A Framework for National Innovation Determinants

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Abstract

In a context of globalization and market openness, innovation has become a decisive engine to build a competitive advantage for economies on a national scale. Innovation is today essential for both entrepreneurs and policy-makers. In many countries, governments have used a set of incentives and processes, commonly referred to as National Innovation Systems (NIS), to boost innovation. However, these NISs require permanent monitoring and evaluation of existing potentials, reached results, as well as important weaknesses. To this end, several indicators have been used for comparative evaluations of innovation efforts and performances. The aim of this study is to contribute to the understanding of factors influencing the innovation performance of a country. Hence, a framework is proposed for analyzing innovation in a country and predicting its ability to innovate. A case study is also presented based on the 2015 data of the Global Innovation Index, defining the most important drivers (i.e., determinants) of the National Innovative Capacity.

Keywords
National Innovation System, National Innovative Capacity, Innovation Determinants, Innovation Framework.

1. Introduction

The development of any economy, especially in the 21st century, is based on knowledge and innovation as key drivers of economic growth. Innovation and technical progress are the product of a complex set of interactions between the actors producing, distributing and applying various kinds of knowledge (NIS, OECD, 1997). To a large extent, the innovative performance of a country depends on how these actors relate to each other as elements of a collective system. Both academic scholars and policy-makers focus on the increasing importance of innovation sources and consequences. In the late 1980s, the assessment of the capacity to innovate became an important asset for providing information about the dynamics of innovation. Therefore, many determinants and indexes were introduced in order to measure the innovation capacity (L. Suarez-Villa, 1990). We propose to analyse the innovative capacity of countries and identify the main factors that can differentiate the innovation dynamics of each country. This can be achieved using two complementary concepts: (i) National Innovation System and (ii) National Innovative Capacity.

1.1. Overview of National Innovation Systems

The first integrated approach to National Innovation Systems (NISs) was proposed by Lundvall (1985 and 1988). This approach is based on the concept of "National System of Production," suggested by Liszt and Von Hippel's work on the informal technical collaborations among companies. Lundvall proposed three interacting spheres for the said national system of innovation as depicted in Figure 1. First, a productive sphere related to its economic and industrial structure. Second, a training-based sphere related to human resources training. Finally, a research sphere, characterized mainly by bonds built between public research institutions and companies (Djeflat, 2002).

An NIS is largely influenced by 30 determinants (U. Seidel & al., 2013). Each of these determinants reflects an aspect of the innovation system, and they may be grouped into three levels: (i) Micro level, that provides support for main actors in the innovation system such as: enterprises, universities, organisations and R&D institutions (public and private). (ii) Meso level containing institutions. in this level can be considered as an important intermediary tool to convert policy decisions in practice. Generally, we find clusters, technology transfer centres, innovation service providers and funding agencies. (iii) Macro level, a level of national policies: laws, regulations, master plans, training and education. Therby, the 30 determinants are distributed as depicted in Figure 2.

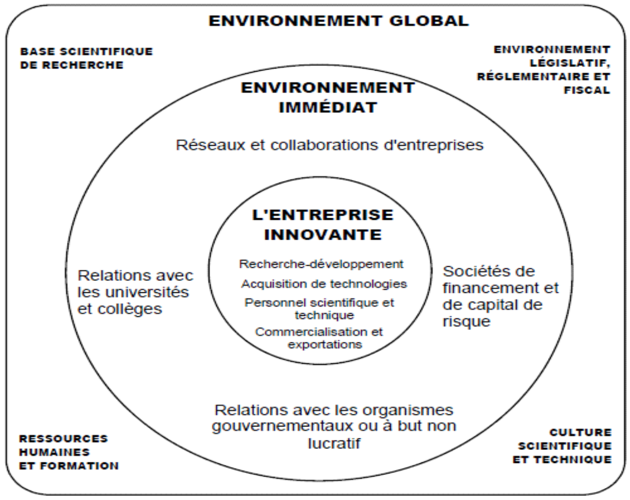

Figure 1: National Innovation System (Manuel d'Oslo, OCDE, 1997)

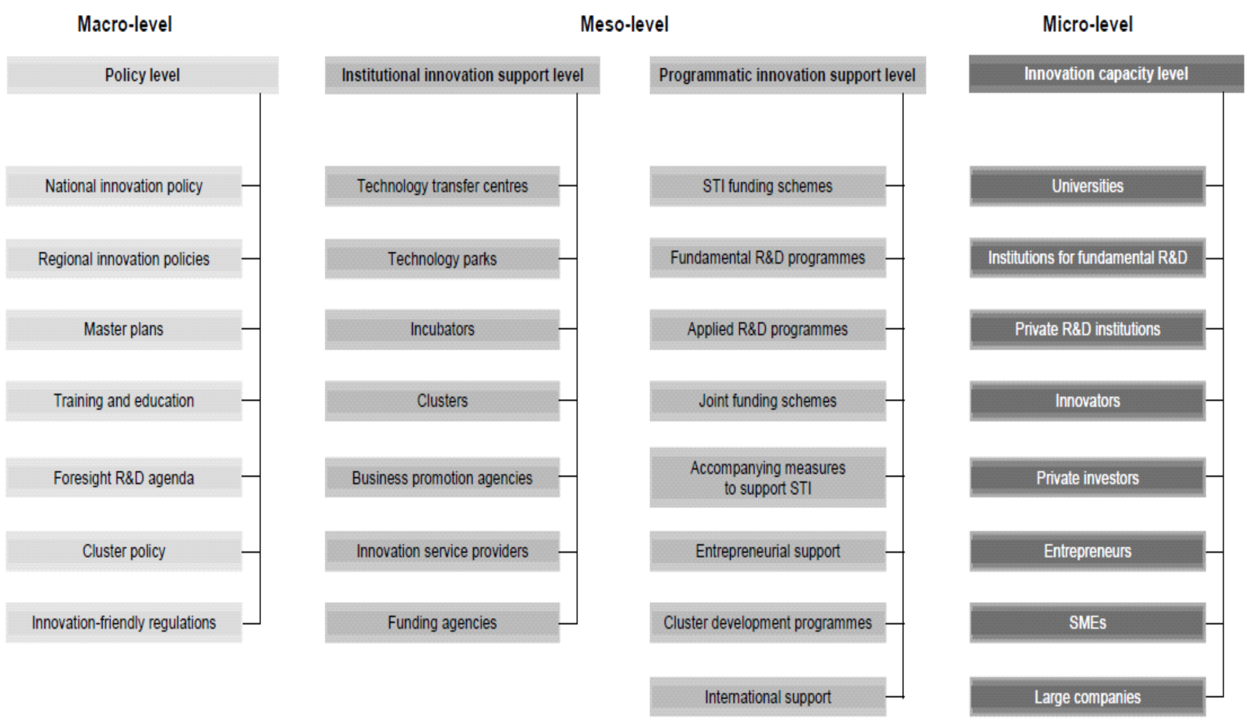

Figure 2: The 30 determinants of an innovation system - Source: Institute for Innovation and Technology, Berlin (2012)

1.2. Overview of National Innovative Capacity

National Innovative Capacity is often defined as the institutional potential of a country to sustain innovation (Hu & Mathews, 2008, Huang & Shih, 2009). This concept was introduced by Suarez-Villa (1990) to measure the level of invention and the potential for innovation in a nation. The author defined it as "the ability of a country – both a political and economic entity- to produce and commercialize a flow of innovative technology over the long term". One of the clearest indications of innovation performance, according to Suarez-Villa (1990), is the rate of patents take up issued by the US Patent and Trademarks office (USPTO). As such, the National Innovative Capacity depends on three broad elements (Furman & al., 2002, M. Porter and S. Stern): (i) Common innovation infrastructure, (ii) Cluster-specific environment for innovation, and (iii) Linkage quality. These elements are discussed hereafter.

The common Innovation Infrastructure of a nation is a set of the most important investments and policies that support innovative activities. This set includes human and financial resources, the technological sophistication, and the public policies related to the innovative activity. To assess a nation's innovation public policy, three measures are proposed: (i) The effectiveness of intellectual property protection, (ii) The ability of a country to retain its scientists and engineers, and (iii) The size and availability of R&D tax credits for the private sector.

While the Common Innovation Infrastructure gives the general context for innovation, it is ultimately in firms where innovation can be developed and commercialized. These activities take place generally in clusters. Cluster-specific environment for innovation is measured by three indicators: (i) The sophistication and pressure to innovate from domestic buyers, (ii) The presence of suppliers of specialized research and training, and (iii) The prevalence and depth of clusters.

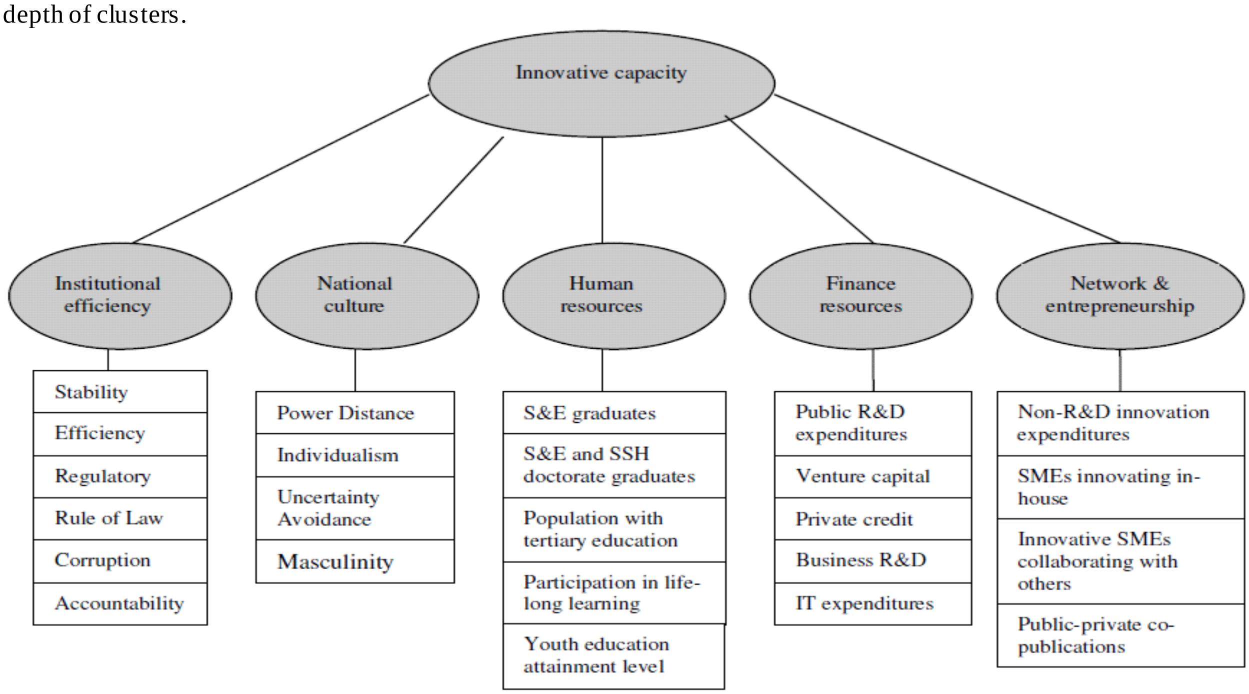

Figure 3: The determinants of Innovative capacity according to Natário et al. (2011)

The strength of linkages, on the other hand, influences the role of the Common Innovation Infrastructure to translate the potential of innovation into specific innovative outputs in a nation's industrial cluster. The relationship between the Common Innovation Infrastructure and a nation industrial cluster is reciprocal: clusters can feed the Common Innovation Infrastructure can also benefit from it. The quality of linkages between the first two blocs is measured by two indicators: (i) The overall quality of scientific research institutions (percentage of R&D performed by universities), and (ii) The strength of venture capital markets. Natário et al. (2011) proposed five levels, depicted in Figure 3, to identify and classify the determinants of national innovative capacity: institutional efficiency, national culture, human resources, finance resources, and finally network and entrepreneurship.

1.3. Review of Indexes used to assess innovation

Recognizing innovation importance in any economic development, many countries are making efforts to improve their national innovative capacity. Various international organizations have developed competitiveness indexes designed to evaluate the level of national innovation capacity. Measuring this latter is projected to become a major indicator of a country's aptitude in terms of sustainable innovation, as well as economic stability and growth. A few examples of the available international indexes are presented in the following section.

The European Innovation Scoreboard (EIS) is an index assessing the strengths and weaknesses of research and innovation systems in Europe. Since 2012, this annual scoreboard evaluates the performance of members of the European Union in terms of research and innovation. The comparison is based on a total of 25 indicators (Figure 4), combined in three pillars: enablers, firm activities, and innovators and economic effects as outputs.

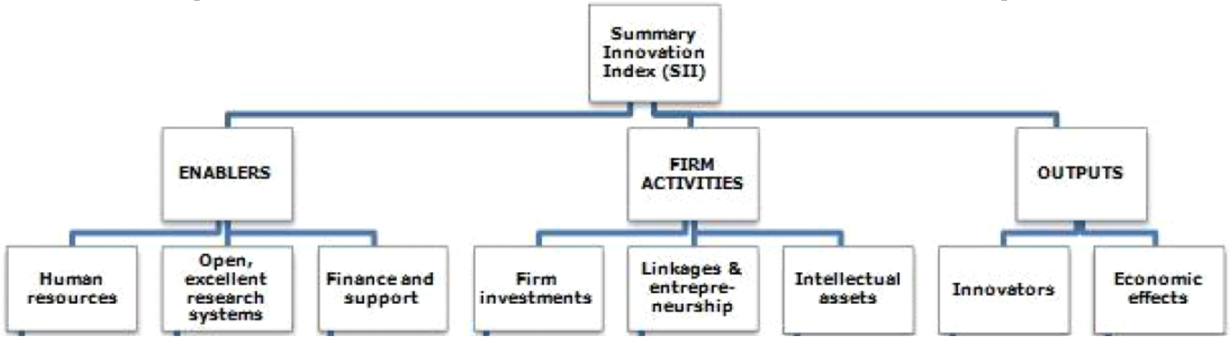

Figure 4: The basic determinants of the European Innovation Scoreboard

The Global Innovation Index (GII), on the other hand, is an annual global ranking of countries according to their ability and success in innovation. The GII is broader than the EIS in terms of both indicators and countries. The purpose of this index is to evaluate the innovation preparation processes of countries and to inform governments, businesses and individuals, with the aim of full use of innovation. As illustrated in Figure 5, GII combines institutions, human capital and research, infrastructure, market and business sophistication, as well as scientific and creative output. Other examples of indexes: (i) Innovation Index- US Innovation Capacity and (ii) Innovation Capacity Index.

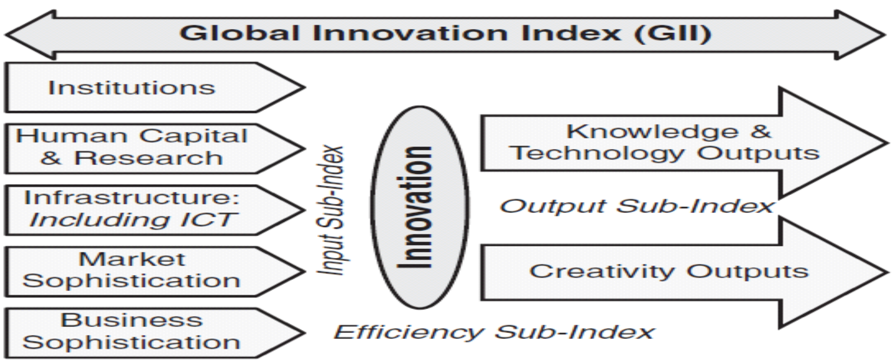

Figure 5: the basic dimensions of the Global Innovation Index

2. Proposed Framework to assess a national innovative capacity

In order to elaborate a framework to assess any country's national innovative capacity, we have identified 4 steps presented in Figure 6 and detailed hereafter.

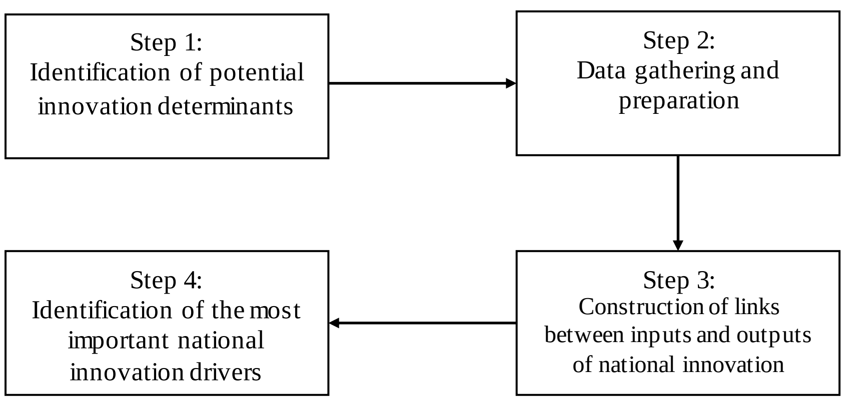

Figure 6: Proposed framework for assessment of the national innovative capacity.

Step 1: Identification of potential innovation determinants

Since the correlation between economic growth and innovation has been proved in the literature, the question of analyzing the determinants to asses it, both in firms and countries, has been investigated by numerous scholars (S. Krammer, 2009). Such as presented above, the determinants of innovation vary mainly between national policy factors, infrastructure, human and financial resources, and the capacity of networking. The outputs of national innovation performance are mainly defined in literature by technology outputs and patents; it is widely recognised as providing a reliable indication of the innovation effort of a country (Griliches, 1990, Trajtenberg, 1990, Poter & Stern, 1999, Hu & Mathews, 2008).

Step2: Data gathering and preparation

The various determinants of a national innovative capacity can be measured using indicators providing by international organisations such as UNESCO institute of statistics, United Nations Industrial Development organisation, World Economic Forum, and World Intellectual Property Organisation. The Global Innovation Index give a good example reflecting the mainly determinants mentioned above, including inputs and outputs innovation indicators. It also provides annual data from various non-governmental organizations, on 79 indicators among 142 countries.

Step 3: Construction of links between inputs and outputs of a NIS

To construct links between inputs and outputs of a national innovation system, we would like to answer to three questions: (i) why does the intensity of innovation vary between countries? (ii) which variables can we used to assess the innovation capacity? and (iii) are there any specific factors and/or policies that improve the capacity to innovate?

To answer to these questions, we propose to use a data analysis technique based on the Random Forest Method (RFM). Introduced by Breiman in 2001, RFM is a non-parametric statistical method that proved to be very effective in many applications, both for regression and classification problems. It also provides good results on data of very large size and can deal with correlated predictor variables (Ehrlinger, 2015).

Step 4: Identification of the most important national innovation drivers

An important task in this study is the prediction of the most important improvement drivers of the national innovative capacity. NISs often require permanent monitoring and evaluation of existing potentials, achieved results and also important weaknesses. Given the large number of determinants of any NIS, extracting the most important ones is crucial for scholars, entrepreneurs and policy-makers. The Random Forest method technique, used herein for data analysis, provides the possibility of variable importance measures, helping identify the most important national innovation drivers.

3. Case Study

In order to illustrate the use of the proposed framework, the analysis is performed on actual 2015 data of the global innovation index (GII) using Tree based methods.

3.1. Data gathering

As stated earlier, various studies addressed national and regional values and rankings of countries innovative capacity. Such studies are conducted for instance by the *World Economy Bank*, the *European Union* and the *European Economic Cooperation Organisation*. The data selected for this study originates from the 2015 GII report. The values are the result of a synergic collaboration between renowned international entities in academia and industry, including the *Cooperation of Cornel University*, the *Business School for the World (INSEAD)*, the *Confederation of India Industry (CII)* and *World Intellectual Property Organization (WIPO)*. Further details about GII and its annual reports can be consulted at www.globalinnovationindex.org.

3.2. Data analysis

The database used in this study is revised annually and contains data on 142 countries' innovative activities and performances. Considered variables (innovation inputs) are classified into five categories according to GII 2015, and are presented in Table 1 (in our analysis, we have named each variables Xijk, as shown in the following table).

Table 1: Innovation Inputs used in this study (according to GII 2015)

1 Institutions	2 Human capital & research	3 Infrastructure	4 Market sophistication	5 Business sophistication
X1.1.1 Political stability	X2.1.1 Expenditure on education, % GDP	X 3.1.1 ICT access	X 4.1.1 Ease of getting credit	X 5.1.1 Knowledge-intensive employment, %
X1.1.2 Government effectiveness	2.1.2 Gov'texpenditure/pupil, secondary, % GDP/cap	X 3.1.2 ICT use	X 4.1.2 Domestic credit to private sector, % GDP	X 5.1.2 Firms offering formal training, % firms
X1.2.1 Regulatory quality	X 2.1.3 School life expectancy, years	X 3.1.3 Government's online service	X 4.1.3 Microfinance gross loans, % GDP	X 5.1.3 GERD performed by business, % of GDP
X1.2.2 Rule of law	X 2.1.4 PISA scales in reading, maths, & science	X 3.1.4 E-participation	X4.2.1 Ease of protecting investors	X 5.1.4 GERD financed by business, %
X1.2.3 Cost of redundancy dismissal, salary weeks	X 2.1.5 Pupil-teacher ratio, secondary	X 3.2.1 Electricity output, kWh/cap	X4.2.2 Market capitalization, % GDP	X 5.1.5 Females employed with advanced degrees, % total employed
X1.3.1 Ease of starting a business	X 2.2.1 Tertiary enrolment, % gross	X 3.2.2 Logistics performance	X4.2.3 Total value of stocks traded, % GDP	X 5.2.1 University/industry research collaboration
X1.3.2 Ease of resolving insolvency	X 2.2.2 Graduates in science & engineering, %	X 3.2.3 Gross capital formation, % GDP	X4.2.4 Venture capital deals/tr PPP$ GDP	X 5.2.2 State of cluster development
X 1.3.3 Ease of paying taxes	X 2.2.3 Tertiary inbound mobility, %	X 3.3.1 GDP/unit of energy use, 2005 PPP$/kg oil eq	X4.3.1 Applied tariff rate, weighted mean, %	X 5.2.3 GERD financed by abroad, %
	X 2.3.1 Researchers, FTE/mn pop	X 3.3.2 Environmental performance	X4.3.2 Intensity of local competition	X 5.2.4 JV–strategic alliance deals/tr PPP$ GDP
	X 2.3.2 Gross expenditure on R&D, % GDP	X 3.3.3 ISO 14001 environmental certificates/bn PPP$ GDP		X 5.2.5 Patent families 3+ offices/bn PPP$ GDP
	X 2.3.3 QS university ranking, average score top 3			X 5.3.1 Royalty & license fees payments, % total trade

Random Forest (RF) is a machine learning algorithm that is particularly effective in identifying links between a dependent variable and the explanatory variables. It will rank the variables according to their relationship with the dependent variable. The main objective the analysis of the GII data is to investigate the association between variables (innovation inputs) and predicting (innovation outputs).

For our analysis, the application of RF method enables the explanation of 83.7% of the analysed data. In other words, the model explains about 84% of the variability in GII. This presents a good indicator for the quality of our model.

For the Pruned Regression Tree, we have 6 terminal nodes (leaves) of the tree, depicted in Figure 7.

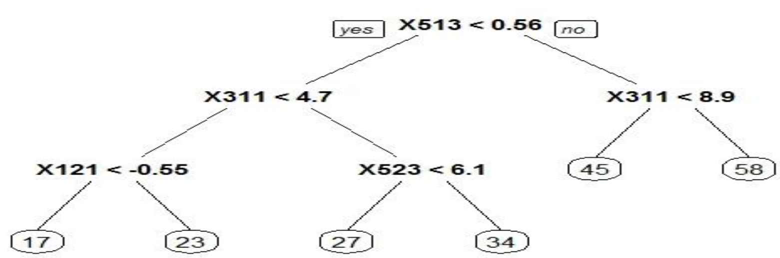

Figure 7: Regression Tree for predicting innovation outputs based on the innovation inputs

In addition, the R^2 (the percent of variance explained by the model) of our model is about 0.8733, meaning more than 87% of the variance in innovation outputs is explained by the innovation inputs. Also, it has a low predictable R^2 of 0.65 which means that it lacks good generalization capacity.

3.3. Variable importance

Random forests use all available variables in the construction of a response predictor. On the other hand, it does not propose explicit p-value or significance test for variable selection. Instead, this method ascertains, through the split rule optimization, which variables contribute to the prediction; optimally choosing variables that separate observations.

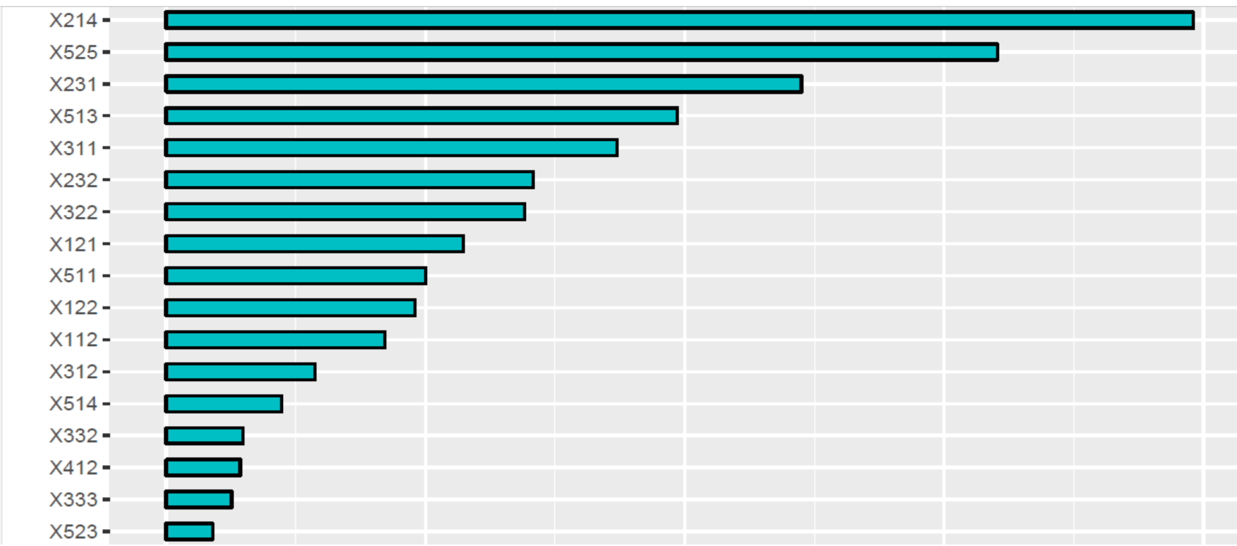

Figure 8: Random forest Variable Importance

Figure 8, allows as outputting a list of innovation inputs variables that are important in predicting the innovation outputs. It offers the possibility to subset the data to only include the most important variables. For this random forest analysis, the top two variables (X214 and X525, i.e., “assessment in reading, mathematics, and science” and “patent families filed in at least three offices”, respectively) have the largest variable importance, with a sizable difference to the remaining variables. This indicates that attention must be focus on these two variables, at least, over the others.

Indeed, the innovation input X214 representing the “assessment in reading, mathematics, and science” is developed [by the *Organisation for Economic Co-operation and Development* (OECD) and the *Programme for International Student Assessment* (PISA)] through three yearly surveys that examine 15-year old students’ performance in reading, mathematics, and science. Innovation input X525, on the other hand, represents patent families filed in at least three offices. A “patent family” is defined as a set of interrelated patent applications filed in one or more country/jurisdiction to protect the same invention. In this study, ‘patent family data’ refers to patent applications filed by residents in at least three IP offices. Finally, input X231 measures the number of researchers per million populations. This number considers fulltime equivalence of researchers in academia and R&D, as well as professionals engaged in the conception or creation of new knowledge, products, processes, methods, or systems and in the management of the projects concerned. Postgraduate PhD students engaged in R&D are also included. These categories belong respectively to the sub-indexes: Education (Human capital and research), Innovation Linkages (Business sophistication) and Research & Development (Human capital and research). Lower values for these determinants indicate that countries should reinforce their efforts in each area to increase their national innovative capacity.

4. Conclusion

Understanding the role of innovation in competitiveness and economic development is becoming increasingly important as a challenge for building innovative capacity. The innovation system approach has proven useful in explaining the mechanisms behind varying economic performances in developing countries. In this study, we propose an assessment framework for the determinants of national innovation performances. The framework contains 4 steps: (i) Identification of potential innovation determinants, (ii) Data gathering and preparation, (iii) Construction of links between inputs and outputs of national, and (iv) Identification of the most important national innovation drivers.

To illustrate our approach, a case study for data analysis is presented, based on the 2015 Global Innovation Index data. The analysis shows that three factors are the most important variables improving the national innovative capacity, namely (i) the assessment in reading, mathematics, and science for 15-year old students, (ii) the patent families filed in at least three offices, and (iii) the researchers' fulltime equivalence. Further analysis is needed to establish a better understanding of the determinants of innovation, their mutual interactions, and to investigate possible new clustering of determinants.

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Biography

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