the cases, uncorrelated to each other. The question here is not really about reliability, but rather what these rankings measure. Since all three rankings claim to measure innovation performance and all three result in very different outcomes, it becomes increasingly clear that they all cannot be dealing with measuring the same parameter. This leads to further thought, if these three rankings show significantly different results, and assuming that one of them is measuring innovation, what is measured by two other rankings.

Unless the researcher assumes that innovation is relative and hence, all three rankings are measuring innovation from different perspectives and using different indices. Innovation has many different definitions and can be perceived differently by different individuals. In such a case, in relative terms and by comparing similarities and differences, the reliability of three rankings was presented through bivariate analysis, which showed that all three studied rankings are generally more similar when comparing ranking score values rather than rank positions. However, even a comparison of the score values shows significant differences between all three measurement frameworks.

It is also important to notice that all three rankings use very different methodologies, evaluate different parameters, and often assign different weights to these parameters. While R&D expenditure and number of patents are common indicators used to evaluate innovation performance across all three rankings, each ranking also uses its own unique parameters. For example, Global Competitiveness Ranking uses international co-invention or multi-stakeholder collaboration, among many other unique parameters; however, these are generally not used in two other rankings. Bloomberg Innovation Index, among other parameters, uses a parameter called researcher concentration, which looks at the number of active researchers per country, whereas Global Innovation Index uses parameters like online creativity, political environment, or knowledge absorption, which are not used in two other rankings.

Because of three very different methodologies, that use different parameters with different weights to measure innovation performance, the outcomes both in terms of ranking scores but also the overall country rank are very different. All three rankings use a different approach and come up with different outcomes; it is unclear which ranking measures innovation more or most precisely than the others. The perception of innovation differs and is relative based on which methodology and ranking are selected.

The results presented in the study are not consistent enough to answer the question. All three rankings show significantly different results, and as such, extrapolating of these results did not provide the answer to the question. The solution to the problem would be to consider each of the rankings for each of the countries separately, which would lead to three, most likely, very different results for each of the studied countries, which once again would not provide a clear answer to the above question.

Possibly, based on previously provided analysis, the best overview of the future of innovation in Europe would be Figure 8 and Figure 12, as they compare the historical position of each of the European Union member states over a period between 2014 and 2019. The image emerging from those figures shows that the majority of the European Union member states have held a steady global innovation position during the study period. Many of the EU member states have seen a slight improvement in their innovation performance. In contrast, new European Union member states have significantly improved their innovation performance since joining the EU. It has to be noted that Figure 12 potentially presents a better overview as it lists the rank position of each of the EU member states and, by doing so, allows to compare the state's position globally, compared to all other studied countries.

The answer to the main research question, w*hich are the most innovative European Union member states?*, is not straightforward. Generally, European Union member states hold a consistent and robust position in all three rankings. However, depending on the rankings country's position changes, which makes it challenging to provide a clear answer to the question. Moreover, some of the plots shown in the results chapter of the study illustrated that the European Union is divided into two groups, one of which is leading innovators globally and the second group being average innovators. The latter group consists mainly of new European Union members. It can be debated whether both groups should be considered collectively or separately.

It seems that based on the rank values Sweden, Finland and Germany in this order are the most innovative European Union economies irrespective of ranking type. In addition, the position of all three economies remains stable over the years. The order becomes less obvious based on the ranking score values.

Readers must bear in mind that these rankings are relative and that there is no gold standard. The current study proved that there are a number of reasons to treat these rankings skeptically. Bloomberg Innovation Index defined innovation as "*the creation of products and services that make life better*," which implies that the authors have focused on tangible results of innovation. The Global Innovation Index takes a different and more comprehensive approach to measuring innovation, in which both inputs and outcomes of innovation processes are evaluated. All three reports acknowledge that their methodologies are not flawless and that certain metrics might be missing or be incomplete. The authors also are upfront about inherent problems with the measurement of innovation and their active pursuit to improve their approaches with each edition. However, this itself makes it hard to compare the results over time. Some metrics present in all three rankings seem to be irrelevant or slightly irrelevant. For example, it is hard to measure the relative value of patents, especially when it is unclear whether these patents will produce any tangible results. As such, using a number of patents generated in a specific year is against Bloomberg's definition of innovation already brought up before.

Nevertheless, these three methodologies to evaluate, measure, and quantify innovation performance appear useful to identify a rough grouping of the world's most innovative economies and regions. Further improvements and revaluation of the methodologies themselves could result in more robust and reliable outcomes.

Future perspectives

The work presented here is only an introduction to a bigger and very complex problem of measuring innovation performance and how individuals perceive innovation. There are numerous interesting and worthwhile avenues to explore beyond the current study.

It would be interesting to expand the scope of the study beyond 28 European Union member states and see how robust and comparative the three rankings are when considering both developed and developing nations. Doing so would require a very systematic approach, but lessons learned from the current study can serve as a guide. Also, it is important to note that only a limited number of countries can be compared because the Bloomberg Innovation Index provides results only for a limited number of countries. Bloomberg Innovation Index used to be limited to 50 top innovators, and more recently, the list expanded to 60 most innovative countries.

It would be of interest to explore how the three studies performance indices align with the recommendations from the Oslo Manual and how these recommendations can be implemented in existing methodologies to make the three rankings more robust, reliable, and consistent with each other. Currently, the three rankings give very different results, and as such, they are not reliable. This makes people think that all the glory heralded in numerous publications that relied on those rankings was most likely wrong and promoted countries that may not be as innovative as those rankings claim. More in-depth analysis has to be done to provide further recommendations to publishers of all three rankings to make them aware that their work may not be reliable, misleading, or even simply wrong. This further work should also analyse what steps and measures have to be taken to improve the reliability of those rankings and provide clear and reliable recommendations to the authors.

Further discussion should also be coined around whether the ranking position is a parameter that should be reported. As seen in the current work, these rankings can be very fragile, even to a relatively small change in the overall score position. It might be a better idea to report only the overall score of the country, i.e., on the 0-100 scale, which shows to be more robust to changes.

One important and essential question which could be addressed in the future work is having three different rankings, often providing very different results and assuming that one of those rankings is correct and gives an indication of the country’s innovation performance, which is measured by the two other rankings.

Another avenue that would be of interest to explore is to answer a question of whether the discrepancies in the rankings are caused by methodological factors or differences in the input data. Further, if these rankings influenced the national and international innovation policies, are these policies still relevant, or are they wrong and to what extent. If so, should these policies be changed or significantly adjusted based on new evidence.

An important question which would be of benefit to answer is since the methodological approaches have changed or have been adjusted over the years, are the reports published in different years reporting the same thing or something different every time the ranking methodology has changed. In this case, how comparable are these results? Are significant changes in the country’s position a result of the methodological difference between the years and how to evaluate the impact of such methodological change or adjustment.

Finally, would it be of benefit for all three publishers to consolidate their approaches and methodologies and redirect their resources to develop one, more robust approach to measuring innovation performance, or would this mean that single ranking could divert even further because there would be no comparison? Having three competing rankings ensures some degree of quality, would monopoly in evaluating innovation performance result in poor performance, bias, and flaws.

An interesting exercise would be to calculate average value for each of the countries based on all three rankings and compare the results and country order in this new ranking.

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