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STRUCTURAL PCA-MLR MODEL OF THE INNOVATION ENVIRONMENT IN BRICS COUNTRIES

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Abstract

The process of globalization forces market changes in the form of intense competition. Economies can survive by getting competitive advantage in the global market through developing innovation. The main target of this empirical research is to discover the most important innovation components that constitute structure of the global innovation index (GII) and judge their influence in emerging BRICS economies. Innovation process is discussed on the grounds of GII ranking scores accumulated from 2011 to 2021. The research outcome of the Principal Component Analysis adopted nine components that represent seven dimensions. Extracted components are further used in the regression analysis to establish a multiple linear regression (MLR) equation for predicting the GII score used in the overall ranking. Derived regression solution introduced valuable MLR results with high coefficient of determination where 98.2% of the GII values are explained by the extracted components. The dominant effects on GII are attained in innovation components that include general infrastructure and knowledge workers. Moreover, comparison analysis of the actual and computed GII scores illustrated 99.1% overlap between the two values. Evaluated results of the PCA-MLR analysis serve to investigate the success in developing innovation performances in emerging economies by comparing innovation index accomplished by BRICS.

Keywords: innovation, Global Innovation Index, BRICS, principal component analysis, regression

1. INTRODUCTION

Nowadays, every country in the world organize and plan its innovation activities through innovation systems that shape national innovation environment. Innovation systems across the world differ in actors, their communication and elementary

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institutions (Intarakumnerd & Goto, 2018). Due to globalization process, national innovation systems are constantly challenged and under pressure to adjust to the needs of the global market. Contemporary literature has already discovered the positive coherence among economic, politic and social globalization effects and technological innovation performances (Feng et al., 2019; Zheng et al., 2019). Global market is undergoing innovation transition from European and North America long term leaders to emerging economies that threaten to occupy leading positions by disclosing disruptive technology and innovations (Si et al., 2020). Emerging economies perceive their opportunity to triumph on the market and have shifted their focus from the primary goal reflected in the speed of the economic growth to the new approach that stimulates the quality of the development. Instead of investing resources into faster economic progression, authorities in emerging economies have switched towards investing in innovations that enable sustainable competitive advantage (Tian et al., 2019; Zhao et al., 2019). The evolution from the extensive development perspective to the innovation-driven perspective is expected to accelerate new development path for organizations. Therefore, the subject of this study is analysing innovation environment in emerging BRICS economies.

The main aim of this research is to propose a structural model of the innovation performances of BRICS countries as the representatives of the emerging world economies in the light of the most contributing global innovation index (GII) components. Therefore, conducted analysis provides possibility for countries to extract the most important components that establish decisive national innovation performances. Model is designed so that can be flexible and adjusted to any country in the world. Prior studies have mainly focused on the development outcomes of the individual dimensions of the global innovation index (Hu, 2021) and a few of them tried to identify the internal relationship between innovation input and innovation output dimensions (Nair et al., 2014). This study offers different perspective on the assessment of innovation performances and attempts to associate the most effective components in the GII structure. The newly narrowed model of the GII structure is validated using the prediction accuracy results provided by the regression analysis.

The research results of the study will provide broad knowledge about innovation areas that are progressing in the right direction and otherwise innovation weak points where BRICS economies are not so successful. Empirical results will supply enough information about fostering efforts towards innovation climate and acquiring appropriate innovation outcomes in comparison to the other countries in the world. In addition, it will discuss what the main problems in emerging countries are when it comes to the transformation towards innovation society. In that way, BRICS economies can coordinate their strategies that are supported by adequate policies and targets. Based on identified challenges and opportunities reflected into evaluation scores of various innovation dimensions and components, other emerging economies can carry out benchmarking analysis and gather valuable intelligence about the best practice in the innovation domain. Additional benefit that emerges from this study is related to the factor analysis methodological framework that illustrates research approach to the complex problems that have to be

decomposed into integral components to simplify solving procedure. Employed methodology will allow reducing a variety of components to the most important one-factor or two-factor solution for each innovation dimension. After implementing factor analysis, the results will be used to build a regression model. The research output can be used as a feedback information instrument for governments that supervise effectiveness of the innovation development strategies and policies. All other stakeholders like researchers or investors in the field of innovation can also use the research results as a support in making decisions and a guide for the future investments. Proposed methodology can be used for solving other complex problems not only in the innovation domain but also for problems that can occur in different research areas.

The paper is structured into seven sections. The first section is introducing the importance of innovation process. The second section provides theoretical background of different innovation research issues in the scientific environment of the emerging economies. Third section presents brief overview of the BRICS innovation performances. Section four deals with a theoretical description of a hybrid PCA-MLR methodological framework employed in the study. Following sections five, six and seven report the most important research results, discussion, limitations and conclusion with regard to the future investigation plan.

2. LITERATURE REVIEW

Innovation activities are subordinated by strong institutional framework (Wang et al., 2021). In many industrialized countries effective innovation policy has been used as an instrument in improving competitiveness for years and has been adapted to the needs of emerging and developing countries as well (Aguirre-Bastos & Weber, 2018). Governments' role in improving national innovation performances is powerful since it simultaneously triggers several effects. Innovation policies brought by the authority provide incentives for institutions and organizations to transform their activities towards innovation, in turn managers encourage their employees to be innovative therefore their business results straighten national innovation competitiveness (Hameed et al., 2021). With its regulations and public policies, authorities are the ones who control and shape the market conditions and competitiveness of a country or a region (Veiga et al., 2020). Samara et al. (2012) define innovation in the context of production, diffusion and translation of acquired technological expertise into novel products and processes. Therefore, the most important institutional objective is reaching a common goal of all stakeholders in the context of innovation strategies and policies that are empowering the connection between academic and industrial research (Prokop et al., 2021).

Innovative solutions are appraised as the driving force of the economic development and competitive advantage hence governments around the world are responsible for creating appropriate measurement of the national innovation performance (Mahroum & Al-Saleh, 2013; Kim et al., 2020). Following studies briefly provide meaningful contribution explaining the development path of innovation performances in emerging countries. Aguirre-Bastos and Weber (2018) discuss the significance of foresight in planning national

innovation systems and urgency to engage its results in guiding future policies that would frame appropriate economic and social development. Commonly measurement of the innovation productivity provides empirical evidence on the disparity of the past and current national innovation results and allows comparison with other territories and their distribution to "leading" and "lagging" countries (Zabala-Iturriagagoitia et al., 2021). One way for measuring the success of a national innovation environment is possible using the GII and this evaluation framework has already been a research topic in many studies reported by various scholars (Nair et al., 2014; Erciş & Ünalan, 2016; Franco & de Oliveira, 2017). Nair et al. (2014) engage artificial neural network methodology to investigate the relationship between innovation input and innovation output described by the GII ranking positions for 125 world economies. Empirical evidence recognizes implying prediction methodology in the sphere of innovation as a smart decision for planning future investments and solving financial issues. An earlier study from 2014 discovered a wide range of practical policies and actions in the field of human capital, innovation capital and social capital that can boost innovation performances. The most important proposed policies are concerning innovation education, trainings, cooperation between stakeholders and R&D capabilities (Lu et al., 2014). Erciş and Ünalan (2016) use GII to describe the underlying dynamics of innovation activities in Turkey and South Korea. Their comparative analysis provided a practical guideline on how Turkey as a lower ranked economy can improve its position in the global innovation environment. Esteves & Feldmann (2016) were interested in exploring the position of Brazil compared to other economies in the field of innovation by means of linear regression. Their study included GII scores and other relevant indicators into the research that proved a lag in innovation performances in Brazil due to inadequate institutional support, coordination among government, universities and organizations and low research and development financial allocations. Franco and de Oliveira (2017) report about the innovation activities in BRICS using the relationship among individual input and output dimensions of the GII concerning innovation technology and its impact on the competitiveness. Their study is addressing the timespan from 2008 to 2013 with special attention directed towards economic crisis in 2009. The research outcome suggest that BRICS should be aware about lower scores of dimensions of human capital, market sophistication, and business sophistication. The regression analysis revealed that nearly 65% of the sample could be explained by included variables. With its swift economic development in the recent decades, China has recognized the importance of boosting innovation performances of the country by allocating more financial, human and other resources into institutions, organizations and other relevant actors (Băzăvan, 2019). Other studies regarding BRICS innovation outcomes recognize China as the leader among the member states (Lacasa et al., 2019). In addition, contemporary research results about the underlying technological innovation dynamics in BRICS discover the positive effects that economic growth, human capital and research and development expenditures leave on the innovation outcome (Hu, 2021).

3. GII FRAMEWORK IN BRICS

The main aspect of this research is to discover innovation trends in emerging economies. Therefore, for the purpose of this objective, empirical research is done on the sample of BRICS group of economies comprised of Brazil, Russia, India, China and South Africa. BRICS investigation ground is particularly interesting research area since it is considered for the fastest worldwide emerging market that accounts for almost a half of the global population therefore its position in the innovation domain cannot be overlooked. Some studies report that the trend of population growth is related to the intensive technological innovations since in highly populated countries the demand is driven by the population size (Coccia, 2014). Moreover, demographical structure of BRICS highlights population increase in all member states (World data bank, 2021a). Accordingly, it is the major reason for incorporating BRICS data into the research study.

The aggregated dataset combines scores adopted from the GII reports from 2011 to 2021 (Global Innovation Index, 2011 - Global Innovation Index, 2021). GII has been established by the World Intellectual Property Organization (WIPO) with the idea to systematically report the most important trends in the global innovation world and rank each considered country by its innovation performances on a global ranking list (Silva et al., 2017). GII report is published by INSEAD Cornell University in collaboration with WIPO on annual basis since 2007. Graphical representation of the GII conceptual framework given in the Figure 1 is used to provide insight into the relationship established between dimensions and components. Calculating GII score is a complex procedure because it considers a variety of different dimensions and components. Each of the GII component represents an index measured by the World bank, UNESCO, or other relevant institutions that are presented in a form of quantitative date, qualitative data or composite indicators data (determined as the weighted average of each component) (Global innovation index, 2011; Khedhaouria & Thurik, 2017). Components are then normalized from 0 to 100 score using the min-max method to allow ranking procedure (Khedhaouria & Thurik, 2017). Ranking lists are available for the overall GII and each dimension and component.

GII report for 2021 included 132 countries in the world (Global innovation index, 2021). Presented GII structure contains following three hierarchical level that are input and output level, dimension level and component level. The quantitative data are collected for the overall GII scores, all seven dimensions that constitute GII and their components. Dimensions are split in two main groups that comprise innovation inputs and innovation outputs. Innovation inputs enable innovation activity through securing appropriate environment and innovation outputs present the results of the innovation activity. Integral part of dimensions are the components that can be further divided into subcomponents however subcomponents will not be the subject of this research therefore are not included in the figure.

GII positions of BRICS economies have changed over the time and Figure 2 illustrates their transition.

Overall GII. Overall GII score is obtained as a computed ratio of innovation inputs and innovation outputs (Global innovation index,

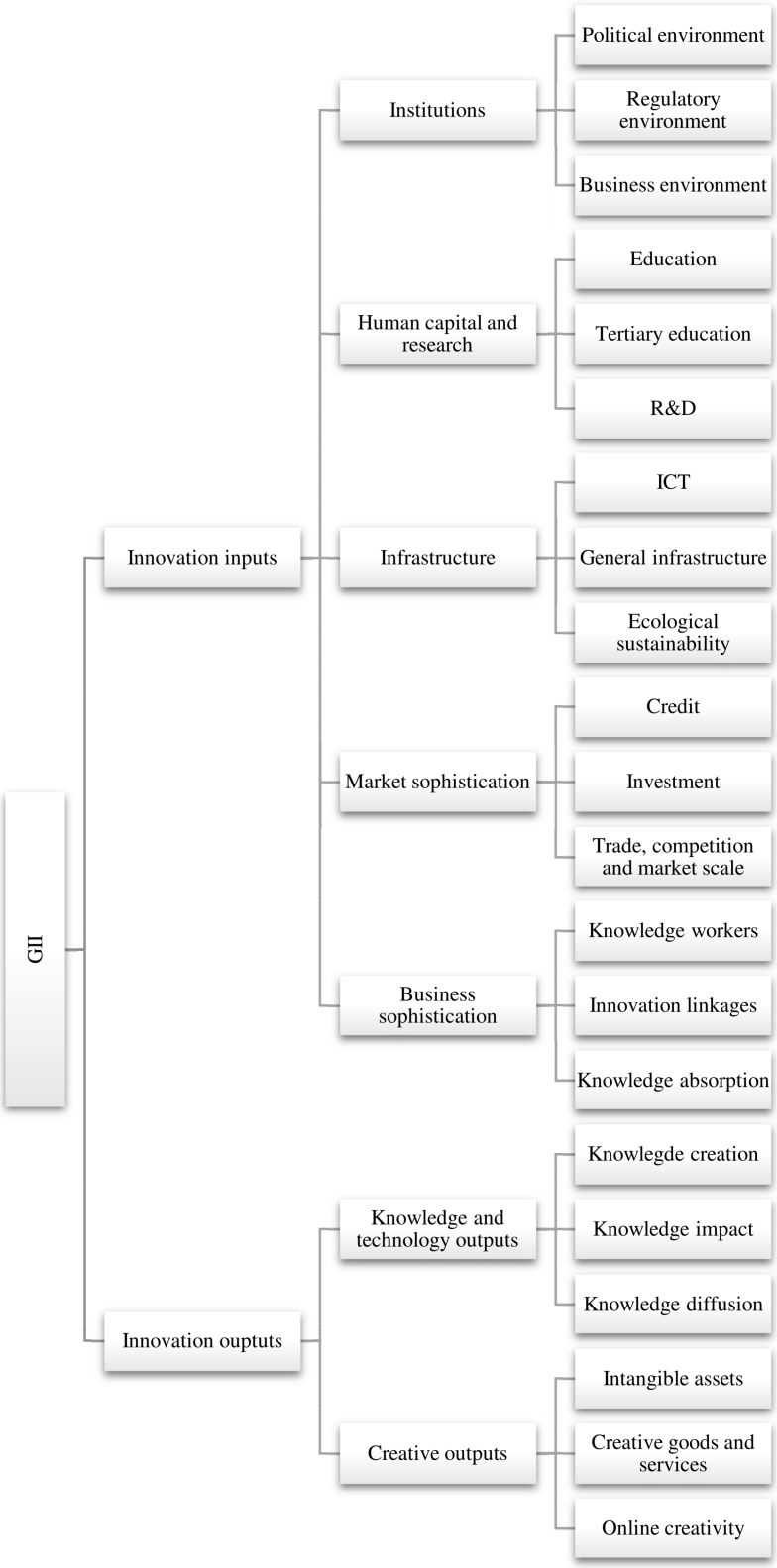


Figure 1. GII dimensions and components structure

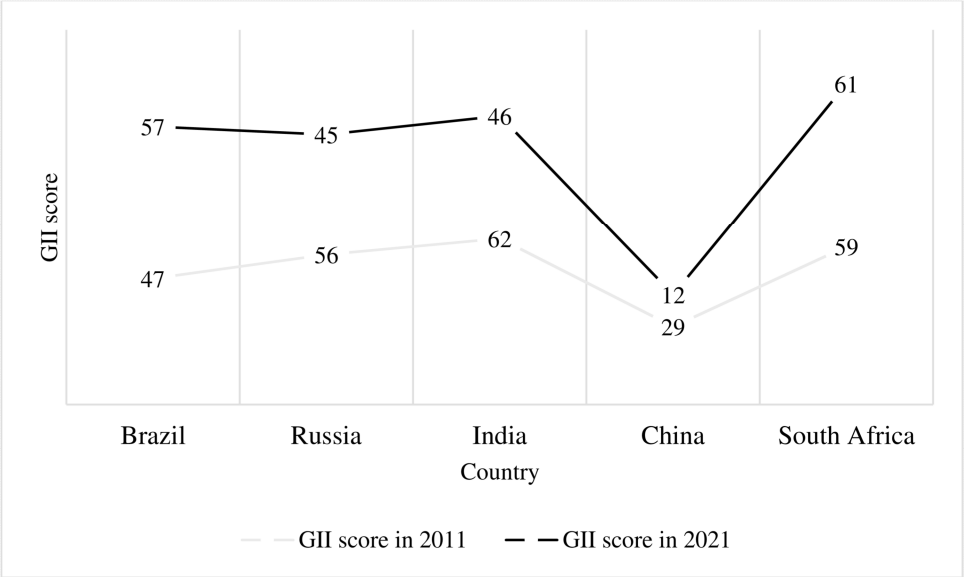


Figure 2. BRICS GII ranking positions in 2021 compared to 2011

2021). When comparing initial year of considered GII rankings with the final year the most effective results are identified in the case of China that has made progress in the ranking list and now holds 12th place in the overall score. Growth results are recognized in Russia and India. South Africa has reported slight decline, however the results of Brazil had downward trend for 10 places. South Africa is now on the last position in regards to the other BRICS economies. Reasons for these changes can partially be found in economic growth that is divergent in each economy. In the observed timespan, China has doubled its GDP per capita and India achieved nearly same results (World data bank, 2021b). Brazil, Russia and South Africa reported decline of the economic growth in the same period. Therefore, the great results that are confirmed in China are followed by a high increase in economic activities while the largest dropdown of economic growth in Brazil is followed by decrease in innovation development.

Theoretical description of dimensions in the GII structure that is presented below is adopted from the GII official reports from 2011 (Global innovation index, 2011) and 2019 (Global innovation index, 2019).

Institution dimension. Dimension is comprised of a political, regulatory and business environment (Global innovation index, 2019).

- Political environment is focused on political stability along with the absence of terrorism. Furthermore, it includes government effectiveness and press freedom (Global innovation index, 2019).

- Regulatory environment is concerning the effectiveness of establishing and adopting right policies, supported by fair laws and acceptable employment conditions. Corruption problems in organizations can produce decline in the innovation performances therefore, each country is dependent on the effectiveness of their national institutions (Lee et al., 2020).

-Business environment represents acquired conditions to start a business with a view on startup costs and taxation regulation

(Global innovation index, 2011).

The antecedent in the overall institution score is South Africa however, empirical evidence confirms a dropdown of its ranking position in the last observed year. China has done a lot of work in institution domains since it has improved for 37 positions in the observed timespan. Brazil has improved its business environment results however, the running political framework has significantly dropped. Political and business environment climate have improved its position in Russia and China. All BRICS members except China have developed their regulatory environment. Bonds between authorities and organizations should be close and mutually binding, especially in emerging economies. Organizations should plan their business in line with innovation policies and incentives that governments arrange and on the other side, governments should follow the needs of the organizations at the national level and coordinate their policies according towards favorable market environment (Tian et al., 2019).

Human capital and research dimension. Human capital is representing education perspective of the dimension by incorporating education expenditures, number of students and education duration into measurement (Global innovation index, 2019). The research and development aspect is considering some basic measurements like the number of researchers, R&D expenditures and the quality of the research institutions (Global innovation index, 2011). Dimension is characterized by overall improvement in BRICS. Leaders in this dimension are Russia and China, however the efforts that India has putted into developing human capital and research is impressive. India has outdriven 50 countries from 2011 to 2021 and credits for that go to developing tertiary education. Russia holds 14th place for its tertiary education environment. China has expressed its preference towards developing education and is currently 12th economy by its education possibilities and 14th by research and development. In overall, all BRICS members are progressing in the right direction when it comes to the human capital and research dimension. In organizations and institutions that operate in emerging economies, corporate social responsibility plays a significant role in creating innovation environment that serves to enhance competitive advantage (Chkir et al., 2021).

Infrastructure dimension. Dimension is established of three components that include information and communication technology (ICT) access and use, general infrastructure and ecological sustainability. General infrastructure is presenting the electricity output, logistic performances and gross capital formation (Global innovation index, 2019). Leader in infrastructure dimension is China that has progressed in the overall ranking (24th place) for the observed time. China has outperformed other BRICS members in general infrastructure conditions and holds fifth position in the world. On the other side, the least developed infrastructure is reported in Brazil. Problems with infrastructure sustainability report Russia, India and South Africa while the best performing country is China. When it comes to the ICT rank, the impressive results come from Brazil and Russia that have advanced in the overall ranking list for more than fifty positions. Prokop et al. (2021) suggests that developing ICT is possible when appropriate ICT investment environment is established that includes relevant ICT infrastructure and ICT skilled personnel. It is known that emerging economies face higher threats of

environmental pollution since their overall growth is accelerated and economic growth is not harmonized with environmental standards (Cai et al., 2021). Empirical findings from emerging economics including BRICS prove that investments in technological innovation narrow environmental pollution in places where they are installed (Afrifa et al., 2020). Governments are already changing their focus from conventional to ecological and environment aware innovations to induce sustainable development (Mavi & Mavi, 2021).

Market sophistication dimension. Dimension includes credits, investments, trade and competition scale (Global innovation index, 2019). Credit and investment measurement represents available conditions for accessing financial resources and their security. On the other side trade and competition components are mainly measuring the competitiveness on the market and the volume of the imports and exports (Global innovation index, 2019). Dimension market sophistication is where South Africa, China and India achieve better rankings in comparison to other BRICS (in the top 28 countries). In general, this dimension is characterized by a slight incline and decline in ranking results. It is established of components credits, investments and trade, competition and market scale. China (1), India (7) and Russia (17) BRICS economies are superior in the last cited component and hold positions among best economies in the world. In the case of investments, BRICS countries record decline in their ranking positions, especially in the cases of Russia and China. Positive and negative changes are reported for the component credits however there is a lot more effort in front of BRICS in terms of improving credits climate. In BRICS, banks have a special supporting role in facilitating technological innovations that are usually expensive and require additional financial resources that banks can provide (Wang et al., 2021).

Business sophistication dimension. Dimension is focused on knowledge perspective of the innovation. It is established of knowledge workers, innovation linkages and knowledge absorption. It considers the number of knowledge workers and employee's access to the formal trainings, collaboration among university and industry in the field of innovation, and technology imports (Global innovation index, 2011). Another GII dimension that is considerably advanced in BRICS is business sophistication. Positive trends are recognized in majority of BRICS except Russia and South Africa. China holds strongly its second place in the world by the number of knowledge workers and impressive 9th place by knowledge absorption. On the other side, India is having troubles with knowledge workers and it is placed at the very end of the ranking list. In South Africa all business sophistication components are evaluated negatively. Erciş and Ünalan (2016) propose establishing appropriate mechanism for supporting research institutions and universities to create and promote innovation and education, followed by proper tax incentives in the innovation domain. BRICS organizations who are investing in education and different kind of trainings at workplace attain higher innovation capability results (Cui et al., 2016).

Knowledge and technology outputs dimension. It is comprised of knowledge creation, knowledge impact and knowledge diffusion measurements. The outcome of the

knowledge creation is reflected in the number of patents and research articles. Knowledge impact is considering the GDP growth rate per engaged person, firm's density and computer software spending. Knowledge diffusion depicts financial resources for the license fees for using intangible assets and proprietary rights, technology exports and investments abroad (Global innovation index, 2011). In the field of knowledge technology outputs China is a decisive leader. China is in the top four countries in the world in this dimension and in the beginning of the ranking list for all three components that are knowledge creation (4), knowledge impact (5) and knowledge diffusion (9). Its results outperform other BRICS members however, positive effects are highlighted in the case of India and South Africa. By component knowledge creation, majority of BRICS economies fitted in the top fifty countries. Although other two components that include knowledge impact and diffusion do not achieve desirable outcomes.

Creative outputs dimension. It consists of three components that represent intangible assets, creative goods and services and online creativity. Intangible assets are measured by the number of issued trademarks and ICT influence on business and organizational model creation. Creative goods and services measure the cultural environment that is reflected in the expenses volume for the recreation and culture, produced films and newspapers and exported creative goods and services. Country code domains, Wikipedia editors, and mobile app creation evaluate online creativity (Global innovation index, 2019). The last dimension is expressed in the creative outputs. And again, as it was explained in the previous dimension, China is the pioneer in this field. Overall ranking position for China is 14th, supported by impressive second place for the component intangible assets. Brazil and India reported decline in their ranking positions. Low rankings of online creativity are noticed for all BRICS members.

4. METHODOLOGY

The main goal of this study is to extract the most influential components that affect the GII score in the BRICS countries and evaluate their individual influence on the GII ranking. The decision-making framework for selecting components is supported by empirical findings that provides factor analysis. In this case, the selected type of factor analysis is principal component analysis (PCA). PCA is engaged in reducing the number of components to minimum so they can be employed to construct a reliable predictive model. The appointed methodological approach for establishing predictive model that can explain the behaviour of components is multiple linear regression (MLR). The predictive power and quality of the regression model outcome will be evaluated through comparing calculated values with the realized GII score. Therefore, a hybrid PCA-MLRA methodology will be used to explain inner relationships in the GII structure. Figure 3 illustrates the research phases in details.

The research phases derived from the study simplify complex hierarchical structure of GII into several steps. The first step considers gathering data for the study and preparing a suitable dataset. General statistical parameters and correlations are computed in this first phase. The second step acquires running a PCA factor analysis to reduce a certain number of variables to one

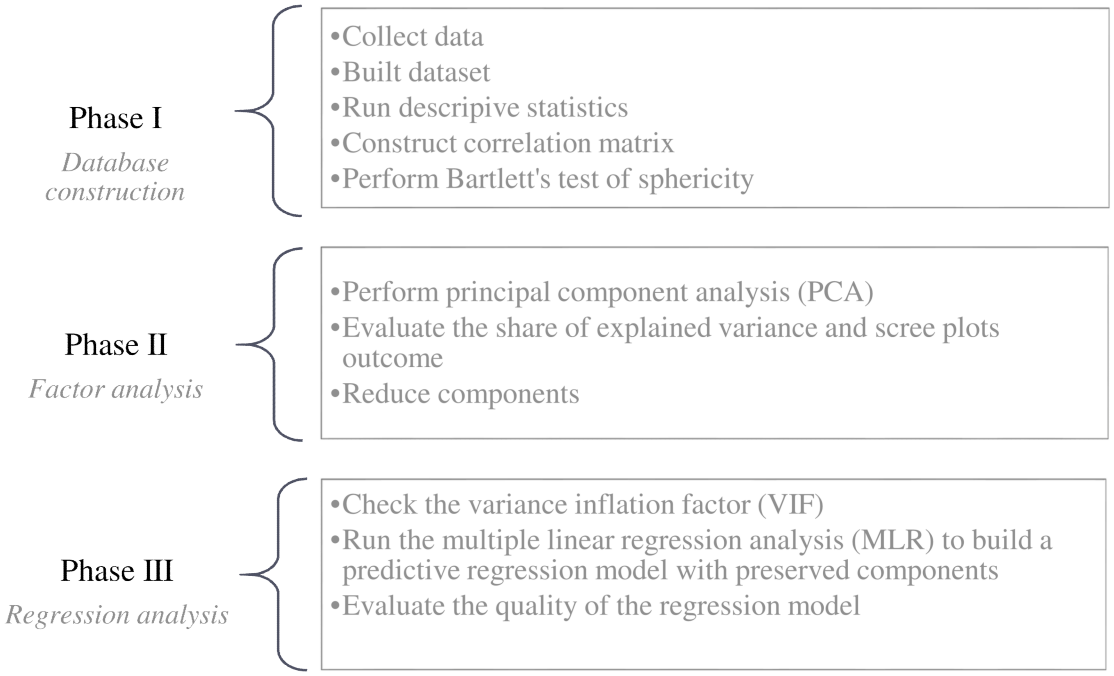


Figure 3. Research phases

or few components in each dimension that in the most suitable way explain the correlation among the components in the same group and name it for the group representative. In the third step, the reduced variables that represent the foundation for MLR model are used to build a predictive model of GII score. In that way, a mass of dimensions' elements will be replaced with predominant elements and it will enable construction of predictive regression equation that consists of a few most important elements.

4.1. Principal component analysis (PCA)

PCA is an often-used tool for narrowing large data that are used in researches to an understandable form without losing the most important information variability from the initial dataset (Jolliffe & Cadima, 2016). PCA is an artificial intelligence algorithm for analyzing variety of correlated variables to extract the right number of them so that the total amount of data can be reduced using linear transformation for simplifying further analysis and the new variables are called principal components (De Silva et al., 2019 Mamipour et al., 2019; Ahmed et al., 2020). The number of extracted components equals to the initial number of variables and from those extracted components only few of them can be selected for further investigation and selected components in the most credible way depict original information (Xu et al., 2020). The process of selecting principal components is based on the rule that the first component accounts for major fraction of the total variance (Lamichhane et al., 2021). Other rules that can be employed to select principal components include eigenvalues and analysis of scree plots (Rodionova et al., 2021). PCA analysis is a multivariate technique for extracting the most important

information from big data sets; it is simple and non-parametric method (Shlens, 2014). Underlined by mathematical formulas, PCA allows users to identify patterns in the data easier than in the original dataset (Richardson, 2009).

4.2. Multiple linear regression (MLR) analysis

Regression analysis is used to identify correlations usually among one or more independent variables and one dependent variable among which is MLR analysis (Tabrizi & Sancar, 2017; Mehmanpazir et al., 2019). MLR is a powerful tool for discovering future values of variables based on the information collected in the past from the explanatory variables (Maaouane et al., 2021). MLR model is given in the following part (Perez, 2017; Abrougui et al., 2019):

$$y_i=b_0+b_1x_{i,1}+b_2x_{i,2}+\cdots b_kx_{i,k}+e_i \quad (1)$$

Where,
y_i - dependent variable;
b_0 - intercept;
$x_{i,k}$ - independent variables;
b_k - vector of regression coefficients;
e_i - random measured error.

5. RESEARCH RESULTS

Following section introduces primary empirical findings following the order illustrated in the Figure 3. First group of the research results discuss computed statistical parameters distinguished for GII dimensions and explain the results in practice. The most important statistical indicators for all seven dimensions that comprise GII in BRICS are reported in the Table 1. The maximum value of the dimensions is recorded for institutions (71.6) followed by market sophistication (66.0). The lowest values are confirmed with human capital and research (18.5) and knowledge and technology outputs (18.9). Reported values are used to provide a better understanding of the evaluation score of each GII dimension for BRICS economies. The largest diversity in dimension score values is noticed in knowledge and technology output, while the lowest difference is seen in creative outputs. Empirical findings in BRICS suggest that dimensions in the sphere of innovation inputs are more advanced than innovation output dimensions.

When it comes to the average statistics in individual members of BRICS from 2011 to 2021, the results are following. Institution dimension is evaluated with the highest score and slight difference between minimum and maximum value in Brazil, Russia and South Africa. In India, dimensions like institutions and market sophistication record the highest scores. Results gathered for China are the best in comparison to the other BRICS members. China is achieving great scores in both, input and output innovation dimensions. Overall conclusion of the BRICS members' results is that institution dimension is the strongest evaluated dimension in the GII structure.

Calculated correlation among dimensions is the following. Statistically significant Pearson's correlation for innovation input dimensions is recorded in the relationship between components human capital and research ($r = 0.599$; $p = 0.000$), infrastructure ($r = 0.659$; $p = 0.000$), market sophistication ($r = 0.289$; $p = 0.000$), business sophistication ($r = 0.840$; $p = 0.000$), knowledge and technology outputs ($r = 0.907$; $p = 0.000$) and creative outputs ($r = 0.774$; $p = 0.000$) towards the dependent

Table 1. Overall descriptive statistics for BRICS countries

Country	Indicator	GII	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creative outputs
Brazil	Min	31.94	50.40	30.10	35.70	35.60	35.80	18.90	18.60
	Max	37.75	60.60	37.50	48.30	45.20	44.40	30.50	46.90
	Mean	34.69	55.31	33.59	41.76	42.64	38.79	24.79	29.27
	SD	1.82	3.06	2.61	4.04	3.53	2.68	3.04	8.27
	Var	3.31	9.34	6.79	16.34	12.43	7.17	9.25	68.41
Russia	Min	35.63	49.10	43.80	36.40	35.00	31.80	26.40	22.80
	Max	39.30	63.10	50.40	47.50	49.70	44.90	38.40	31.40
	Mean	37.67	57.02	46.87	42.03	44.38	38.32	31.32	28.29
	SD	1.25	4.07	2.36	3.85	4.96	4.14	4.52	2.71
	Var	1.56	16.59	5.56	14.80	24.65	17.12	20.42	7.36
India	Min	31.70	38.40	18.50	27.50	44.60	26.40	24.80	20.60
	Max	36.58	64.70	34.10	44.60	56.30	37.60	34.70	40.70
	Mean	34.97	53.64	27.85	37.20	50.68	30.69	31.81	28.65
	SD	1.48	7.41	6.02	5.59	4.07	3.18	2.96	7.52
	Var	2.18	54.96	36.26	31.26	16.60	10.10	8.79	56.56
China	Min	44.70	39.10	31.40	39.80	47.80	41.80	52.70	31.90
	Max	54.82	64.60	50.60	58.70	61.50	56.00	61.80	48.30
	Mean	49.97	54.90	44.65	51.44	54.66	50.61	56.81	41.20
	SD	3.91	7.98	5.72	6.08	4.20	5.17	2.58	5.91
	Var	15.28	63.71	32.77	36.98	17.64	26.76	6.67	34.91
South Africa	Min	32.67	65.60	23.70	21.80	57.00	29.30	21.20	19.80
	Max	38.20	71.60	33.10	43.40	66.00	42.30	29.10	37.80
	Mean	35.63	68.38	29.51	34.52	60.41	34.15	24.56	27.03
	SD	1.93	2.24	2.71	6.65	3.15	4.24	2.93	5.55
	Var	3.71	5.02	7.35	44.20	9.95	18.00	8.58	30.76

GII score. Interpreted correlation results provide empirical evidence about their importance for determining GII ranking. Positive correlation values indicate that increase in score dimension values improves overall GII ranking. When it comes to the significant correlation outcomes on macroeconomic level the situation is following. In the case of Brazil, the strongest statistically significant positive correlation is reported between creative outputs with the GII score ($r = 0.945$; $p = 0.000$). The same results are reported in China and South Africa, where dimension creative outputs highly correlates with the GII score ($r = 0.945$; $p = 0.000$ and $r = 0.915$; $p = 0.000$).

Prior running the PCA factor analysis for reducing dimensions a Bartlett's test of sphericity is performed. Bartlett's test of sphericity is used to assess whether the aggregated dataset is convenient for

reduction technique. It is employed to control and manage correlation within groups of variables. The results of the performed test are presented in the Table 2 and the computational outcome shows statistically significant correlations among six GII dimensions ($p<0.05$) with degree of freedom that equals to three and appropriate Chi-square values. The only exception is the dimension of infrastructure where the value of statistical significance is higher than the chosen significance value of 5%. The outcome of the test approves the use of the following dataset for reducing dimensions by means of PCA analysis.

The second phase in the research is to perform the PCA factor analysis. PCA is done separately for each individual dimension that constitute GII. The selected methodological approach for the rotation is orthogonal varimax method. Decision about how many components to retain or reject is made by analyzing the outcome of the total variance explained by the components in the Table 3 and comparing it with the results illustrated in the Figure 4 with the help of scree plots. The adopted extraction method for both procedures assume eigenvalue value greater than one. The results obtained by explained variance outcome of the scree plots match in all seven cases. The PCA provides one-factor and two-factor solutions based on the eigenvalues. Cumulative values of the explained variance in each dimension is higher than 50%, which is a desired outcome. The slope of change for every dimension differs in each scree plot and offers valuable graphical solution.

Summarized results of the components' matrix are presented in the Figure 5. Correlations between selected items and components are strongly positive. Dimensions human capital and research, infrastructure, business sophistication, knowledge and technology outputs and creative outputs propose one-factor solutions. While institutions and market sophistication suggest two-factor solutions. The selected one-factor and two-factor solutions present the foundation for constructing the MLR equation in the form of predictors.

The third and final phase in the research is dealing with MLR analysis. MLR computational outcome allows assessing the level of influence that each integrating component/variable is achieving on the GII score. Its role is to report the essential components from the reduced set of components that constitute GII score by means of regression analysis. Predictive items that are considered in the regression model as input values are made of political environment, business environment, R&D, general infrastructure, investment, trade, competition and market scale, knowledge

Table 2. Bartlett's Test

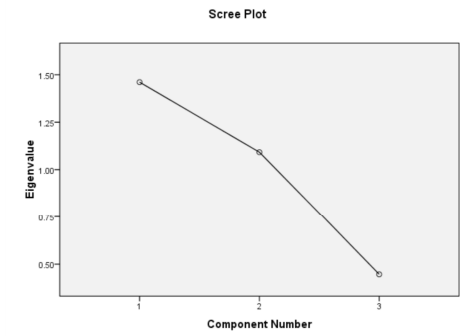
Dimension name	Label	Bartlett's Test of Sphericity		
		Approx. Chi-Square	df	Sig.
Institutions	I	17.636	3	.001
Human capital and research	HC_R	19.938	3	.000
Infrastructure	INF	6.727	3	.081
Market sophistication	MS	36.947	3	.000
Business sophistication	BS	44.986	3	.000
Knowledge and technology outputs	KTO	62.028	3	.000
Creative outputs	CO	34.211	3	.000

Table 3. Total variance explained

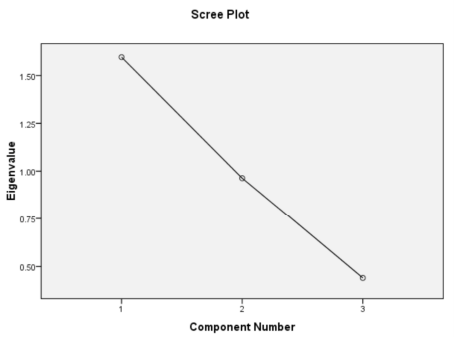
Dimension	Component	Initial Eigenvalues		
		Total	% of Variance	Cumulative %
Institutions	1	1.461	48.698	48.698
	2	1.092	36.402	85.100
	3	0.447	14.900	100
Human capital and research	1	1.596	53.211	53.211
	2	0.963	32.106	85.317
	3	0.440	14.683	100
Infrastructure	1	1.395	46.514	46.514
	2	0.919	30.650	77.164
	3	0.685	22.836	100
Market sophistication	1	1.617	53.910	53.910
	2	1.108	36.927	90.837
	3	0.275	9.163	100
Business sophistication	1	1.832	61.052	61.052
	2	0.917	30.570	91.622
	3	0.251	8.378	100
Knowledge and technology outputs	1	2.183	72.762	72.762
	2	0.574	19.139	91.901
	3	0.243	8.099	100
Creative outputs	1	1.845	61.516	61.516
	2	0.843	28.116	89.632
	3	0.311	10.368	100

workers, knowledge impact and intangible assets. Before constructing the regression equation some elementary indicators have been computed. Pearson's correlation is performed to identify the nature of the relationship between remained components and the GII score. The relevant correlation outcome is recognized in innovation input components like R&D (r = 0.826; p = 0.000) and general infrastructure (r = 0.790; p = 0.000). Concerning innovation output components, the relationship that knowledge impact (r = 0.807, p = 0.000) and intangible assets (r = 0.820, p = 0.000) achieve with the GII score is highlighted as extremely high and positive. In addition, a variance inflation factor (VIF) has been computed in order to obtain collinearity diagnostics. The feedback information of the VIF test approved further use of the selected components for constructing regression equation (VIF < 10). Regression model statistics consists of Pearson's correlation (R = 0.982), coefficient of determination (R^2 = 0.964), standard error of the estimate (SEE = 1.300). The model expressed statistical significance (p = 0.000). Computed unstandardized values of the GII score that are the outcome of the regression analysis are compared with observed GII scores. The comparison outcome is graphically illustrated in the Figure 6 and it reports high coefficient of determination between the two elements (R^2 = 0.991).

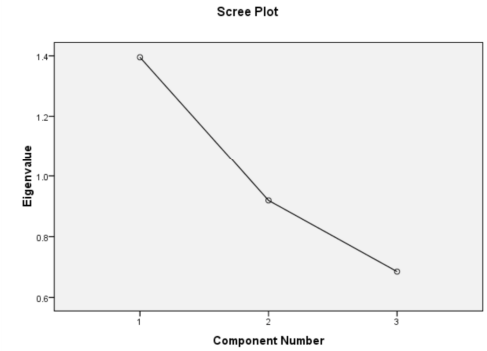
Regression analysis outcome provided significant information about unstandardized coefficients that determine the final regression equation result. The influence of the components is presented in the following rising order: investment (-0.026) → R&D (0.032) → trade, competition and market scale (0.041) → business environment (0.044) → political environment (0.061) → knowledge impact (0.091) → intangible assets (0.102) → knowledge workers (0.129) → general infrastructure (0.140).



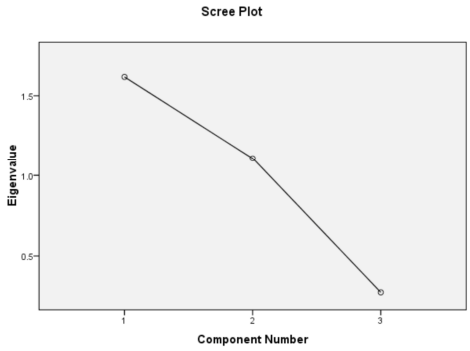
(a) Institutions



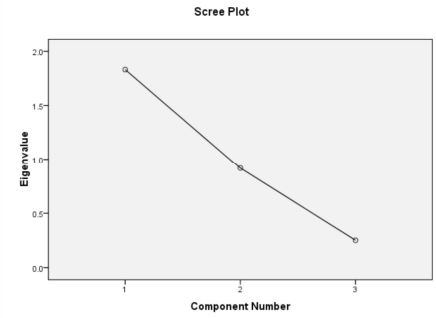
(b) Human capital and research



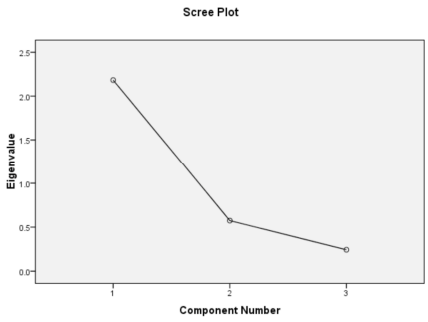
(c) Infrastructure



(d) Market sophistication



(e) Business sophistication



(f) Knowledge and technology outputs

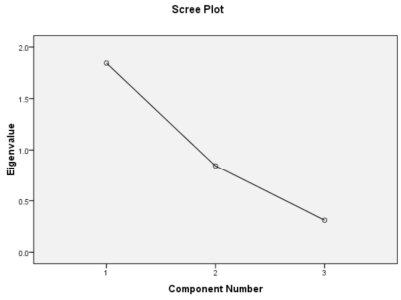


Figure 4. Scree plot for dimension components

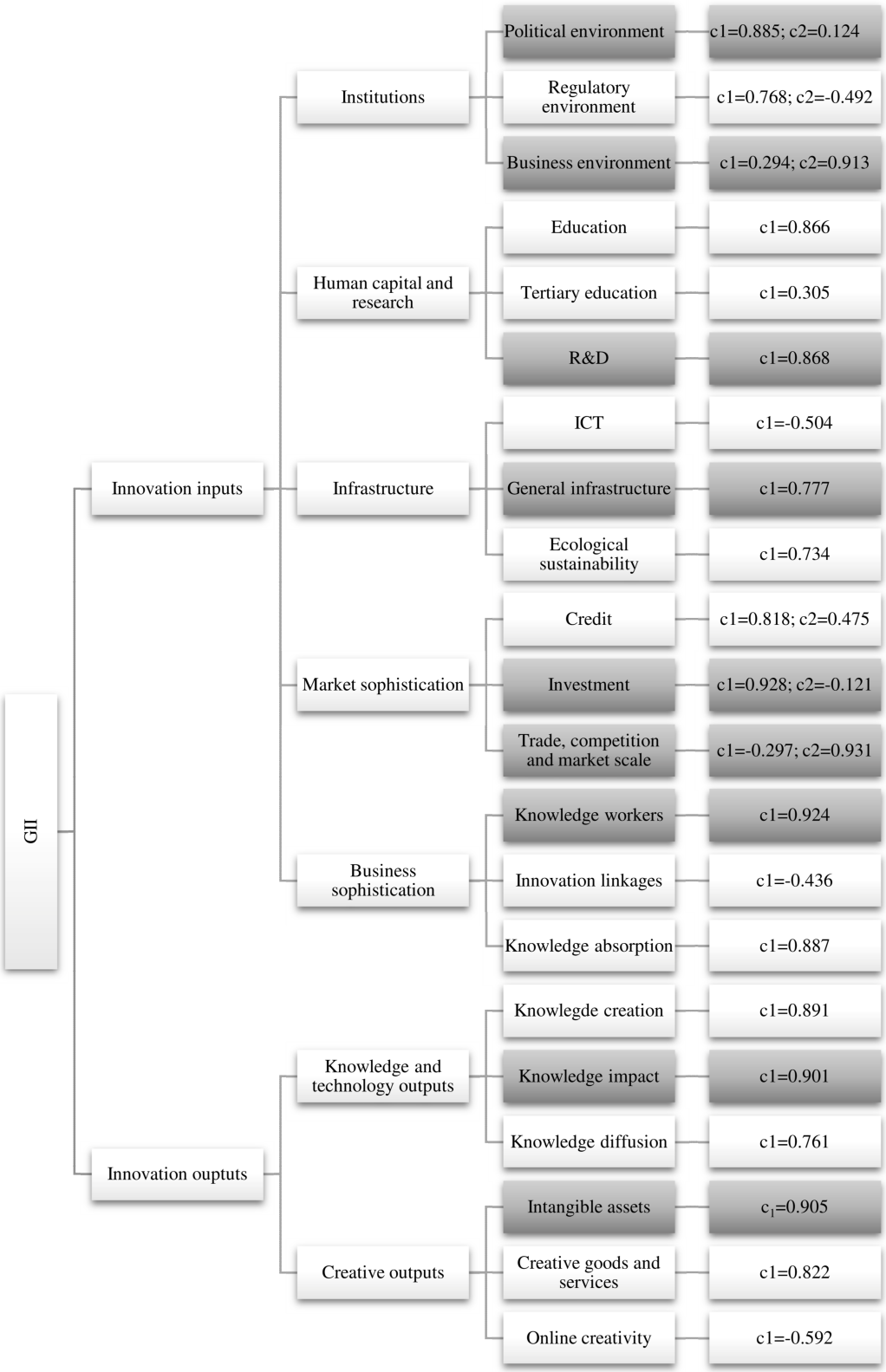


Figure 5. GII structural model with reduced components

Furthermore, gathered values of the GII score that are realized and the computed regression outcome are demonstrated for each BRICS country in the Figure 7. The illustration is providing visual information about GII rank for the observed timespan.

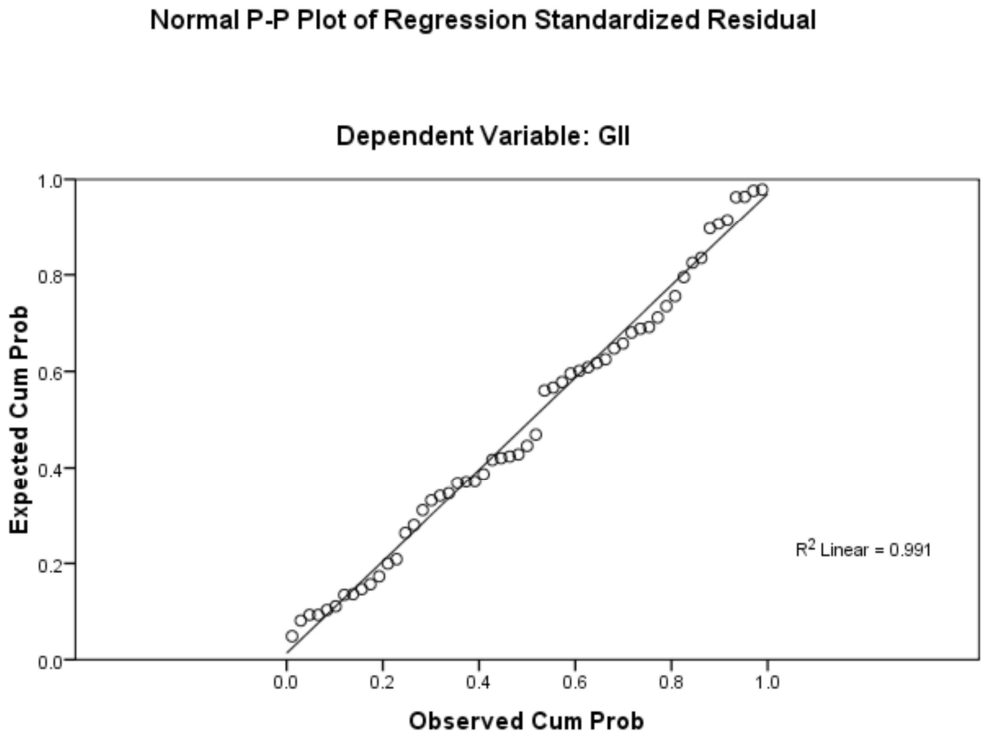


Figure 6. Realized and unstandardized predicted GII values in BRICS countries

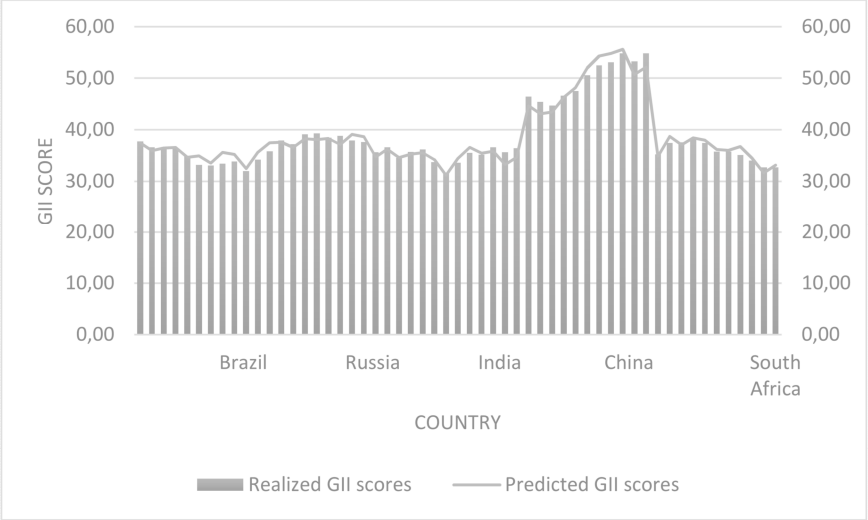


Figure 7. Disparity between realized and unstandardized predicted GII values in BRICS countries from 2011 to 2021

6. DISCUSSION

Innovation is a major driver for developing sustainable competitive advantage in a global market (Hameed et al., 2021). It provides a wide range of possibilities, especially in emerging economies like BRICS to foster national innovative performances (Feng et al., 2019). The main aim of the study was to distinguish valuable components that comprise GII dimensions for the future GII ranking by reducing its number to a few most important features. Empirical results presented in this study serve as a guideline for BRICS innovation practice in terms of summarizing their innovation input and output results in the eleven year timespan. The research outcome is used to outline successful innovation practice and reveal innovation domains with poor outcome. In brief, the essential knowledge that arises from this survey is the following.

The most successful of all BRICS economies judged by the majority of innovation dimensions is China while South Africa is recognized as a country with the highest number of low ranks of GII dimensions followed by Brazil. Innovation activities in Brazil have declining character. Dominant impact on the GII score share components like general infrastructure, intangible assets, knowledge impact and knowledge workers therefore they should be the starting and inevitable elements in any future innovation strategies and policies. Innovation environment in Brazil is supported by developed business sophistication and is constrained by poor knowledge and technology outputs. Efforts for developing innovation in Brazil are recognized in great results in the sphere of R&D activities, trade and competition regulation, knowledge workers and knowledge absorption. However, critical points in innovation development are weak infrastructure, poor credit and investment opportunities. Therefore, better innovation climate in Brazil can be secured by government's regulation of critical points perceived in the market context that could allow easier access to the required financial resources. Russia's innovation performances are strongly empowered by progression of human capital and research especially in the sphere of tertiary education. Challenges for developing innovation in Russia are seen in poor institution regulations in the context of political and regulatory environment. In general, innovation linkages in Russia are at an enviable level however, they are not exploited enough since the linkage between universities and industry is not reached. Investment environment in Russia reports poor performances. In India trade, competition and market scale results are among the best results in the world and are followed by considerable knowledge diffusion. The main obstacles in improving innovation performances are insufficient ecological sustainability, low education among population, inadequate business environment and not enough knowledge workers. These are the key points that need to be addressed in the future innovation strategies. In the case of China innovation performances are better than other BRICS countries. China is doing excellent job in trade, competition and market scale, knowledge and technology outputs when it comes to the creating knowledge and its impact. China has developed its creative outputs especially in the sphere of intangible assets. However, there are some identified challenges and the most important among them is ineffective regulatory environment,

tertiary education, online creativity and investments. China needs better planning of regulatory environment in order to enhance innovation performances. In addition, South Africa is achieving considerable results in market sophistication domain and investments, however the greatest problem is recognized in tertiary education, ecological sustainability and creative goods and services.

By looking at the outcome of the overall BRICS scores, the research outcome of the PCA discovered special role of the institution dimension reflected in political and business environment that manage the innovation development. This result is in a way anticipated since government's role in addressing innovation targets through developing innovation strategies is crucial. BRICS economies are highly dependent on political framework and governments should contribute to the effectiveness of the transformation process by providing support for any initiative towards innovation. There is also an important role of public research institutes in helping organizations to cross the gap between the basic research and development (Intarakumnerd & Goto, 2018). Business environment is the second source of innovation incentives since organizations are encouraging employees to express their creativity at work to strengthen their competitiveness. Important element in shaping the innovation among employees is national culture and it should be considered when discussing about innovation capabilities of nations (Boubakri et al., 2021). The following dimension of GII that considers human capital and research supports this interpretation. Predominant component of this dimension is research and development that is imperative for achieving any innovation prosperity. Development of general infrastructure is important to consolidate basics needed for the innovation activities. Here a special attention must be focused towards providing ecological sustainability of the infrastructure. When discussing market sophistication that is made of credits, investments, trade, competition and market scale, the attention is focused towards expanding investments that can be used to develop some aspects of innovation process. The most important feature of the business sophistication dimension is recognized in the number of knowledge workers. Lack of knowledge workers can produce innovation slowdown and less innovation output results, therefore BRICS countries must nurture innovative culture in organizations. Human resources are the major input factor in organizations and governments that create innovation capability (Intarakumnerd & Goto, 2018). The most important knowledge and technology output is recognized in the knowledge impact. On the other side, the most important creative output is seen in intangible assets.

Next research phase that included MLR model discovered component intangible assets as the most contributing predictor of the GII score. Components that follow the predominant component of general infrastructure are knowledge workers, intangible assets and knowledge impact. These are the four main predictors of the innovation development in BRICS. There is overlap between conducted study by Franco and de Oliveira (2017) with the regression results obtained by this study. However, this study goes deeper into the question of innovation successfulness of BRICS and provides accurate information about which components among described dimensions need to be improved. Furthermore, prediction

power of the regression model is straighten by including components as innovation predictors rather than dimensions. The study results are partially supported by another survey conducted in 2017 (Khedhaouria & Thurik, 2017) where authors provided evidence about the importance of developing all innovation input dimensions to increase country's innovation capability.

So far, the explained components were the ones that achieve highest prediction abilities towards the GII score. However, the rest of the components from the GII structure represent those aspects that BRICS countries do not advance as required. Meaning that BRICS economies have to put additional effort to develop their regulatory environment, improve education and infrastructure needed for any development. Some scholars (Filippetti & Guy, 2020) have already confirmed that knowledge and skills diversity offered by universities facilitates innovation capability of population rather than acquiring narrow education. For improving market sophistication countries should secure available credit sources and appropriate investments. In case of the business sophistication, stakeholders should work on improving gaps in innovation linkages and knowledge workers. Universities is given a special place of institution actors in enabling innovation linkage with national innovation systems and business sector (Datta et al., 2019). In order to enhance innovation output attention should be directed towards creating knowledge and knowledge diffusion, moreover to expand creative goods and services and online creativity. Governments need to adjust the education profiles and skills attained by population to satisfy future demands that innovation systems suggest (Wiseman & Anderson, 2012).

7. CONCLUSION

In this study, global innovation index (GII) has been used as a foundation to evaluate the primary innovation predictors based on the various components in each GII dimension. For that purpose, a hybrid PCA-MLR methodology has been engaged to analyze the structure of the GII components and retain the most important among them for predicting the GII scores. The study has highlighted the pioneers in the innovation field among BRICS economies and underlined the main weak points in transformation towards innovation.

Following empirical findings are also the main conclusions regarding the BRICS innovation progress and a brief overview of the innovation priorities in emerging economies. The largest problem for BRICS is recognized in dimensions that represent institutions and infrastructure where BRICS achieve the lowest ranks compared to other dimensions. On the other side, BRICS economies are reporting fine progress in the sphere of trade, competition and market scale where they record the highest ranks. BRICS members should tend to overcome low scores in institutions by focusing more attention towards developing innovation climate through different policies and regulations. Additional work in BRICS is needed in providing appropriate infrastructure that allows further innovation growth and support for increasing creative outputs. Proposed guideline for enhancing innovation performances will allow supportable environment for boosting competitive advantage on the global market.

The main limitation of the study is recognized in the low number of economies that are included into the survey. However, this study tends to find its application in the

future planning of the BRICS innovation strategies. Making plans for the future development of innovation activities is another opportunity to employ the research results. The results of the study can be used for comparison with other economy grouping. Future research can be inspired by investigating the value of developing certain innovation dimensions in practice.

Acknowledgement

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References

Abrougui, K., Gabsi, K., Mercatoris, B., Khemis, C., Amami, R., & Chehaibi, S. (2019). Prediction of organic potato yield using tillage systems and soil properties by artificial neural network (ANN) and multiple linear regressions (MLR). Soil and Tillage Research, 190, 202-208.

Afrifa, G.A., Tingbani, I., Yamoah, F., & Appiah, G. (2020). Innovation input, governance and climate change: Evidence from emerging countries. Technological Forecasting and Social Change, 161, 120256.

Aguirre-Bastos, C., & Weber, M.K. (2018). Foresight for shaping national innovation systems in developing economies. Technological Forecasting and Social Change, 128, 186-196.

Ahmed, N., Roy, S., & Islam, M.A. (2020). Forecasting Supply Chain Sporadic Demand Using Principal Component Analysis (PCA).

Băzăvan, A. (2019). Chinese government's shifting role in the national innovation system. Technological Forecasting and Social Change, 148, 119738.

Boubakri, N., Chkir, I., Saadi, S., & Zhu, H. (2021). Does national culture affect corporate innovation? International evidence. Journal of Corporate Finance, 66, 101847.

Cai, Z., Tan, K.H., Zhang, L., Du, J., Song, M., & Zhou, X. (2021). Technological Innovation and Structural Change for Economic Development in China as an Emerging Market. Technological Forecasting and Social Change, 167, 120671.

Chkir, I., Hassan, B.E.H., Rjiba, H., & Saadi, S. (2021). Does corporate social responsibility influence corporate innovation? International evidence. Emerging Markets Review, 46, 100746.

Coccia, M. (2014). Driving forces of technological change: the relation between population growth and technological innovation: analysis of the optimal interaction across countries. Technological Forecasting and Social Change, 82, 52-65.

Cui, Y., Jiao, J., & Jiao, H. (2016). Technological innovation in Brazil, Russia, India, China, and South Africa (BRICS): an organizational ecology perspective. Technological Forecasting and Social Change, 107, 28-36.

Datta, S., Saad, M., & Sarpong, D. (2019). National systems of innovation, innovation niches, and diversity in university systems. Technological Forecasting and Social Change, 143(C), 27-36.

De Silva, C.C., Beckman, S.P., Liu, S., & Bowler, N. (2019). Principal component analysis (PCA) as a statistical tool for identifying key indicators of nuclear power

СТРУКТУРНИ PCA-MLR МОДЕЛ ИНОВАЦИОНОГ ОКРУЖЕЊА У ЗЕМЉАМА БРИКС-А

Ivana Veličkovska

Извод

Процес глобализације изазива промене на тржишту у форми интензивне конкуренције. Економије могу опстати стицањем конкурентске предности на глобалном тржишту путем развоја иновација. Главни циљ овог емпиријског истраживања је откривање најважнијих компоненти иновација које чине структуру глобалног индекса иновација (GII) и евалуација њиховог утицаја на ово рангирање у земљама БРИКС-а. Подаци о иновационом процесу прикупљени су на основу резултата рангирања GII акумулираних од 2011. до 2021 године. Резултат анализе главних компоненти (PCA) предлаже девет компоненти које представљају седам димензија. Издвојене компоненте се даље користе у регресионој анализи како би се формирала једначина вишеструке линеарне регресије (MLR) за предвиђање GII резултата који се користе у укупном рангирању. Добијено МЛР решење указује на важне MLR резултате са високим коефицијентом детерминације, где се 98,2% вредности GII објашњава издвојеним компонентама. Доминантни ефекти на GII постижу се путем компоненти општа инфраструктура и радници знања. Штавише, упоредна анализа стварних и израчунатих GII резултата показује преклапање од 99,1% између ове две вредности. Процењени резултати PCA-MLR анализе служе за анализу успеха развоја иновационих перформанси у земљама у развоју упоређивањем индекса иновација који постижу земље БРИКС-а.

Кључне речи: иновације, глобални иновациони индекс, БРИКС, анализа главних компоненти, регресија

plant cable insulation degradation. In Proceedings of the 18th International Conference on Environmental Degradation of Materials in Nuclear Power Systems–Water Reactors (pp. 1227-1239). Springer, Cham.

do Carmo Silva, M., Gavião, L.O., Gomes, C.F.S., & Lima, G.B.A. (2017). A proposal for the application of multicriteria analysis to rank countries according to innovation using the indicators provided by the World Intellectual Property Organization. RAI Revista de Administração e Inovação, 14(3), 188-198.

Erciş, A., & Ünalan, M. (2016). Innovation: A comparative case study of Turkey and South Korea. Procedia-Social and Behavioral Sciences, 235, 701-708.

Esteves, K., & Feldmann, P.R. (2016). Why Brazil does not innovate: a comparison among nations. RAI Revista de Administração e Inovação, 13(1), 29-38.

Feng, G.F., Zheng, M., Wen, J., Chang, C.P., & Chen, Y.E. (2019). The assessment of globalization on innovation in Chinese manufacturing firms. Structural Change and Economic Dynamics, 50, 190-202.

Filippetti, A., & Guy, F. (2020). Labor market regulation, the diversity of knowledge and skill, and national innovation performance. Research Policy, 49(1), 103867.

Franco, C., & de Oliveira, R. H. (2017). Inputs and outputs of innovation: analysis of the BRICS: Theme 6–innovation technology and competitiveness. RAI Revista de Administração e Inovação, 14(1), 79-89.

Global Innovation index (2011). The Global Innovation Index 2011: Accelerating Growth and Development. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/economics/gii/gii_2011.pdf

Global Innovation index (2012). The Global Innovation Index 2012: Stronger Innovation Linkages for Global Growth. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.globalinnovationindex.org/userfiles/file/GII-2012-Report.pdf

Global Innovation index (2013). The Global Innovation Index 2013: The Local Dynamics of Innovation. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/economics/gii/gii_2013.pdf

Global Innovation index (2014). The Global Innovation Index 2014: The Human Factor in Innovation. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.globalinnovationindex.org/userfiles/file/reportpdf/GII-2014-v5.pdf

Global Innovation index (2015). The Global Innovation Index 2015: Effective Innovation Policies for Development. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_gii_2015.pdf

Global Innovation index (2016). The Global Innovation Index 2016: Winning with Global Innovation. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2016.pdf

Global Innovation index (2017). The Global Innovation Index 2017: Innovation Feeding the World. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2017.pdf

Global Innovation index (2018). The Global Innovation Index 2018: Energizing the World with Innovation. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2018.pdf

Global Innovation index (2019). The Global Innovation Index 2019: Creating Healthy Lives – The Future of Medical Innovation. World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2019.pdf

Global Innovation index (2020). The Global Innovation Index 2020: Who Will Finance Innovation? World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2020.pdf

Global Innovation index (2021). The Global Innovation Index 2021: What is the Future of Innovation-driven Growth? World Intellectual Property Organization (WIPO). Geneva, Switzerland. Retrieved from: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2021.pdf

Hameed, K., Arshed, N., Yazdani, N., & Munir, M. (2021). Motivating business

towards innovation: A panel data study using dynamic capability framework. Technology in Society, 65, 101581.

Hu, G.G. (2021). Is knowledge spillover from human capital investment a catalyst for technological innovation? The curious case of fourth industrial revolution in BRICS economies. Technological Forecasting and Social Change, 162, 120327.

Intarakumnerd, P., & Goto, A. (2018). Role of public research institutes in national innovation systems in industrialized countries: The cases of Fraunhofer, NIST, CSIRO, AIST, and ITRI. Research Policy, 47(7), 1309-1320.

Jolliffe, I.T., & Cadima, J. (2016). Principal component analysis: a review and recent developments. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374(2065), 20150202.

Khedhaouria, A., & Thurik, R. (2017). Configurational conditions of national innovation capability: A fuzzy set analysis approach. Technological Forecasting and Social Change, 120, 48-58.

Kim, S., Parboteeah, K.P., Cullen, J.B., & Liu, W. (2020). Disruptive innovation and national cultures: Enhancing effects of regulations in emerging markets. Journal of Engineering and Technology Management, 57, 101586.

Lacasa, I.D., Jindra, B., Radosevic, S., & Shubbak, M. (2019). Paths of technology upgrading in the BRICS economies. Research Policy, 48(1), 262-280.

Lamichhane, S., Eğilmez, G., Gedik, R., Bhutta, M.K.S., & Erenay, B. (2021). Benchmarking OECD countries' sustainable development performance: A goal-specific principal component analysis approach. Journal of Cleaner Production, 287, 125040.

Lee, C.C., Wang, C.W., & Ho, S.J. (2020). Country governance, corruption, and the likelihood of firms' innovation. Economic Modelling, 92, 326-338.

Lu, W.M., Kweh, Q.L., & Huang, C.L. (2014). Intellectual capital and national innovation systems performance. Knowledge-based systems, 71, 201-210.

Maaouane, M., Zouggar, S., Krajačić, G., & Zahboune, H. (2021). Modelling industry energy demand using multiple linear regression analysis based on consumed quantity of goods. Energy, 225, 120270.

Mahroum, S., & Al-Saleh, Y. (2013). Towards a functional framework for measuring national innovation efficacy. Technovation, 33(10-11), 320-332.

Mamipour, S., Yahoo, M., & Jalalvandi, S. (2019). An empirical analysis of the relationship between the environment, economy, and society: Results of a PCA-VAR model for Iran. Ecological Indicators, 102, 760-769.

Mavi, R.K., & Mavi, N.K. (2021). National eco-innovation analysis with big data: A common-weights model for dynamic DEA. Technological Forecasting and Social Change, 162, 120369.

Mehmanpazir, F., Khalili-Damghani, K., & Hafezalkotob, A. (2019). Modeling steel supply and demand functions using logarithmic multiple regression analysis (case study: Steel industry in Iran). Resources Policy, 63, 101409.

Nair, H., Kumar, A., & Ahmed, O. (2014). Neural Network Modelling, Simulation and Prediction of Innovation Growth in United Arab Emirates (UAE). Procedia Computer Science, 36, 269-275.

Perez, L.V. (2017). Principal Component Analysis to Address Multicollinearity. Walla Walla: Whitman College.

Prokop, V., Hajek, P., & Stejskal, J. (2021). Configuration Paths to Efficient

‘,National Innovation Ecosystems. Technological Forecasting and Social Change, 168, 120787.

Richardson, M. (2009). Principal component analysis. URL: http://people.maths.ox.ac.uk/richardsonm/SignalProcPCA.pdf (last access: 3.5. 2013).

Rodionova, O., Kucheryavskiy, S., & Pomerantsev, A. (2021). Efficient tools for principal component analysis of complex data—A tutorial. Chemometrics and Intelligent Laboratory Systems, 104304.

Samara, E., Georgiadis, P., & Bakouros, I. (2012). The impact of innovation policies on the performance of national innovation systems: A system dynamics analysis. Technovation, 32(11), 624-638.

Shlens, J. (2014). A tutorial on principal component analysis. arXiv preprint arXiv:1404.1100.

Si, S., Zahra, S.A., Wu, X., & Jeng, D.J.F. (2020). Disruptive innovation and entrepreneurship in emerging economics. Journal of Engineering and Technology Management, 58, 101601.

Tabrizi, S.S., & Sancar, N. (2017). Prediction of Body Mass Index: A comparative study of multiple linear regression, ANN and ANFIS models. Procedia computer science, 120, 394-401.

Tian, Y., Wang, Y., Xie, X., Jiao, J., & Jiao, H. (2019). The impact of business-government relations on firms' innovation: Evidence from Chinese manufacturing industry. Technological Forecasting and Social Change, 143, 1-8.

Veiga, P.M., Teixeira, S.J., Figueiredo, R., & Fernandes, C.I. (2020). Entrepreneurship, innovation and competitiveness: A public institution love triangle. Socio-Economic Planning Sciences, 72, 100863.

Wang, C., Qiao, C., Ahmed, R.I., & Kirikkaleli, D. (2021). Institutional Quality, Bank Finance and Technological Innovation: A way forward for Fourth Industrial Revolution in BRICS Economies. Technological Forecasting and Social Change, 163, 120427.

Wiseman, A.W., & Anderson, E. (2012). ICT-integrated education and national innovation systems in the Gulf Cooperation Council (GCC) countries. Computers & Education, 59(2), 607-618.

World data bank (2021a). Population database. Retrieved from: https://data.worldbank.org/indicator/SP.POP.TOTL

World data bank (2021b). GDP database. Retrieved from: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

Xu, B., Chen, X., & Wang, Y. (2020). A new dynamic classification of enterprises for implementing precise industrial policies. Journal of Business Research, 118, 463-473.

Zabala-Iturriagagoitia, J.M., Aparicio, J., Ortiz, L., Carayannis, E.G., & Grigoroudis, E. (2021). The productivity of national innovation systems in Europe: Catching up or falling behind?. Technovation, 102, 102215.

Zhao, C., Qu, X., & Luo, S. (2019). Impact of the InnoCom program on corporate innovation performance in China: Evidence from Shanghai. Technological Forecasting and Social Change, 146, 103-118.

Zheng, M., Feng, G.F., Feng, S., & Yuan, X. (2019). The road to innovation vs. the role of globalization: A dynamic quantile investigation. Economic Modelling, 83, 65-83.