

# A Taxonomy of Country Performance Based on GDP and Innovation Indicators for the Group of Twenty (G20)



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**Abstract** This chapter proposes a taxonomy of country performance based on GDP and innovation indicators within G20 economies. This study considers the impact of GDP on the “development degree” (fi) for the G20 economies and investigates how the development of G20 economies relates to the innovation promotion factors extracted from the *Global Innovation Index* (GII) indicators, used as the secondary data for the period 2010–2016. Various variables are used, such as population (in millions), GDP (in USD billion), and seven indicators that are extracted from the GII data. Through the evaluation process, the seven indicators are divided into input and output data; five of them are the input data (institutions, human capital and research, infrastructure, market sophistication, and business sophistication), and the other two are the output data (knowledge and technology output and creative output). The taxonomy provides the identification of country performance and presents relevant information to policymakers, who seek to apply effective economic strategies and develop global policies.

## 1 Introduction

A group of world’s major economies, G20<sup>1</sup> (Group of Twenty), as a leading global forum, seeks to apply effective economic strategies and develop global policies. Thus, the group attempts to promote innovation and economic growth, by utilizing accumulative capabilities, based on existing resources. The most important resources

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<sup>1</sup>G20 countries (Argentina, Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, the United States).

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are represented by some indicators to provide proper patterns toward methodical and stable development.

The G20 brings together substantially important advanced economies that account for over 85% of global GDP<sup>2</sup> and two-thirds of the world's population (G20.org. Archived). Nowadays, economic growth has an impact on increasing competitiveness and innovation among nations like G20 countries and the European Union.<sup>3</sup> G20 was formed in 1999 (consisting of 19 major economies plus the European Union<sup>4</sup>) for international collaboration in the promotion of global financial stability (Goedhuysa and Veugelers 2012).

During the depression years (especially from 2010 to 2012), the G20 economies faced many challenges that are manifested in GDP.<sup>5</sup> An estimate of GDP growth for the G20 aggregate, on the basis of quarterly seasonally adjusted data (as reported by G20 members), is rendered by the OECD<sup>6</sup> secretariat:

- Growth of real gross domestic product (GDP) in the G20 area<sup>7</sup> was stable, at 0.9%, in the first quarter of 2017, according to provisional estimates and comprehensive information chosen from the OECD report (in 2016).
- Growth picked up in Korea (to 1.1%, from 0.5%) and, to a lesser extent, in Canada (to 0.9%, from 0.7%), Germany (to 0.6%, from 0.4%), and Italy (to 0.4%, from 0.3%). Real GDP also grew by 1.0% in Brazil.
- Growth was unchanged in India (at 1.5%), Indonesia (1.2%), Mexico (0.7%), the European Union (0.6%), and Japan (0.3%).
- On the other hand, economic growth slowed markedly in Turkey (to 1.4%, from 3.4%) and Australia (to 0.3%, from 1.1%).

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<sup>2</sup>GDP (gross domestic product that is the standard measure of the value of the goods and services produced by a country during a reference period).

<sup>3</sup>The European Union contains 28 of the countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom).

<sup>4</sup><http://www.eprs.ep.parl.union.eu>

<sup>5</sup>The study group was chaired by Canada, with the participation of Argentina, Australia, Brazil, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, the Russian Federation, South Africa, Turkey, the United States, the United Kingdom, and the European Central Bank, along with the IMF and the three technical notes for G20 GDP, Paris, 15 June 2017 News Release: G20 GDP growth Quarterly National Accounts.

<sup>6</sup>The OECD (the Organisation for Economic Co-operation and Development countries) is a unique forum where the governments of 30 democracies work together to address the economic, social, and environmental challenges of globalization. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy, and the challenges of an aging population. The Organization provides a setting where governments can compare policy experiences, seek answers to common problems, and identify good practice and work to coordinate domestic and international policies.

<sup>7</sup>See countries notes in the technical analytics notes.

- Growth also weakened in the United Kingdom (to 0.2%, from 0.7%), China (to 1.3%, from 1.7%), the United States (to 0.3%, from 0.5%), and France (to 0.4%, from 0.5%).

In South Africa, GDP declined further (to  $-0.2\%$ , compared with a drop of  $0.1\%$  in the previous quarter).

Innovation policies and technology advancement create new economic benefits and opportunities to boost economic growth and lead to improvement in quality of life. A mix of innovative and highly productive industries promotes economic growth and stability, with information and communication technology playing a key role (Atkinson and Stewart 2012).

Indeed, recently an increasing general policy focus on innovation progress is observed, and not only innovation is remarked as the central phase in economic policymaking, but the perception of a coordinated, coherent, “whole-of-government” approach requirement is emphasized. This encompasses knowledge absorption and exploitation from R&D across countries and industries, and also fruitful cooperation among researchers and scientists (Van de Ven and Johnson 2006).

Access to knowledge depends on the type of research and development (R&D) activities and network governance among companies (Zalewski and Skawinska 2009). Many OECD member countries have adopted national strategic road maps to innovation and enhance its economic impacts (OECD 2017).<sup>8</sup>

Investing in the knowledge has produced a composite indicator of “investment in knowledge” made up of investment in R&D, investment in higher education, and investment in IT software. By this input measure, we can identify three groups of economies.<sup>9</sup>

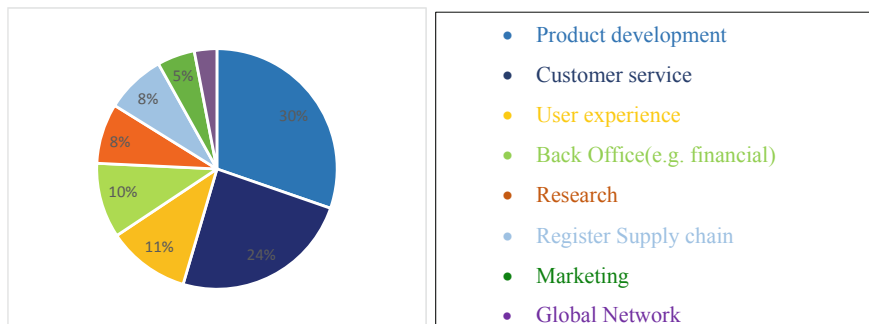
- High knowledge investment economies of North America, OECD Asia, and Japan, investing around 6% of GDP
- Middle knowledge investment economies of Northern Europe and Australia, investing between 3% and 4% of GDP
- Low investment economies of Southern Europe, investing between 2% and 3% of GDP

In this decade, many transitions have occurred crucially in technology, and the developed economies achieved significant improvements. These countries generate strength and the ability to grow in the global economy. This capability in technology consists of many major elements, for instance, GDP growth, innovation, and entrepreneurship. In contemporary thinking on economic growth, one of the main views is that technological change inherently creates growth in economy (Hu and Png 2013).

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<sup>8</sup>OECD (2017), *Innovation in Energy Technology: Comparing National Innovation Systems at the Sectoral Level*.

<sup>9</sup>Defining the knowledge economy prepared by Ian Brinkley and first published July 2006 [ibrinkley@theworkfoundation.com](mailto:ibrinkley@theworkfoundation.com) Ian Brinkley.



**Fig. 1** The area of a business that would benefit most from innovation (% of respondents). Source: [www.cbi.org.uk](http://www.cbi.org.uk) (Annual Conference London 2016) (authors' own figure)

The ICT sector for the European Union, the United States, and Japan is the largest R&D-investing sector.<sup>10</sup> The most considerable percentage of incomes in the ICT industry businesses is spent on R&D in the European Union (Veugelers et al. 2012).

The innovation subindexes rendered by GII emphasize on institution, infrastructure, research, knowledge, and technology as the determining components, highly significant in promoting economic development (GII 2017).

The societies demonstrate evidences of expanding in many layers of the economy. The interest of economists in the sources of long-run economic growth has led to exploring the role of innovation in creating growth (Encaoua et al. 2000).

R&D as the efficient force behind innovation supports economic growth. This goal achieved through effective communication, knowledge sharing, valuable information utilization, and use of appropriate channels of communication depends mainly on workforce abilities and skills, e.g., social capital, collaboration, and co-creation of both individuals and organizations. Trust within individuals and organizations is determinant in its effectiveness (Romuald and Eulalia 2009). Organizations operating on the R&D innovate a new product or process, thus extending markets and sales, promoting investment, and ultimately creating position for vocations. These firms and organizations take advantage of shared knowledge and expertise and are often the first to modify new products and generative technologies.<sup>11</sup> Figure 1 depicts the area of a business that would benefit most from innovation.

<sup>10</sup><http://is.jrc.ec.europa.eu>

<sup>11</sup>North Carolina Department of Commerce Office of Science, Technology & Innovation.

## 2 Methodology

Innovation in the GII (Global Innovation Index) consists of two categories, input and output data. Input’s subindexes include institutions, human capital and resources, infrastructure, market sophistication, and business sophistication factors. Output’s subindexes are knowledge, technology outputs, and creative outputs (Framework of the Global Innovation Index 2016). GII as a renowned international index which is published annually, in its 2017 report, included 127 countries which stand for 92.5% of the world population and 97.6% of world’s GDP. GII overall index is the simple statistical average of five input indexes and two output ones, which are summarized in Table 1.

The GII indexes (2010–2017) corresponding to the G20 countries, together with two additional indicators, i.e., population and GDP, are compared by application of “numerical taxonomy” analysis (using matrix operations) during 2010–2016. Figure 2 depicts a description of the methodological steps.

**Table 1** Input and output indexes which constitute the overall *GII*

<i>GII</i> 's input indexes
Institution
Human capital and researcher
Infrastructure
Market sophistication
Business sophistication
<i>GII</i> 's output indexes
Knowledge and technology outputs
Creative output

Source: Authors’ own table



**Fig. 2** Description of methodological steps. Authors’ own figure

This method of analysis forms matrices containing dimensionless elements (replacing quantities with different units of measurement or dimensions), enabling comparison of indicators by computing dimensionless numbers for matrix elements (Forouharfar et al. 2018; Sazegar et al. 2018).

A method of selecting from a data matrix the characters most likely to lead to valid conclusions is put forward, based on the concept of a uniquely derived character and its logical consequences (Le Quesne 1969). As explained in the next section (and subsections), following final measurements, a development factor (fi) is obtained with a quantitative value between zero and unity, such that an economy with a factor value less than others and closer to zero would be more developed than those closer to unity (Forouharfar et al. 2018; Sazegar et al. 2018).

### 3 Computations of Comparative Indexes

The computations proceed in seven steps described in the following subsections (Le Quesne 1969; Phillips 1983; Forouharfar et al. 2018; Sazegar et al. 2018).

#### 3.1 Step 1: Development of the Data Matrix

Consider:

$$X_{oj} = \left( \sum_{i=1}^n X_{ij} \right) / n \quad (1)$$

The purpose of step 1 was to develop a matrix with “ $n$ ” members (1, 2, 3, . . . ,  $n$ ) to represent the variables as a group. The variables were shown with “ $m$ ” (as an indicator of each study). The matrix, as it was shown in Eq. (1), consisted of “ $i$ ” rows and “ $j$ ” columns. Thus, the data matrices of the G20 countries were formed by using the GII’s indexes data from 2010 to 2016, as shown in Tables 2, 3, 4, 5, 6, 7, and 8. It should be noted that each indicator (for the scores of the indexes and subindexes) was normalized. In the tables that follow, the subindexes of the innovation input and output for each year are placed in columns. Additionally, population, GDP, and five subindexes of institution, human capacity, infrastructure, market sophistication, and business sophistication (1–7), besides the two subindexes of knowledge (scientific outputs) and creative outputs (8–9), comprise the (GII) innovation input index and innovation output index, respectively.

Considering that the European Union (EU) is also a G20 member, consisting of 28 countries, the data for the EU was obtained as an average of each indicator for the EU members within the time span of 2010–2016.

**Table 2** GII's data matrix for G20 countries in 2010

2010 ( $X_{ij}$ )	Population	GDP (US \$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge creation and technology outputs	Creation output
Argentina	40.7	307.2	51.1	37.2	31.5	28.3	38.3	23.5	43.4
Australia	21.5	924.8	91	57.8	52.3	58.8	54.1	33.1	40.6
Brazil	195.4	1573.4	54.1	33.9	32.2	35.7	41.5	25.2	46.9
Canada	33.9	1336.1	93.3	53.9	53.1	63.4	58.4	42.5	54
China	1354.1	4985.5	51.7	39.9	35.4	54.1	49.3	52.7	40.9
France	62.6	2649.4	77.9	53	43.1	53.8	50.3	41.1	44.7
Germany	82.1	3330	83.5	57.5	43.2	59.3	51.6	49.8	51.7
India	1214.5	1310.2	52.3	26.9	27.7	44.6	30.8	24.8	40.3
Indonesia	232.5	540.3	53.4	29.6	24.5	32.2	28.2	18.3	25.7
Italy	60.1	2112.8	71.1	44.5	35.9	42.7	45.2	27.8	39.2
Japan	127	5069	83.8	53.7	45.4	57.9	55.9	49.8	32.8
Mexico	110.6	874.8	58.6	34.7	27	37.2	29.9	16.7	30.1
Russia	140.4	1231.9	51.8	45.1	25.8	36.4	44.9	32.9	28.9
Saudi Arabia	26.2	369.2	67.5	40.4	27.8	52.7	41.3	18.3	35.6
South Africa	50.5	285.4	71	30	24.8	63.9	42.3	21.5	26.6
South Korea	48.5	832.5	77.4	59.9	48.2	61.8	49.8	53.7	42.2
Turkey	75.7	614.6	62.1	32.9	27.5	38	29.4	18.9	41.6
United Kingdom	61.9	2174.5	86.4	56.1	43.6	74.4	57.8	52.3	44.3
United States	317.6	14,119	86.5	57.4	44.6	70.9	54.8	57.4	43.2
European Union	501.800	608.633	80.707	50.493	38.389	50.793	48.937	37.374	42.211
Sum	4757.60	45,249.23	1405.21	894.89	731.99	1016.89	902.74	697.67	794.91
Ave. ( $X_{ij}$ )	237.88	2262.46	70.26	44.74	36.60	50.84	45.14	34.88	39.75

Source: Authors' own work based on GII data

**Table 3** GII's data matrix for G20 countries in 2011

2011 ( $X_{ij}$ )	Population	GDP (US\$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creation output
Argentina	40.9	435.2	44.9	39.1	37.3	31.3	40.6	24.3	36
Australia	22.5	1507.4	90	53.3	56.3	63.2	54	34.9	45.9
Brazil	194.9	2517.9	50.4	31.5	39.1	35.6	44.4	30.5	35.4
Canada	34.4	1758.7	95	53.2	55.2	68.4	57.4	46.4	49.7
China	1348.1	6988.5	39.1	31.4	44.3	47.8	50.9	61.8	34.4
France	63.2	2808.3	82.7	55.1	54.5	52	51.3	45.5	43.3
Germany	81.4	3628.6	76.7	55.4	55.1	54.9	51.7	54.9	52.6
India	1206.9	1843.4	38.4	18.5	31	44.6	37.6	34	40.7
Indonesia	240.5	834.3	25.4	29.9	30.5	33	34.2	20.4	30.6
Italy	60.6	2245.7	70.2	44.7	53.5	41.1	47.8	38.2	36.8
Japan	127.9	5855.4	79	54.6	61.6	57.7	53.6	51.7	32.3
Mexico	109.7	1185.2	55.9	31.8	38.4	36.8	36.1	22.3	29.5
Russia	142.4	1884.9	49.1	43.8	37.8	35	44.3	38.4	29.1
Saudi Arabia	28.2	560.3	63.8	44.8	42.6	47.5	47.5	15.3	43.4
South Africa	50.6	422	69.7	27.2	30.8	62.5	41.9	28.2	28.8
South Korea	49	1163.8	73.8	59	64.2	60.5	51.7	57.5	34.3
Turkey	72.2	763.1	50	31.8	34	39.4	32.5	27.8	33.7
United Kingdom	62.6	2481	90.4	53.8	61.8	76.6	57.3	57.6	51.4
United States	312.9	15,064.8	85.1	53.4	56.1	76.8	59.9	56.1	42.2
European Union	504.600	643.729	77.814	50.304	50.800	50.889	49.596	45.468	44.168
Sum	4753.500	54,592.229	1307.414	862.604	934.900	1015.589	944.296	791.268	774.268
Ave. ( $X_{oj}$ )	237.675	2729.611	65.371	43.130	46.745	50.779	47.215	39.563	38.713

Source: Authors' own work based on GII data



Table 4 GII's data matrix for G20 countries in 2012

2012 ( $X_{ij}$ )	Population	GDP (US\$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creation output
Argentina	42.2	474.8	50.7	36.7	35	37.3	34.2	25.6	47.5
Australia	23.8	1542.1	89.4	57.8	52.7	72.7	48.2	30.9	53.1
Brazil	201.5	2425.1	53.8	30.3	37.2	44.9	38	26.5	37.2
Canada	36.1	1770.1	93.3	49.4	53	78.8	49.3	44.4	56.5
China	1374	8250.2	48.3	40.6	39.8	54.2	42.9	56.4	31.9
France	67	2580.4	79	54.6	52.4	63.1	46.1	44.3	49
Germany	86.3	3366.7	82.5	54.3	53.5	62.8	45.9	49.1	54.7
India	1267.6	1946.8	51.9	21.7	27.5	49.5	28.3	34.5	38.6
Indonesia	246.8	894.9	37.2	24.3	29.1	41.2	25	24.3	40.8
Italy	64.7	1980.4	73.6	43.2	51	54.7	44.1	41.7	43
Japan	135.2	5984.4	83.5	57.2	56.3	69.7	47.4	44.6	38.7
Mexico	117.8	1162.9	61.8	31.9	35.5	45.6	28.9	23.4	42.4
Russia	147	1953.6	56	44.1	37.2	45.4	36.1	30.4	30.8
Saudi Arabia	28.9	657	58.4	39.8	40.6	53.5	37.2	24.8	48.2
South Africa	51.1	390.9	70.1	23.7	28.5	66	31.5	24.7	37.8
Republic of Korea	49.7	1151.3	76	64.8	60.7	65.7	43.3	47.8	41.3
Turkey	75.2	783.1	55.8	29.8	31.2	47.5	25.7	30.4	37.8
United Kingdom	65.8	2433.8	88.4	56.2	59.4	84.6	52.3	51.1	57.5
United States	327.9	15,653.4	86	61.1	52.5	87.1	59.2	53.6	49.2
European Union	532.400	588.286	80.004	47.743	47.789	57.893	43.046	39.586	49.264
Sum	4941.000	55,990.186	1375.704	869.243	880.889	1182.193	806.646	748.086	885.264
Ave. ( $X_{oj}$ )	247.050	2799.509	68.785	43.462	44.044	59.110	40.332	37.404	44.263

Source: Authors' own work based on GII data

Table 5 GII's data matrix for G20 countries in 2013

2013 ( $X_{ij}$ )	Population	GDP (US\$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creation output
Argentina	41.1	488.2	49.1	38.3	38	37.7	32.9	25.2	36.9
Australia	22.7	1505.3	88.9	61.8	60.1	68.1	43.9	38.5	52.5
Brazil	198.7	2242.9	53.9	31.1	39.2	45.2	39.3	28.1	33.6
Canada	34.9	1825.1	92.7	56.4	58.4	75.9	48	43.7	48.3
China	1350.7	9181.4	48.3	43.4	45	50.5	41.8	59	35.7
France	65.7	2737.4	78.6	55.9	54.7	61	47.4	44.2	45.5
Germany	81.9	3636	82.7	56.3	56.3	60.1	46.1	53.1	50.4
India	1236.7	1870.7	50.8	22.7	32.1	51.2	28	32.2	28.6
Indonesia	246.9	870.3	38.1	22.8	33.1	45.3	22.8	23.2	39.2
Italy	60.9	2072	73.2	42.1	49.8	51	40	42.7	37.5
Japan	127.6	4901.5	84.1	54.4	58.9	66.8	46.8	47.2	38.1
Mexico	120.8	1258.5	61.8	32.5	39.9	46.9	29.9	26.9	32.9
Russia	143.5	2118	56.4	44.5	41.1	42.5	34.3	37.6	31.4
Saudi Arabia	28.3	745.3	60	35.6	47	59	37.6	25.7	45
South Africa	51.2	350.8	69.9	28.7	32.9	63.8	32.7	29.1	32.7
Republic of Korea	50	1221.8	75.8	64.1	62.8	65.4	42.7	54.5	42.2
Turkey	74	827.2	54.9	33.3	35.6	49.1	25.4	32.3	41.2
United Kingdom	61.2	2535.8	88.6	60.3	60.6	81.4	50.2	56.4	56.6
United States	313.9	16,399.7	86.2	58.3	57.5	83.8	53.7	58.1	46.5
European Union	506,800	620,425	79,850	46,675	49,671	55,696	42,211	42,475	46,114
Sum	4817,500	57,408,325	1373,850	889,175	952,671	1160,396	785,711	800,175	820,914
Ave. ( $X_{oj}$ )	240,875	2870,416	68,693	44,459	47,634	58,020	39,286	40,009	41,046

Source: Authors' own work based on GII data

**Table 6** GII's data matrix for G20 countries in 2014

2014 ( $X_{ij}$ )	Population	GDP (US\$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creation output
Argentina	41.8	540.2	48	37.7	38.2	35.9	36.3	22.2	36.5
Australia	23.6	1444.2	89.3	57	63.7	66.7	47.4	34.8	56.5
Brazil	202	2353	55.8	30.1	40.1	44.3	41.6	25.4	29.6
Canada	35.5	1788.7	92.7	49	60.9	73.5	49.3	41.9	50.9
China	1393.8	10,380.4	54	43.1	50.5	49.2	44.9	58	35.1
France	64.6	2846.9	81.7	55.5	60.8	59	49.3	41.1	50.8
Germany	82.7	3859.5	83.2	56.6	56.7	59.2	49.2	53.4	52.8
India	1267.4	2049.5	50	20	34.6	46.5	26.4	30.1	25.9
Indonesia	252.8	888.6	39.8	24.3	35.6	44.4	24.6	20.9	30.8
Italy	61.1	2148	73.8	41.3	57.6	53.6	40.6	41.2	37.6
Japan	127	4616.3	86.5	55	63.1	64.3	50.4	48.6	39.6
Mexico	123.8	1282.7	61.5	34.3	39.5	47	36.9	29.4	35
Russia	142.5	1857.5	56.6	47.5	40.6	43.5	38.4	36.6	30.1
Saudi Arabia	29.4	752.5	60.4	39.8	50.2	50.3	35.8	25.1	42.9
South Africa	53.1	350.1	71.6	27.4	33.9	59.1	34	28.3	31.1
South Korea	49.5	1416.9	76.1	64.8	62.4	63.3	45.2	56.7	43.6
Turkey	75.8	806.1	55.8	35.9	41	49.5	26.3	27.2	40.6
United Kingdom	63.5	2945.1	87.3	57.5	63	74.3	53.6	54.9	60.5
United States	322.6	17,418.9	86.8	54	58.8	81.5	55.4	58	47.8
European Union	510.300	660.554	80.246	45.936	52.493	55.854	44.189	40.614	48.296
Sum	4922.800	60,405.654	1391.146	876.736	1003.693	1120.954	829.789	774.414	825.996
Ave. ( $X_{oj}$ )	246.140	3020.283	69.557	43.837	50.185	56.048	41.489	38.721	41.300

Source: Authors' own work based on GII data

Table 7 GII's data matrix for G20 countries in 2015

2015 ( $X_{ij}$ )	Population	GDP (US\$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creation output
Argentina	43.4	585.6	47.2	37.3	43.3	34.7	30.8	18	25.3
Australia	24	1223.9	88.8	59.7	65.1	65.8	45	34.3	48.2
Brazil	207.8	1772.6	55.3	32.5	44.9	43.9	37	23.7	23.6
Canada	35.9	1552.4	91.7	52.9	62.3	73.6	46.5	40.9	47.1
China	1376	10,982.8	55.2	48.1	52	56.6	53.8	53.3	42.7
France	64.4	2421.6	80.4	58.9	63.7	61.9	48	41.3	49.8
Germany	80.7	3357.6	84.1	58.9	58.5	59.7	48.3	51.6	56.3
India	1311.1	2090.7	50.7	32.2	37	50.3	32.2	31	22.5
Indonesia	257.6	859	41.6	23.1	38.5	43.3	23.7	23	25.2
Italy	59.8	1815.8	72.8	46.5	59.7	53.6	37.8	38.7	41.8
Japan	126.6	4123.3	87.1	57.5	64.4	68.3	52.8	46.9	39.2
Mexico	127	1144.3	60.5	33.7	42.8	45.7	29.8	23.3	29.9
Russia	14.5	1324.7	57.9	50.4	44.5	43.1	37.5	31.9	28.7
Saudi Arabia	31.5	653.2	57.9	44.7	51.4	49.6	31.3	22.4	34.6
South Africa	54.5	313	69.1	33.1	37.4	58.7	32.2	24.7	26.5
South Korea	50.3	1376.9	75.4	66.9	63.3	62	50.1	54.1	47.4
Turkey	78.7	733.6	54.6	39.2	43.6	47.7	27.6	29.1	42
United Kingdom	64.7	2849.3	87.6	62.6	66.4	71.6	49.2	50.2	62.5
United States	321.8	17,947	85.7	57	61.7	86.6	52.4	56.5	51.6
European Union	505.100	579,300	79,593	48,693	55,221	51,904	42,821	40,225	47,261
Sum	4835,400	57,706,600	1383,193	943,893	1055,721	1128,604	808,821	735,125	792,161
Ave. ( $X_{oj}$ )	241,770	2885,330	69,160	47,195	52,786	56,430	40,441	36,756	39,608

Source: Authors' own work based on GII data

**Table 8** GII's data matrix for G20 countries in 2016

2016 ( $X_{ij}$ )	Population	GDP (US\$ billion)	Institutions	Human capital and research	Infrastructure	Market sophistication	Business sophistication	Knowledge and technology outputs	Creation output
Argentina	43.8	541.7	46.4	42.6	46.6	37.7	33.6	17.6	27.6
Australia	24.3	1256.6	87.4	60.2	64.8	65.3	45.4	32.1	46.1
Brazil	209.6	1769.6	51.8	35.9	48.3	44.2	37.2	18.9	26.6
Canada	36.3	1532.3	91	53.3	62.1	73.7	47.8	38.7	44.8
China	1382.3	11,391.6	54.8	49.2	57.9	54.7	54.5	56.4	45.3
France	64.7	2488.3	80.7	58.1	63.4	64.3	50.6	38.5	51.4
Germany	80.7	3494.9	83.5	60.1	61.5	60	51.4	51.1	55.9
India	1326.8	2251	51.4	32.3	44.1	51.9	34.6	30.3	25.9
Indonesia	260.6	941	41.2	23	42	46	26.2	20.9	28.1
Italy	59.8	1852.5	71.9	46.3	61.8	52.6	39.6	36.1	42.9
Japan	126.3	4730.2	87.4	56.7	64.3	64.3	54.5	47.1	40.8
Mexico	128.6	1063.6	58.5	33.7	49.7	50	30.8	21.5	32.6
Russia	143.4	1267.8	56.1	50	47.5	47.1	40.3	27.6	31
Saudi Arabia	32.2	637.8	52.4	46.5	53.3	49.4	35	21.6	28.4
South Africa	55	280.4	66.3	32.8	43.4	57.4	34.4	21.5	28
South Korea	50.5	1404.4	74.5	66.2	63.4	61.6	51.1	54.7	49.4
Turkey	79.6	735.7	50.6	38.1	45.7	47.8	29.3	27.6	43.4
United Kingdom	65.1	2649.9	88.4	63.3	67.1	70.2	52.2	46.5	60.5
United States	324.1	18,561.9	86.2	57.2	61	83.4	56.4	54.4	53.5
European Union	505.900	589.961	79.307	48.396	58.646	53.171	45.350	38.104	47.346
Sum	4999.600	59,441.161	1359.807	953.896	1106.546	1134.771	850.250	701.204	809.546
Ave. ( $X_{oj}$ )	249.980	2972.058	67.990	47.695	55.327	56.739	42.513	35.060	40.477

Source: Authors' own work based on GII data

### 3.2 Step 2: Forming the Standard Matrix

Since the indicators have different units of measurement (dimensions), a “standard matrix” is formed, containing dimensionless elements  $Z_{ij}$ :

$$S_j = \sqrt{\sum_{i=1}^n (X_{ij} - \overline{X_j})^2 / n} \quad (2)$$

$$Z_{ij} = (X_{ij} - X_{oj}) / S_j \quad (3)$$

“ $X_{ij}$ ” is a data matrix, “ $X_{oj}$ ” is an average matrix (Eq. 1), and “ $S_j$ ” denotes the standard deviation for “ $j$ ” indicators, which are derived from the GII reports for 2010–2016. Thus, in this data analysis, “ $i$ ” represents the G20 countries in the above time period. The corresponding standard matrices were computed and presented in the tables that follow. Moreover, eliminating the discrepancy between the indicators’ units (by generating scale-free indexes) renders average = 0 and standard deviation = 1 in the  $Z$  matrix. Thus, “ $Z$ ” matrix acceptability could be controlled for the required computations, as shown in Tables 9, 10, 11, 12, 13, 14, and 15.

### 3.3 Step 3: Computing Compound Distances Among the G20 Economies

Compound distances between the G20 economies are measured by

$$D_{ab} = \sqrt{\sum_{i=1}^n (Z_{aj} - Z_{bj})^2} \quad (4)$$

where  $D_{ab}$  is the distance between any two economies “ $a$ ” and “ $b$ .” Thus,

$$D_{aa} = 0$$

$$D_{bb} = 0$$

$$D_{ab} = D_{ba}$$

Therefore, as shown in the following tables, the *compound distance matrices* “ $D$ ” computed for the G20 countries are symmetric, and their diameter elements are equal to zero. As seen, each element  $D_{ab}$  in the matrices  $D$  shows the distance between two countries ( $a$ ,  $b$ ), as numbered in Tables 16, 17, 18, 19, 20, 21, and 22.

**Table 9** Standard matrix for 2010

2010 year	G20 countries standard matrix ( $Z_{oj}$ )												
Argentina = 1	-0.536	-0.641	-1.323	-0.697	-0.551	-1.739	-0.720	-0.834	0.486				
Australia = 2	-0.589	-0.439	1.432	1.207	1.696	0.614	0.944	-0.131	0.114				
Brazil = 3	-0.116	-0.226	-1.116	-1.002	-0.475	-1.168	-0.383	-0.709	0.951				
Canada = 4	-0.555	-0.304	1.591	0.846	1.782	0.968	1.397	0.558	1.895				
China = 5	3.037	0.893	-1.282	-0.448	-0.130	0.251	0.438	1.305	0.153				
France = 6	-0.477	0.127	0.528	0.763	0.702	0.228	0.544	0.455	0.658				
Germany = 7	-0.424	0.350	0.914	1.179	0.713	0.652	0.681	1.093	1.589				
India = 8	2.657	-0.312	-1.240	-1.650	-0.961	-0.482	-1.510	-0.739	0.074				
Indonesia = 9	-0.015	-0.565	-1.164	-1.400	-1.307	-1.438	-1.784	-1.215	-1.867				
Italy = 10	-0.484	-0.049	0.058	-0.023	-0.076	-0.628	0.007	-0.519	-0.073				
Japan = 11	-0.302	0.920	0.935	0.828	0.951	0.544	1.134	1.093	-0.923				
Mexico = 12	-0.346	-0.455	-0.805	-0.929	-1.037	-1.052	-1.605	-1.332	-1.282				
Russia = 13	-0.265	-0.338	-1.275	0.033	-1.167	-1.114	-0.025	-0.145	-1.441				
Saudi Arabia = 14	-0.576	-0.621	-0.191	-0.402	-0.951	0.143	-0.404	-1.215	-0.551				
South Africa = 15	-0.510	-0.648	0.051	-1.363	-1.275	1.007	-0.299	-0.980	-1.747				
South Korea = 16	-0.515	-0.469	0.493	1.401	1.253	0.845	0.491	1.378	0.326				
Turkey = 17	-0.441	-0.540	-0.564	-1.095	-0.983	-0.991	-1.658	-1.171	0.246				
United Kingdom = 18	-0.479	-0.029	1.115	1.050	0.756	1.817	1.334	1.276	0.605				
United States = 19	0.217	3.888	1.121	1.170	0.864	1.547	1.018	1.649	0.459				
European Union = 20	0.718	-0.542	0.721	0.531	0.193	-0.004	0.400	0.182	0.328				
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000				
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				

Source: Authors' own work based on GII data

**Table 10** Standard matrix for 2011

2011 year	G20 countries standard matrix ( $Z_{oj}$ )														
Argentina = 1	-0.538	-0.696	-1.048	-0.344	-0.855	-1.421	-0.847	-1.106	-0.369						
Australia = 2	-0.588	-0.371	1.261	0.869	0.864	0.906	0.869	-0.338	0.977						
Brazil = 3	-0.117	-0.064	-0.766	-0.994	-0.692	-1.107	-0.360	-0.657	-0.450						
Canada = 4	-0.556	-0.295	1.517	0.860	0.765	1.285	1.304	0.496	1.493						
China = 5	3.037	1.293	-1.345	-1.002	-0.221	-0.217	0.472	1.612	-0.586						
France = 6	-0.477	0.024	0.887	1.023	0.702	0.089	0.523	0.430	0.623						
Germany = 7	-0.427	0.273	0.580	1.048	0.756	0.301	0.574	1.112	1.887						
India = 8	2.651	-0.269	-1.380	-2.104	-1.425	-0.451	-1.231	-0.403	0.270						
Indonesia = 9	0.008	-0.575	-2.046	-1.130	-1.470	-1.297	-1.666	-1.389	-1.103						
Italy = 10	-0.484	-0.147	0.247	0.134	0.611	-0.706	0.075	-0.099	-0.260						
Japan = 11	-0.300	0.949	0.698	0.980	1.344	0.505	0.818	0.880	-0.872						
Mexico = 12	-0.350	-0.469	-0.485	-0.968	-0.755	-1.020	-1.423	-1.251	-1.252						
Russia = 13	-0.261	-0.256	-0.833	0.057	-0.809	-1.151	-0.373	-0.084	-1.307						
Saudi Arabia = 14	-0.573	-0.658	-0.080	0.143	-0.375	-0.239	0.037	-1.759	0.637						
South Africa = 15	-0.512	-0.700	0.222	-1.361	-1.443	0.855	-0.680	-0.824	-1.347						
South Korea = 16	-0.516	-0.475	0.431	1.356	1.579	0.709	0.574	1.300	-0.600						
Turkey = 17	-0.453	-0.597	-0.787	-0.968	-1.153	-0.830	-1.884	-0.853	-0.681						
United Kingdom = 18	-0.479	-0.075	1.281	0.912	1.362	1.884	1.291	1.307	1.724						
United States = 19	0.206	3.744	1.010	0.877	0.846	1.898	1.624	1.199	0.474						
European Union = 20	0.730	-0.633	0.637	0.613	0.367	0.008	0.305	0.428	0.741						
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						

Source: Authors' own work based on GII data



**Table 11** Standard matrix for 2012

2012 year	G20 countries standard matrix ( $Z_{oj}$ )														
Argentina = 1	-0.542	-0.665	-1.126	-0.518	-0.845	-1.560	-0.672	-1.095	0.424						
Australia = 2	-0.591	-0.360	1.283	1.098	0.808	0.972	0.862	-0.604	1.157						
Brazil = 3	-0.121	-0.107	-0.933	-1.008	-0.639	-1.016	-0.256	-1.012	-0.925						
Canada = 4	-0.558	-0.295	1.526	0.455	0.836	1.408	0.983	0.649	1.603						
China = 5	2.982	1.560	-1.275	-0.219	-0.396	-0.351	0.281	1.763	-1.619						
France = 6	-0.476	-0.063	0.636	0.853	0.780	0.285	0.632	0.640	0.620						
Germany = 7	-0.425	0.162	0.854	0.830	0.883	0.264	0.610	1.085	1.367						
India = 8	2.701	-0.244	-1.051	-1.666	-1.545	-0.687	-1.318	-0.270	-0.742						
Indonesia = 9	-0.001	-0.545	-1.966	-1.467	-1.395	-1.281	-1.680	-1.216	-0.454						
Italy = 10	-0.483	-0.234	0.300	-0.020	0.649	-0.315	0.413	0.399	-0.165						
Japan = 11	-0.296	0.911	0.916	1.052	1.144	0.757	0.774	0.668	-0.729						
Mexico = 12	-0.342	-0.468	-0.435	-0.885	-0.798	-0.966	-1.253	-1.300	-0.244						
Russia = 13	-0.265	-0.242	-0.796	0.049	-0.639	-0.980	-0.464	-0.650	-1.763						
Saudi Arabia = 14	-0.577	-0.613	-0.646	-0.280	-0.322	-0.401	-0.343	-1.170	0.516						
South Africa = 15	-0.519	-0.689	0.082	-1.513	-1.452	0.493	-0.968	-1.179	-0.846						
South Korea = 16	-0.522	-0.472	0.449	1.634	1.555	0.471	0.325	0.965	-0.388						
Turkey = 17	-0.455	-0.577	-0.808	-1.046	-1.199	-0.830	-1.603	-0.650	-0.846						
United Kingdom = 18	-0.480	-0.105	1.221	0.975	1.434	1.823	1.311	1.271	1.733						
United States = 19	0.214	3.678	1.072	1.351	0.790	2.002	2.067	1.503	0.647						
European Union = 20	0.755	-0.633	0.698	0.328	0.350	-0.087	0.297	0.202	0.655						
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						

Source: Authors' own work based on GII data

Table 12 Standard matrix for 2013

2013 year	G20 countries standard matrix ( $Z_{oj}$ )														
Argentina = 1	-0.540	-0.650	-1.220	-0.472	-0.937	-1.618	-0.760	-1.274	-0.555						
Australia = 2	-0.590	-0.373	1.259	1.329	1.212	0.803	0.549	-0.130	1.534						
Brazil = 3	-0.114	-0.171	-0.921	-1.024	-0.820	-1.021	0.002	-1.025	-0.997						
Canada = 4	-0.557	-0.285	1.495	0.915	1.047	1.424	1.037	0.318	0.971						
China = 5	3.002	1.723	-1.270	-0.081	-0.256	-0.599	0.299	1.634	-0.716						
France = 6	-0.474	-0.036	0.617	0.877	0.687	0.237	0.966	0.361	0.596						
Germany = 7	-0.430	0.209	0.872	0.907	0.843	0.166	0.811	1.126	1.253						
India = 8	2.693	-0.273	-1.114	-1.667	-1.510	-0.543	-1.343	-0.672	-1.667						
Indonesia = 9	0.016	-0.546	-1.906	-1.660	-1.413	-1.013	-1.962	-1.446	-0.247						
Italy = 10	-0.487	-0.218	0.281	-0.181	0.211	-0.559	0.085	0.232	-0.475						
Japan = 11	-0.306	0.554	0.960	0.762	1.095	0.699	0.894	0.619	-0.394						
Mexico = 12	-0.325	-0.440	-0.429	-0.916	-0.752	-0.886	-1.117	-1.128	-1.091						
Russia = 13	-0.263	-0.205	-0.766	0.003	-0.635	-1.236	-0.593	-0.207	-1.292						
Saudi Arabia = 14	-0.575	-0.580	-0.541	-0.679	-0.062	0.078	-0.201	-1.231	0.530						
South Africa = 15	-0.513	-0.688	0.075	-1.207	-1.432	0.460	-0.784	-0.939	-1.118						
South Korea = 16	-0.516	-0.450	0.443	1.505	1.475	0.588	0.406	1.247	0.155						
Turkey = 17	-0.451	-0.558	-0.859	-0.855	-1.170	-0.710	-1.653	-0.663	0.021						
United Kingdom = 18	-0.486	-0.091	1.240	1.214	1.261	1.862	1.299	1.410	2.083						
United States = 19	0.198	3.693	1.090	1.061	0.959	2.053	1.716	1.556	0.730						
European Union = 20	0.719	-0.614	0.695	0.170	0.198	-0.185	0.348	0.212	0.679						
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						

Source: Authors' own work based on GII data

**Table 13** Standard matrix for 2014

2014 year	G20 countries standard matrix ( $Z_{oj}$ )														
Argentina = 1	-0.537	-0.629	-1.362	-0.502	-1.112	-1.738	-0.588	-1.339	-0.500						
Australia = 2	-0.585	-0.399	1.248	1.076	1.254	0.919	0.669	-0.318	1.582						
Brazil = 3	-0.116	-0.169	-0.869	-1.123	-0.936	-1.014	0.013	-1.080	-1.218						
Canada = 4	-0.554	-0.312	1.463	0.422	0.994	1.506	0.885	0.258	0.999						
China = 5	3.018	1.866	-0.983	-0.060	0.029	-0.591	0.386	1.563	-0.645						
France = 6	-0.477	-0.044	0.767	0.953	0.985	0.255	0.885	0.193	0.989						
Germany = 7	-0.430	0.213	0.862	1.043	0.604	0.272	0.873	1.190	1.197						
India = 8	2.685	-0.246	-1.236	-1.948	-1.446	-0.824	-1.709	-0.699	-1.603						
Indonesia = 9	0.018	-0.540	-1.881	-1.597	-1.353	-1.005	-1.913	-1.445	-1.093						
Italy = 10	-0.487	-0.221	0.268	-0.207	0.688	-0.211	-0.101	0.201	-0.385						
Japan = 11	-0.313	0.405	1.071	0.912	1.198	0.712	1.009	0.801	-0.177						
Mexico = 12	-0.322	-0.440	-0.509	-0.779	-0.991	-0.781	-0.520	-0.756	-0.656						
Russia = 13	-0.273	-0.295	-0.819	0.299	-0.889	-1.083	-0.350	-0.172	-1.166						
Saudi Arabia = 14	-0.570	-0.575	-0.579	-0.330	0.001	-0.496	-0.644	-1.104	0.167						
South Africa = 15	-0.508	-0.677	0.129	-1.343	-1.511	0.263	-0.848	-0.845	-1.062						
South Korea = 16	-0.517	-0.406	0.413	1.713	1.133	0.626	0.420	1.458	0.239						
Turkey = 17	-0.448	-0.561	-0.869	-0.649	-0.852	-0.565	-1.720	-0.934	-0.073						
United Kingdom = 18	-0.480	-0.019	1.121	1.117	1.189	1.575	1.372	1.312	1.999						
United States = 19	0.201	3.650	1.090	0.831	0.799	2.196	1.576	1.563	0.677						
European Union = 20	0.695	-0.598	0.676	0.172	0.214	-0.017	0.306	0.154	0.728						
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						

Source: Authors' own work based on GII data

Table 14 Standard matrix for 2015

2015 year	G20 countries standard matrix ( $Z_{oj}$ )														
Argentina = 1	-0.514	-0.557	-1.410	-0.825	-0.936	-1.767	-1.038	-1.561	-1.233						
Australia = 2	-0.564	-0.403	1.261	1.043	1.215	0.762	0.491	-0.204	0.741						
Brazil = 3	-0.088	-0.270	-0.890	-1.226	-0.778	-1.019	-0.371	-1.087	-1.380						
Canada = 4	-0.533	-0.323	1.447	0.476	0.938	1.396	0.653	0.345	0.646						
China = 5	2.939	1.962	-0.896	0.076	-0.078	0.014	1.439	1.377	0.267						
France = 6	-0.460	-0.112	0.722	0.976	1.077	0.445	0.814	0.378	0.879						
Germany = 7	-0.417	0.114	0.959	0.976	0.564	0.266	0.846	1.235	1.439						
India = 8	2.771	-0.193	-1.185	-1.251	-1.557	-0.499	-0.888	-0.479	-1.475						
Indonesia = 9	0.041	-0.491	-1.770	-2.010	-1.409	-1.068	-1.803	-1.145	-1.242						
Italy = 10	-0.472	-0.259	0.234	-0.058	0.682	-0.230	-0.284	0.162	0.189						
Japan = 11	-0.298	0.300	1.152	0.860	1.146	0.965	1.331	0.844	-0.035						
Mexico = 12	-0.297	-0.422	-0.556	-1.126	-0.985	-0.873	-1.146	-1.120	-0.837						
Russia = 13	-0.589	-0.378	-0.723	0.267	-0.817	-1.084	-0.317	-0.404	-0.940						
Saudi Arabia = 14	-0.545	-0.541	-0.723	-0.208	-0.137	-0.555	-0.984	-1.195	-0.432						
South Africa = 15	-0.485	-0.623	-0.004	-1.176	-1.518	0.185	-0.888	-1.003	-1.130						
South Korea = 16	-0.496	-0.366	0.401	1.644	1.037	0.453	1.040	1.443	0.672						
Turkey = 17	-0.423	-0.521	-0.935	-0.667	-0.906	-0.710	-1.383	-0.637	0.206						
United Kingdom = 18	-0.459	-0.009	1.184	1.285	1.343	1.234	0.943	1.119	1.973						
United States = 19	0.207	3.650	1.062	0.818	0.879	2.454	1.288	1.643	1.034						
European Union = 20	0.682	-0.559	0.670	0.125	0.240	-0.368	0.256	0.289	0.660						
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						

Source: Authors' own work based on GII data

**Table 15** Standard matrix for 2016

2016	G20 countries standard matrix ( $Z_{oj}$ )														
Argentina = 1	-0.534	-0.566	-1.327	-0.435	-1.052	-1.750	-0.961	-1.371	-1.196						
Australia = 2	-0.584	-0.400	1.193	1.068	1.142	0.787	0.311	-0.233	0.522						
Brazil = 3	-0.105	-0.280	-0.995	-1.008	-0.847	-1.153	-0.573	-1.269	-1.288						
Canada = 4	-0.553	-0.336	1.414	0.479	0.817	1.559	0.570	0.286	0.401						
China = 5	2.932	1.962	-0.811	0.129	0.310	-0.187	1.293	1.676	0.448						
France = 6	-0.480	-0.113	0.781	0.889	0.973	0.695	0.872	0.270	1.014						
Germany = 7	-0.438	0.122	0.953	1.060	0.744	0.300	0.958	1.260	1.432						
India = 8	2.788	-0.168	-1.020	-1.315	-1.354	-0.445	-0.853	-0.374	-1.353						
Indonesia = 9	0.028	-0.473	-1.647	-2.110	-1.607	-0.987	-1.759	-1.112	-1.149						
Italy = 10	-0.492	-0.261	0.240	-0.119	0.780	-0.380	-0.314	0.082	0.225						
Japan = 11	-0.320	0.410	1.193	0.769	1.082	0.695	1.293	0.946	0.030						
Mexico = 12	-0.314	-0.445	-0.583	-1.196	-0.678	-0.619	-1.263	-1.065	-0.731						
Russia = 13	-0.276	-0.397	-0.731	0.197	-0.944	-0.886	-0.239	-0.586	-0.880						
Saudi Arabia = 14	-0.564	-0.544	-0.958	-0.102	-0.244	-0.675	-0.810	-1.057	-1.121						
South Africa = 15	-0.505	-0.627	-0.104	-1.272	-1.438	0.061	-0.875	-1.065	-1.158						
South Korea = 16	-0.517	-0.365	0.400	1.581	0.973	0.447	0.926	1.543	0.828						
Turkey = 17	-0.441	-0.521	-1.069	-0.820	-1.161	-0.822	-1.425	-0.586	0.271						
United Kingdom = 18	-0.479	-0.075	1.254	1.333	1.419	1.238	1.045	0.899	1.859						
United States = 19	0.192	3.633	1.119	0.812	0.684	2.451	1.497	1.519	1.209						
European Union = 20	0.663	-0.555	0.696	0.060	0.400	-0.328	0.306	0.239	0.638						
Ave. $Z_{oj}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000						
$S_{oj}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000						

Source: Authors' own work based on GII data









**Table 22** Compound distance matrix for G20 countries in 2016 (“D” matrix)

2016	Argentina=1	Australia=2	Brazil=3	Canada=4	China=5	France=6	Germany=7	India=8	Indonesia=9	Italy=10	Japan=11	Mexico=12	Russia=13	Saudi Arabia=14	South Africa=15	South Korea=16	Turkey=17	United Kingdom=18	United States=19	European Union=20
Argentina=1	0	5.075	1.128	5.522	6.353	5.237	5.732	3.859	2.197	3.526	5.593	1.736	1.687	1.478	2.394	5.672	2.021	6.601	8.158	4.179
Australia=2	5.075	0	4.711	1.206	5.394	1.068	2.054	5.886	6.091	2.102	1.849	4.288	3.755	3.836	4.396	2.160	4.451	2.019	4.986	2.207
Brazil=3	1.128	4.711	0	4.992	5.746	4.838	5.397	3.181	1.936	3.145	5.072	1.190	1.546	1.350	1.765	5.416	2.011	6.228	7.537	3.695
Canada=4	5.522	1.206	4.992	0	5.317	1.365	2.127	5.883	6.210	2.523	1.629	4.507	4.110	4.261	4.374	2.323	4.715	2.005	4.511	2.466
China=5	6.353	5.394	5.746	5.317	0	4.770	4.517	4.644	6.635	4.824	4.415	5.894	5.211	5.786	6.236	4.693	5.797	5.236	4.716	4.106
France=6	5.237	1.068	4.838	1.365	4.770	0	1.219	5.873	6.186	2.142	1.448	4.493	3.823	4.088	4.636	1.552	4.464	1.433	4.445	2.008
Germany=7	5.732	2.054	5.397	2.127	4.517	1.219	0	6.220	6.651	2.641	1.639	5.067	4.280	4.733	5.236	1.158	4.833	1.364	4.225	2.312
India=8	3.859	5.886	3.181	5.883	4.644	5.873	6.220	0.000	3.241	4.619	5.893	3.380	3.581	3.829	3.560	6.259	3.741	6.995	7.649	4.275
Indonesia=9	2.197	6.091	1.936	6.210	6.635	6.186	6.651	3.241	0.000	4.394	6.500	1.872	3.061	2.778	2.302	6.708	2.203	7.466	8.558	4.934
Italy=10	3.526	2.102	3.145	2.523	4.824	2.142	2.641	4.619	4.394	0.000	2.606	2.687	2.451	2.452	3.200	2.772	2.814	3.374	5.623	1.545
Japan=11	5.593	1.849	5.072	1.629	4.415	1.448	1.639	5.893	6.500	2.606	0.000	4.871	4.099	4.444	4.885	1.769	5.063	2.097	3.958	2.450
Mexico=12	1.736	4.288	1.190	4.507	5.894	4.493	5.067	3.380	1.872	2.687	4.871	0.000	1.846	1.399	1.295	5.159	1.391	5.803	7.291	3.386
Russia=13	1.687	3.755	1.546	4.110	5.211	3.823	4.280	3.581	3.061	2.451	4.099	1.846	0	1.177	2.124	4.184	1.993	5.179	6.772	2.891
Saudi Arabia=14	1.478	3.836	1.350	4.261	5.786	4.088	4.733	3.829	2.778	2.452	4.444	1.399	1.177	0	2.020	4.585	1.986	5.455	7.155	3.290
South Africa=15	2.394	4.396	1.765	4.374	6.236	4.636	5.236	3.560	2.302	3.200	4.885	1.295	2.124	2.020	0	5.331	2.141	5.927	7.253	3.692
South Korea=16	5.672	2.160	5.416	2.323	4.693	1.552	1.158	6.259	6.708	2.772	1.769	5.159	4.184	4.585	5.331	0	4.948	1.787	4.708	2.622
Turkey=17	2.021	4.451	2.011	4.715	5.797	4.464	4.833	3.741	2.203	2.814	5.063	1.391	1.993	1.986	2.141	4.948	0	5.652	7.285	3.405
United Kingdom=18	6.601	2.019	6.228	2.005	5.236	1.433	1.364	6.995	7.466	3.374	2.097	5.803	5.179	5.455	5.927	1.787	5.652	0	4.185	3.078
United States=19	8.158	4.986	7.537	4.511	4.716	4.445	4.225	7.649	8.558	5.623	3.958	7.291	6.772	7.155	7.253	4.708	7.285	4.185	0.000	5.449
European Union=20	4.179	2.207	3.695	2.466	4.106	2.008	2.312	4.275	4.934	1.545	2.450	3.386	2.891	3.290	3.692	2.622	3.405	3.070	5.449	0

Source: Authors’ own work based on GII data

economies in the years 2010–2016 are shown (highlighted in green) in Tables 16, 17, 18, 19, 20, 21, and 22.

### 3.5 Step 5: Optimum Chart Drawing

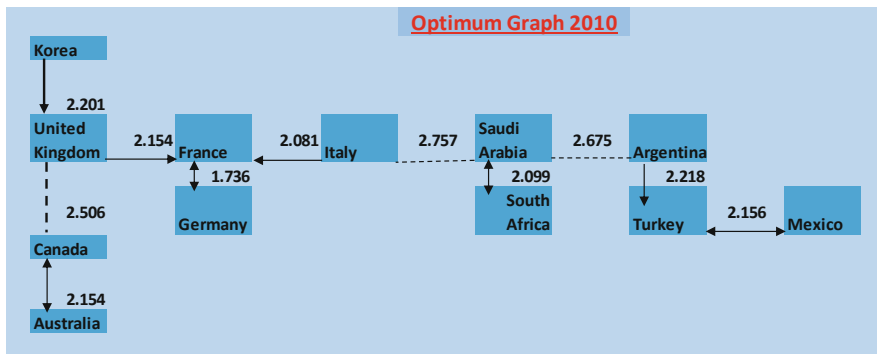
In the drawing of the optimum chart, economies which have the most commonalities are connected by designating a vector toward the economy which is considered as the model with the vector length equal to the shortest distance between the economies. For determining homogeneous economies, at first, upper-line distance  $d(+)$  and lower-limit distance  $d(-)$  were computed, using Eqs. (5) and (6), where  $d$  is the shortest distances’ average and  $S_d$  is the standard deviation:

$$d(+) = d + 2S_d \tag{5}$$

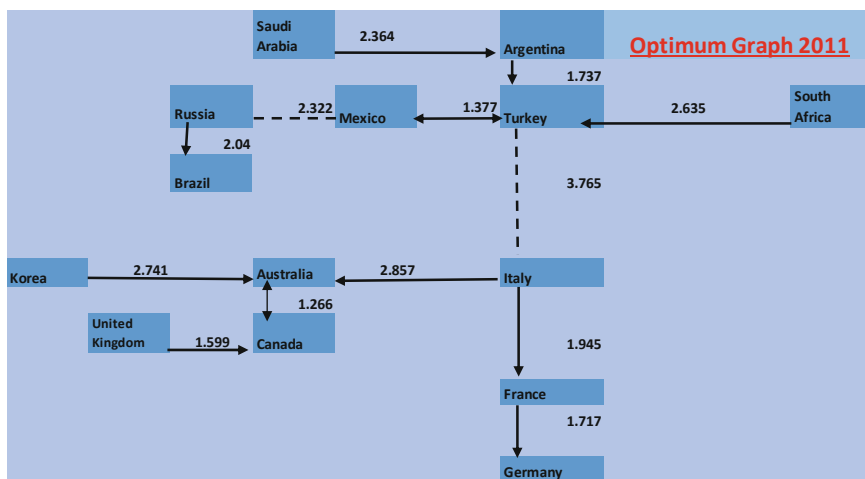
$$d(-) = d - 2S_d \tag{6}$$

It is to be noted that 95.45% of data lie within a band around the mean in a normal (Gaussian) distribution with a width of four standard deviations, i.e.,  $-2S_d$  to  $+2S_d$  (Le Quesne 1969; Phillips 1983).

Furthermore, after calculating  $d(+)$  and  $d(-)$  for the G20 economies in 2010–2016 from Eqs. (5) and (6), it became evident that the distances among the



**Fig. 3** Final values of the shortest distances between economies in the optimum graph for 2010. Source: Authors’ own work based on analyzed GII data



**Fig. 4** Final values of the shortest distances between economies in the optimum graph for 2011. Source: Authors’ own work based on analyzed GII data

economies should not be out of upper  $d(+)$  and lower  $d(-)$  limits range for the years 2010 to 2016; if each economy is out of the range  $d(-)$  and  $d(+)$ , it has to be set aside, and then the other economies pass through this process until the remaining economies are settled within  $d(-)$  and  $d(+)$  range. This leads to a homogenous group of economies that could be compared with one another. Then the countries are connected by vectors. Consequently, the optimum charts, or “optimum graphs,” for the years 2010–2016 are shown in Figs. 3, 4, 5, 6, 7, 8, and 9.

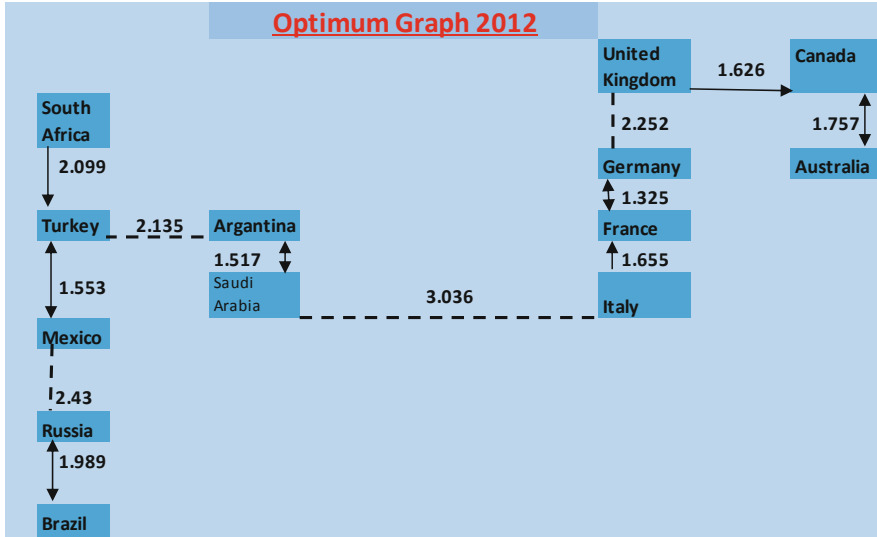


Fig. 5 Final values of the shortest distances between economies in the optimum graph for 2012. Source: Authors’ own work based on analyzed GII data

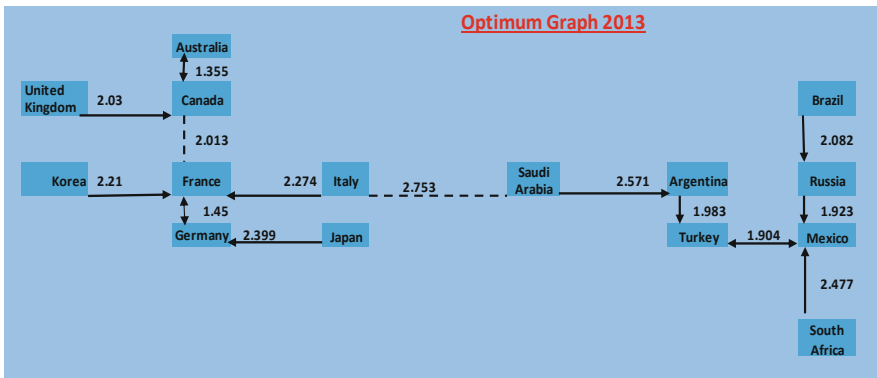
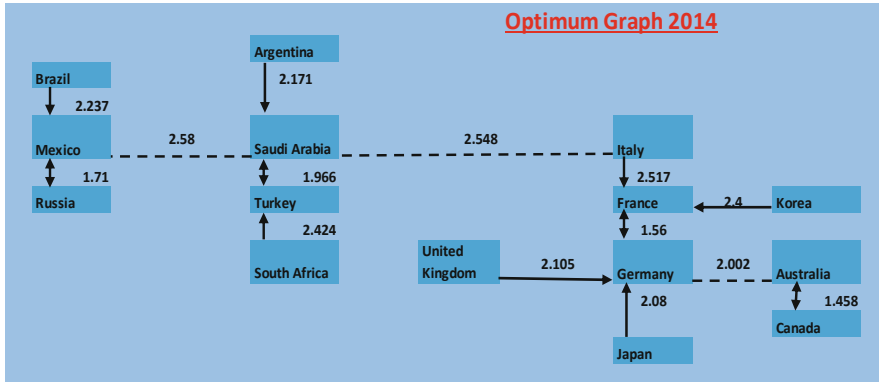


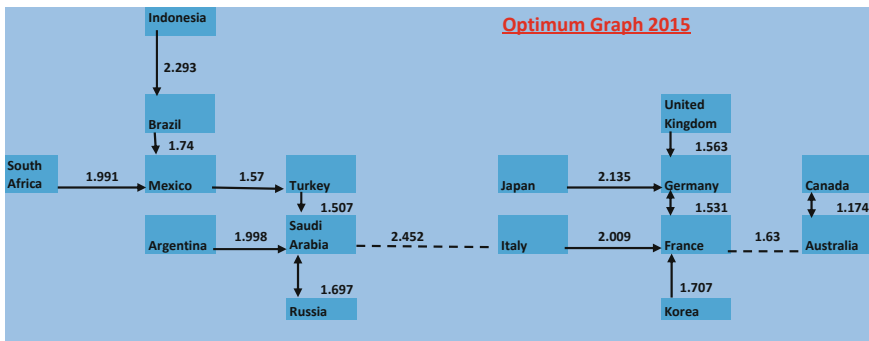
Fig. 6 Final values of the shortest distance between economies in the optimum graph for 2013. Source: Authors’ own work based on analyzed GII data

### 3.6 Step 6: Ranking of the Economies in Terms of Improvement and Development

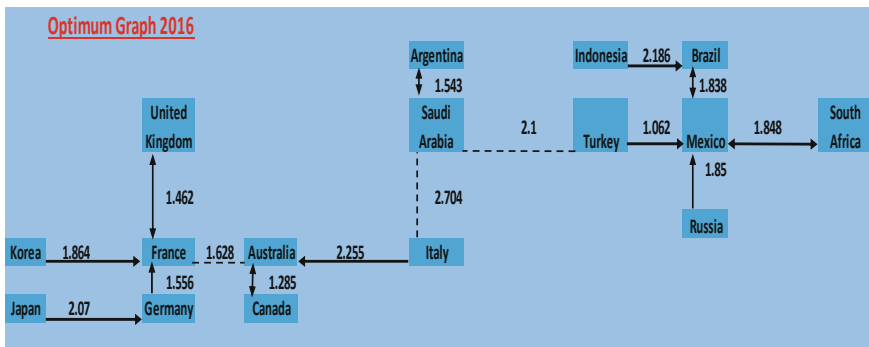
According to step 5, if the G20 economies are not settled in homogeneous groups, then the new data matrix could be formed for homogenous group of economies, and again the standard matrix can be computed. In the standard matrix, the largest value in each column can be found and named the “ideal amount.” It is noteworthy that for



**Fig. 7** Final values of the shortest distances between economies in the optimum graph for 2014. Source: Authors’ own work based on analyzed GII data



**Fig. 8** Final values of the shortest distances between economies in the optimum graph for 2015. Source: Authors’ own work based on analyzed GII data



**Fig. 9** Final values of the shortest distances between economies in the optimum graph for 2016. Source: Authors’ own work based on analyzed GII data

development being a positive function of the indicators, the largest value is the “ideal amount,” and the lowest value is the shortest distance between two economies.

In this chapter, the twenty reviewed economies do not all settle in an equally seamlessly space. Hence, the computation process was followed to achieve a homogeneous group, by calculations in a process of eight steps, for every year from 2010 to 2016 with the outranging data. Thus, an acceptable seamlessly space of distinct economies was obtained (with similar economic features) which could be measured and compared to distinguish the degree of development in economies in order to present a benchmark pattern for development. The calculation processes are shown in Tables 23, 24, 25, 26, 27, 28, and 29.

**Table 23** The eighth round of the homogenization process for the year 2010 (the shortest distances between economies highlighted in blue)

2010 year	Argentina= 1	Australia= 2	Canada= 3	France= 4	Germany= 5	Italy= 6	Mexico= 7	Saudi Arabia= 8	South Africa= 9	South Korea= 10	Turkey= 11	United Kingdom= 12	Shortest distance
Argentina=1		5.323	5.970	4.697	6.096	3.084	3.739	2.675	4.041	5.046	2.218	6.212	2.218
Australia=2	5.323		2.154	3.029	4.177	3.675	6.663	4.055	5.001	2.301	5.734	3.043	2.154
Canada=3	5.970	2.154		2.936	3.308	4.285	7.437	5.172	6.069	2.614	6.290	2.506	2.154
France=4	4.697	3.029	2.936		1.736	2.081	5.362	4.193	4.894	2.434	4.663	2.154	1.736
Germany=5	6.096	4.177	3.308	1.736		3.605	6.457	5.736	6.289	3.299	5.845	2.234	1.736
Italy=6	3.084	3.675	4.285	2.081	3.605		3.694	2.757	3.558	3.488	2.960	3.853	2.081
Mexico=7	3.739	6.663	7.437	5.362	6.457	3.694		4.085	3.752	6.113	2.156	6.732	2.156
Saudi Arabia=8	2.675	4.055	5.172	4.193	5.736	2.757	4.085		2.099	4.286	2.911	5.128	2.099
South Africa=9	4.041	5.001	6.069	4.894	6.289	3.558	3.752	2.099		4.990	3.430	5.426	2.099
South Korea=10	5.046	2.301	2.614	2.434	3.299	3.488	6.113	4.286	4.990		5.338	2.201	2.201
Turkey=11	2.218	5.734	6.290	4.663	5.845	2.960	2.156	2.911	3.430	5.338		6.121	2.156
United Kingdom=12	6.212	3.043	2.506	2.154	2.234	3.853	6.732	5.128	5.426	2.201	6.121		2.154

Source: Authors' own work based on GII data

**Table 24** The fifth round of the homogenization process for the year 2011 (the shortest distances between economies highlighted in blue)

2011 Year	Argentina= 1	Australia= 2	Brazil= 3	Canada= 4	France= 5	Germany= 6	Italy= 7	Mexico= 8	Russia= 9	Saudi Arabia= 10	South Africa= 11	South Korea= 12	Turkey =13	United Kingdom= 14	Shortest distance
Argentina=1		5.005	4.164	5.866	4.975	6.018	3.387	2.247	3.119	2.364	3.174	5.208	1.737	6.796	1.737
Australia=2	5.005		5.973	1.266	2.119	3.299	2.857	5.479	5.241	3.219	4.780	2.741	5.551	2.594	1.266
Brazil=3	4.164	5.973		6.360	4.908	5.354	3.779	2.790	2.040	4.808	4.642	5.942	3.693	6.610	2.040
Canada=4	5.866	1.266	6.360		2.232	2.894	3.496	6.253	5.741	4.215	5.429	2.922	6.306	1.599	1.266
France=5	4.975	2.119	4.908	2.232		1.717	1.945	5.069	4.201	3.940	5.148	2.618	5.317	2.561	1.717
Germany=6	6.018	3.299	5.354	2.894	1.717		3.220	6.093	5.013	5.101	6.305	3.678	6.250	2.427	1.717
Italy=7	3.387	2.857	3.779	3.496	1.945	3.220		3.423	2.914	2.971	3.971	2.979	3.765	4.099	1.945
Mexico=8	2.247	5.479	2.790	6.253	5.069	6.093	3.423		2.322	3.447	2.835	5.557	1.377	6.948	1.377
Russia=9	3.119	5.241	2.040	5.741	4.201	5.013	2.914	2.322		4.056	3.957	4.719	2.990	6.158	2.040
Saudi Arabia=10	2.364	3.219	4.808	4.215	3.940	5.101	2.971	3.447	4.056		3.247	4.462	3.300	5.392	2.364
South Africa=11	3.174	4.780	4.642	5.429	5.148	6.305	3.971	2.835	3.957	3.247		5.218	2.635	6.319	2.635
South Korea=12	5.208	2.741	5.942	2.922	2.618	3.678	2.979	5.557	4.719	4.462	5.218		5.654	3.135	2.741
Turkey=13	1.737	5.551	3.693	6.306	5.317	6.250	3.765	1.377	2.990	3.300	2.635	5.654		7.053	1.377
United Kingdom=14	6.796	2.594	6.610	1.599	2.561	2.427	4.099	6.948	6.158	5.392	6.319	3.135	7.053		1.599

Source: Authors' own work based on GII data

**Table 25** The sixth round of the homogenization process for the year 2012 (the shortest distances between economies highlighted in blue)

2012 Year	Argentina= 1	Australia= 2	Brazil= 3	Canada= 4	France= 5	Germany= 6	Italy= 7	Mexico= 8	Russia= 9	Saudi Arabia= 10	South Africa= 11	Turkey= 12	United Kingdom= 13	Shortest distance
Argentina=1		5.080	4.242	5.720	4.976	5.863	3.828	2.234	3.592	1.517	3.076	2.135	6.783	1.517
Australia=2	5.080		6.205	1.757	2.331	3.211	2.937	5.278	5.434	3.775	5.278	5.743	2.794	1.757
Brazil=3	4.242	6.205		6.469	5.098	5.541	4.152	2.661	1.989	4.430	4.480	3.602	6.917	1.989
Canada=4	5.720	1.757	6.469		2.172	2.613	2.978	5.773	5.927	4.510	5.639	6.128	1.626	1.757
France=5	4.976	2.331	5.098	2.172		1.325	1.655	4.855	4.382	4.032	5.440	5.286	2.352	1.325
Germany=6	5.863	3.211	5.541	2.613	1.325		2.676	5.594	5.142	5.038	6.366	6.122	2.252	1.325
Italy=7	3.828	2.937	4.152	2.978	1.655	2.676		3.699	3.361	3.036	4.270	4.009	3.633	1.655
Mexico=8	2.234	5.278	2.661	5.773	4.855	5.594	3.699		2.436	2.522	2.567	1.533	6.709	1.533
Russia=9	3.592	5.434	1.989	5.927	4.382	5.142	3.361	2.436		3.684	3.962	2.893	6.452	1.989
Saudi Arabia=10	1.517	3.775	4.430	4.510	4.032	5.038	3.036	2.522	3.684		2.747	2.620	5.636	1.517
South Africa=11	3.076	5.278	4.480	5.639	5.440	6.366	4.270	2.567	3.962	2.747		2.099	6.868	2.099
Turkey=12	2.135	5.743	3.602	6.128	5.286	6.122	4.009	1.533	2.893	2.620	2.099		7.127	1.533
United Kingdom=13	6.783	2.794	6.917	1.626	2.352	2.252	3.633	6.709	6.452	5.636	6.868	7.127		1.626

Source: Authors' own work based on GII data

**Table 26** The fourth round of homogenization process for the year 2013 (the shortest distances between economies highlighted in blue)

2013 Year	Argentina= 1	Australia= 2	Brazil= 3	Canada= 4	France= 5	Germany= 6	Italy= 7	Japan= 8	Mexico= 9	Russia= 10	Saudi Arabia= 11	South Africa= 12	South Korea= 13	Turkey= 14	United Kingdom= 15	Shortest distance
Argentina=1		5.831	3.999	6.270	5.201	6.190	3.475	6.787	2.387	3.137	2.571	2.957	5.650	1.983	7.560	1.983
Australia=2	5.831		6.695	1.355	2.231	2.890	3.595	4.373	5.887	5.800	3.973	5.459	2.445	5.686	2.649	1.355
Brazil=3	3.999	6.695		6.638	5.198	5.816	3.949	5.392	2.403	2.082	4.491	4.260	6.227	3.775	7.472	2.082
Canada=4	6.270	1.355	6.638		2.013	2.629	3.553	3.776	6.038	5.866	4.337	5.416	2.398	6.026	2.027	1.355
France=5	5.201	2.231	5.198	2.013		1.450	2.274	2.653	4.936	4.328	3.799	4.982	2.210	5.094	2.823	1.450
Germany=6	6.190	2.890	5.816	2.629	1.450		3.149	2.399	5.759	4.976	4.873	5.986	2.776	5.818	2.458	1.450
Italy=7	3.475	3.595	3.949	3.553	2.274	3.149		3.697	3.097	2.773	2.753	3.334	3.052	3.378	4.734	2.274
Japan=8	6.787	4.373	5.392	3.776	2.653	2.399	3.697		5.757	4.829	5.688	6.255	3.927	6.428	3.947	2.399
Mexico=9	2.387	5.887	2.403	6.038	4.936	5.759	3.097	5.757		1.923	3.131	2.477	5.561	1.904	7.257	1.904
Russia=10	3.137	5.800	2.082	5.866	4.328	4.976	2.773	4.829	1.923		3.952	3.729	4.960	2.954	6.778	1.923
Saudi Arabia=11	2.571	3.973	4.491	4.337	3.799	4.873	2.753	5.688	3.131	3.952		2.623	4.388	2.637	5.674	2.571
South Africa=12	2.957	5.459	4.260	5.416	4.982	5.986	3.334	6.255	2.477	3.729	2.623		5.401	2.438	6.859	2.477
South Korea=13	5.650	2.445	6.227	2.398	2.210	2.776	3.052	3.927	5.561	4.960	4.388	5.401		5.494	3.043	2.210
Turkey=14	1.983	5.686	3.775	6.026	5.094	5.818	3.378	6.428	1.904	2.954	2.637	2.438	5.494		7.095	1.904
United Kingdom=15	7.560	2.649	7.472	2.027	2.823	2.458	4.734	3.947	7.257	6.778	5.674	6.859	3.043	7.095		2.027

Source: Authors' own work based on GII data

For instance, the results of the homogenization process for the year 2010 suggested elimination of China and the United States and then India, the European Union, Japan, Brazil, Indonesia, and Russia, in successive steps of the homogenization process calculations. These results are illustrated in Table 23, and Fig. 3 demonstrates the compound distances between homogenous economies.

Similarly, the results for the year 2011, again, suggested elimination of China and the United States and then India, the European Union, Japan, and Indonesia in

**Table 27** The fourth round of homogenization process for the year 2014 (the shortest distances between economies highlighted in blue)

2014 Year	Argentina=1	Australia=2	Brazil=3	Canada=4	France=5	Germany=6	Italy=7	Japan=8	Mexico=9	Russia=10	Saudi Arabia=11	South Africa=12	South Korea=13	Turkey=14	United Kingdom=15	Shortest distance
Argentina=1		6.006	4.130	6.284	5.592	6.440	3.935	7.019	2.491	3.182	2.171	3.128	5.953	2.245	7.542	2.171
Australia=2	6.006		6.866	1.458	3.218	3.436	4.231	5.470	5.724	4.132	5.530	2.831	5.556	2.712	1.458	
Brazil=3	4.130	6.866		6.625	5.696	6.083	4.298	5.702	2.237	2.385	4.544	4.272	6.526	3.967	7.436	2.237
Canada=4	6.284	1.458	6.625		2.040	2.905	3.176	3.632	5.356	5.645	4.443	5.230	2.754	5.692	2.255	1.458
France=5	5.592	2.002	5.696	2.040		1.560	2.517	2.569	4.695	4.573	4.073	5.405	2.400	5.255	2.338	1.560
Germany=6	6.440	3.218	6.083	2.905	1.560		3.264	2.080	5.311	4.955	5.135	6.157	2.783	5.969	2.105	1.560
Italy=7	3.935	3.436	4.298	3.176	2.517	3.264		3.577	2.916	3.086	2.548	3.506	3.026	3.440	4.355	2.517
Japan=8	7.019	4.231	5.702	3.632	2.569	2.080	3.577		5.489	4.975	5.796	6.450	3.639	6.479	3.268	2.080
Mexico=9	2.491	5.470	2.237	5.356	4.695	5.311	2.916	5.489		1.710	2.580	2.427	5.230	2.026	6.508	1.710
Russia=10	3.182	5.724	2.385	5.645	4.573	4.955	3.086	4.975	1.710		3.447	3.697	4.805	3.047	6.414	1.710
Saudi Arabia=11	2.171	4.132	4.544	4.443	4.073	5.135	2.548	5.796	2.580	3.447		2.699	4.499	1.966	5.899	1.966
South Africa=12	3.128	5.530	4.272	5.230	5.405	6.157	3.506	6.450	2.427	3.697	2.699		5.621	2.424	6.909	2.424
South Korea=13	5.953	2.831	6.526	2.754	2.400	2.783	3.026	3.639	5.230	4.805	4.499	5.621		5.499	2.981	2.400
Turkey=14	2.245	5.556	3.967	5.692	5.255	5.969	3.440	6.479	2.026	3.047	1.966	2.424	5.499		6.963	1.966
United Kingdom=15	7.542	2.712	7.436	2.255	2.338	2.105	4.355	3.268	6.508	6.414	5.899	6.909	2.981	6.963		2.105

Source: Authors' own work based on GII data

**Table 28** The second round of homogenization process for the year 2015 (the shortest distances between economies highlighted in blue)

2015 Year	Argentina=1	Australia=2	Brazil=3	Canada=4	France=5	Germany=6	Indonesia=7	Italy=8	Japan=9	Mexico=10	Russia=11	Saudi Arabia=12	South Africa=13	South Korea=14	Turkey=15	United Kingdom=16	Shortest distance
Argentina=1		5.571	3.091	6.020	5.702	6.513	3.731	3.981	7.008	2.021	2.219	1.998	2.720	6.080	2.235	7.308	1.998
Australia=2	5.571		5.579	1.174	1.630	2.949	7.175	2.300	3.604	4.902	3.999	3.763	4.551	2.165	4.406	2.615	1.174
Brazil=3	3.091	5.579		5.675	5.187	5.737	2.293	3.819	5.650	1.740	3.432	3.381	3.306	5.838	3.025	6.667	1.740
Canada=4	6.020	1.174	5.675		1.680	2.677	7.259	2.509	3.134	5.099	4.383	4.249	4.603	2.223	4.691	2.258	1.174
France=5	5.702	1.630	5.187	1.680		1.531	6.938	2.009	2.343	4.858	3.966	4.115	4.952	1.707	4.459	1.754	1.531
Germany=6	6.513	2.949	5.737	2.677	1.531		7.429	2.876	2.135	5.528	4.701	5.120	5.766	2.350	5.120	1.562	1.531
Indonesia=7	3.731	7.175	2.293	7.259	6.938	7.429		5.372	7.563	2.666	4.827	4.400	4.067	7.422	3.582	8.261	2.293
Italy=8	3.981	2.300	3.819	2.509	2.009	2.876	5.372		3.585	3.148	2.518	2.462	3.424	2.721	2.743	3.497	2.009
Japan=9	7.008	3.604	5.650	3.134	2.343	2.135	7.563	3.585		5.869	5.306	5.710	6.124	3.293	5.942	2.632	2.135
Mexico=10	2.021	4.902	1.740	5.099	4.858	5.528	2.666	3.148	5.869		2.486	2.043	1.991	5.456	1.570	6.342	1.570
Russia=11	2.219	3.999	3.432	4.383	3.966	4.701	4.827	2.518	5.306	2.486		1.697	2.624	4.197	2.205	5.545	1.697
Saudi Arabia=12	1.998	3.763	3.381	4.249	4.115	5.120	4.400	2.462	5.710	2.043	1.697		2.144	4.539	1.507	5.637	1.697
South Africa=13	2.720	4.551	3.306	4.603	4.952	5.766	4.067	3.424	6.124	1.991	2.624	2.144		5.330	2.207	6.325	1.991
South Korea=14	6.080	2.165	5.838	2.223	1.707	2.350	7.422	2.721	3.293	5.456	4.197	4.539	5.330		4.852	2.326	1.707
Turkey=15	2.235	4.406	3.025	4.691	4.459	5.120	3.582	2.743	5.942	1.570	2.205	1.507	2.207	4.852		5.798	1.507
United Kingdom=16	7.308	2.615	6.667	2.258	1.754	1.562	8.261	3.497	2.632	6.342	5.545	5.637	6.325	2.326	5.798		1.562

Source: Authors' own work based on GII data

consecutive steps of homogenization process calculations. The corresponding results are presented in Table 22 and Fig. 4.

Moreover, based on the results for the year 2012, China, the United States, India, the European Union, Japan, Indonesia, and South Korea were omitted in continued steps of homogenization process calculations. These results are depicted in Table 25 and Fig. 5. It is observed that within the G20 economies, only thirteen economies remained in the homogenization process after six rounds of computations.

**Table 29** The third round of homogenization process for the year 2016 (the shortest distances between economies highlighted in blue)

2016 Year	Argentina=1	Australia=2	Brazil=3	Canada=4	France=5	Germany=6	Indonesia=7	Italy=8	Japan=9	Mexico=10	Russia=11	Saudi Arabia=12	South Africa=13	South Korea=14	Turkey=15	United Kingdom=16	Shortest distance
Argentina=1		5.183	2.964	5.755	5.592	6.380	3.969	3.742	6.844	2.247	2.395	1.543	2.510	5.846	2.155	6.959	1.543
Australia=2	5.183		5.511	1.285	1.628	2.982	7.023	2.255	3.834	4.553	4.170	3.890	4.405	2.294	4.526	2.465	1.285
Brazil=3	2.964	5.511		5.752	5.388	5.982	2.186	3.890	5.863	1.838	1.881	3.163	3.237	6.004	2.976	6.705	1.838
Canada=4	5.755	1.285	5.752		1.678	2.850	7.137	2.690	3.472	4.820	4.521	4.439	4.512	2.399	4.885	2.256	1.285
France=5	5.592	1.628	5.388	1.678		1.556	6.971	2.257	2.575	4.772	4.163	4.456	4.958	1.864	4.722	1.462	1.462
Germany=6	6.380	2.982	5.982	2.850	1.556		7.509	3.040	2.070	5.562	4.814	5.436	5.914	2.156	5.396	1.600	1.556
Indonesia=7	3.969	7.023	2.186	7.137	6.971	7.509		5.360	7.537	2.725	3.506	4.412	3.944	7.438	3.517	8.160	2.186
Italy=8	3.742	2.255	3.890	2.690	2.257	3.040	5.360		3.757	2.951	2.774	2.704	3.422	2.847	2.944	3.504	2.255
Japan=9	6.844	3.834	5.863	3.472	2.575	2.070	7.537	3.757		5.825	5.086	5.881	6.258	3.513	6.162	2.893	2.070
Mexico=10	2.247	4.553	1.838	4.820	4.772	5.562	2.725	2.951	5.825		1.850	2.033	1.848	5.349	1.602	6.071	1.838
Russia=11	2.395	4.170	1.881	4.521	4.163	4.814	3.506	2.774	5.086	1.850		2.134	2.649	4.476	2.262	5.488	1.850
Saudi Arabia=12	1.543	3.890	3.163	4.439	4.456	5.436	4.412	2.704	5.881	2.033	2.134		2.031	4.736	2.100	5.807	1.543
South Africa=13	2.510	4.405	3.237	4.512	4.958	5.914	3.944	3.422	6.258	1.848	2.649	2.031		5.409	2.237	6.231	1.848
South Korea=14	5.846	2.294	6.004	2.399	1.864	2.156	7.438	2.847	3.513	5.349	4.476	4.736	5.409		5.032	2.114	1.864
Turkey=15	2.155	4.526	2.976	4.885	4.722	5.396	3.517	2.944	6.162	1.602	2.262	2.100	2.237	5.032		5.913	1.602
United Kingdom=16	6.959	2.465	6.705	2.256	1.462	1.600	8.160	3.504	2.893	6.071	5.488	5.807	6.231	2.114	5.913		1.462

Source: Authors’ own work based on analyzed GII data

Subsequently, for the year 2013, in the fourth round, the results lead to omission of China, the United States, India, the European Union, and Indonesia in the consecutive steps of homogenization process calculations. The results are shown in Table 26 with Fig. 6.

Furthermore, for the year 2014, China, the United States, India, the European Union, and Indonesia were eliminated in the successive steps of homogenization process calculations. The results are rendered in Table 27 and Fig. 7.

Nevertheless, in the year 2015, the second round leads to deletion of China, India, the United States, and the European Union in the consecutive steps of homogenization process calculations. This process is demonstrated in Table 28 and Fig. 8.

Finally, in 2016, the third round leads to omission of China, the United States, India, and the European Union in the consecutive steps of homogenization process calculations. Table 29 with Fig. 9 presents the corresponding results.

### 3.7 Step 7: Calculation of the Economies’ Development Degrees

To find development degrees (fi) for the economies within the G20 group, Co, i.e., the upper limit of the development pattern should be measured for substitution in the following relationship:



$$f_i = (C_{io}/C_o)$$

where  $C_{io}$  is development pattern over the upper limit of the development pattern and  $C_o$  is obtained from Eq. (7):

$$C_o = \overline{C_{io}} + 2 S_{io}, \tag{7}$$

where  $\overline{C_{io}}$  and  $S_{io}$  are the average and standard deviation of the development pattern corresponding to  $f_i$  (Le Quesne 1969; Phillips 1983).

The development degree is between “0” and “1,” that is, when “ $f_i$ ” values get near to “0,” the economy is more developed than the case “ $f_i$ ” approaches to “1”; namely, the economy gets close to less developed characteristics. By measuring  $C_{io}$  and  $f_i$ , the economies were ranked based on the development degrees. In this step, results obtained for the G20 economies lead to the development degree ( $f_i$ ) for each of the economies, as presented in Tables 30, 31, 32, 33, 34, 35, and 36.

## 4 Conclusion

In this chapter, population and GDP, together with seven indicators, extracted from the Global Innovation Index (GII), were used in the measurement of the “development degree” for G20 countries. It was remarkable not only to find out the indicators most effective on the development degrees but also to rank the G20 economies on this basis, as shown in Tables 30, 31, 32, 33, 34, 35, and 36 for the period 2010–2016.

**Table 30** Development degrees for 2010

2010 year	$f_i$	Development ranking	
Argentina = 1	0.910	Germany	0.369
Australia = 2	0.547	France	0.446
Brazil = 3	0.713	Canada	0.469
Canada = 4	0.469	Australia	0.547
France = 5	0.446	Korea	0.555
Germany = 6	0.369	Italy	0.603
Italy = 7	0.603	Brazil	0.713
Mexico = 8	0.856	Russia	0.726
Russia = 9	0.726	Saudi Arabia	0.786
Saudi Arabia = 10	0.786	Mexico	0.856
South Africa = 11	0.865	South Africa	0.865
South Korea = 12	0.555	Argentina	0.910

Source: Authors’ own work

**Table 31** Development degrees for 2011

2011 year	fi	Development ranking	
Argentina = 1	0.880	United Kingdom	0.338
Australia = 2	0.529	Germany	0.357
Brazil = 3	0.689	France	0.431
Canada = 4	0.454	Canada	0.454
France = 5	0.431	Australia	0.529
Germany = 6	0.357	Korea	0.537
Italy = 7	0.583	Italy	0.583
Mexico = 8	0.828	Brazil	0.689
Russia = 9	0.702	Russia	0.702
Saudi Arabia = 10	0.760	Saudi Arabia	0.760
South Africa = 11	0.837	Mexico	0.828
South Korea = 12	0.537	South Africa	0.837
Turkey = 13	0.877	Turkey	0.877
United Kingdom = 14	0.338	Argentina	0.880

Source: Authors' own work

**Table 32** Development degrees for 2012

2012 year	fi	Development ranking	
Argentina = 1	0.846	United Kingdom	0.314
Australia = 2	0.511	Germany	0.329
Brazil = 3	0.697	France	0.400
Canada = 4	0.427	Canada	0.427
France = 5	0.400	Australia	0.511
Germany = 6	0.329	Italy	0.520
Italy = 7	0.520	Brazil	0.697
Mexico = 8	0.766	Russia	0.701
Russia = 9	0.701	Saudi Arabia	0.751
Saudi Arabia = 10	0.751	Mexico	0.766
South Africa = 11	0.845	South Africa	0.845
Turkey = 12	0.848	Argentina	0.846
United Kingdom = 13	0.314	Turkey	0.848

Source: Authors' own work

Scrutinizing the selected indicators measuring the development degrees leads to significant remarks. The United States and China having the largest GDP among these countries during 2010 to 2016 underwent elimination from the group in the first round of iterations for homogeneity (leading to a homogenous group of economies that could be compared with one another). In Tables 16, 17, 18, 19, 20, 21, and 22, compound distance matrices were rendered for the first round of iterations during 2010–2016. Computations for similar homogenous economic groups finally lead to

**Table 33** Development degrees for 2013

2013 year	fi	Development ranking	
Argentina = 1	0.910	Japan	0.350
Australia = 2	0.532	United Kingdom	0.361
Brazil = 3	0.745	Germany	0.363
Canada = 4	0.480	France	0.453
France = 5	0.453	Canada	0.480
Germany = 6	0.363	Australia	0.532
Italy = 7	0.623	Korea	0.533
Japan = 8	0.350	Italy	0.623
Mexico = 9	0.808	Russia	0.723
Russia = 10	0.723	Brazil	0.745
Saudi Arabia = 11	0.763	Saudi Arabia	0.763
South Africa = 12	0.848	Mexico	0.808
South Korea = 13	0.533	Turkey	0.842
Turkey = 14	0.842	South Africa	0.848
United Kingdom = 15	0.361	Argentina	0.910

Source: Authors' own work

**Table 34** Development degrees for 2014

2014 year	fi	Development ranking	
Argentina = 1	0.880	United Kingdom	0.241
Australia = 2	0.450	Germany	0.264
Brazil = 3	0.772	Japan	0.283
Canada = 4	0.412	France	0.349
France = 5	0.349	Canada	0.412
Germany = 6	0.264	Korea	0.444
Italy = 7	0.553	Australia	0.450
Japan = 8	0.283	Italy	0.553
Mexico = 9	0.735	Russia	0.696
Russia = 10	0.696	Saudi Arabia	0.735
Saudi Arabia = 11	0.735	Mexico	0.735
South Africa = 12	0.823	Brazil	0.772
South Korea = 13	0.444	Turkey	0.808
Turkey = 14	0.808	South Africa	0.823
United Kingdom = 15	0.241	Argentina	0.880

Source: Authors' own work

country performance rankings (based on the economic development degrees in consecutive years) presented in Tables 23, 24, 25, 26, 27, 28, and 29.

From the 20 economies within the G20, in 2010, 12 economies formed the homogenous category. Similarly, 14, 13, 15, 16, and 16 economies formed the homogenous categories, corresponding to the years 2011, 2012, 2013, 2014, 2015, and 2016, respectively. Nonetheless, throughout the entire homogenization iterative

**Table 35** Development degrees for 2015

2015 year	fi	Development ranking	
Argentina = 1	0.899	Japan	0.309
Australia = 2	0.524	United Kingdom	0.333
Brazil = 3	0.722	Germany	0.340
Canada = 4	0.482	France	0.409
France = 5	0.409	Korea	0.466
Germany = 6	0.340	Canada	0.482
Indonesia = 7	0.874	Australia	0.524
Italy = 8	0.550	Italy	0.550
Japan = 9	0.309	Brazil	0.722
Mexico = 10	0.757	Russia	0.746
Russia = 11	0.746	Turkey	0.747
Saudi Arabia = 12	0.762	Mexico	0.757
South Africa = 13	0.806	Saudi Arabia	0.762
South Korea = 14	0.466	South Africa	0.806
Turkey = 15	0.747	Indonesia	0.874
United Kingdom = 16	0.333	Argentina	0.899

Source: Authors' own work

**Table 36** Development degrees for 2016

2016 year	fi	Development ranking	
Argentina = 1	0.890	Japan	0.313
Australia = 2	0.551	Germany	0.349
Brazil = 3	0.745	United Kingdom	0.365
Canada = 4	0.510	France	0.422
France = 5	0.422	Korea	0.480
Germany = 6	0.349	Canada	0.510
Indonesia = 7	0.873	Australia	0.551
Italy = 8	0.574	Italy	0.574
Japan = 9	0.313	Russia	0.681
Mexico = 10	0.754	Brazil	0.745
Russia = 11	0.681	Mexico	0.754
Saudi Arabia = 12	0.797	Turkey	0.776
South Africa = 13	0.821	Saudi Arabia	0.797
South Korea = 14	0.480	South Africa	0.821
Turkey = 15	0.776	Indonesia	0.873
United Kingdom = 16	0.365	Argentina	0.890

Source: Authors' own work

processes, the United States, China, the European Union (EU), and India were set aside to achieve homogeneity, with the employed GII data. These countries have highest populations (China, India, and EU) or largest GDPs (the United States, China, and EU) compared to others. It is also noted that the EU encompasses

28 countries (some of them members of G20). Hence, the data for the European Union were prorated; i.e., for GDP and the other indicators, the average values over 28 countries and, for population, the sum of populations of the 28 member countries were calculated and used in each year.

Subsequently, the development degrees “fi” for every year were computed and shown on the left side of Tables 30, 31, 32, 33, 34, 35, and 36. The right side of each table also ranks the countries based on their development degrees. It was noted that the development degrees were between “0” and “1,” that is, when “fi” values get near to “0,” the economy is more developed than the case “fi” approaches to “1”; namely, the economy gets closer to less developed characteristics. For instance, in 2010, Germany with a development degree of 0.369 ( $fi = 0.369$ ) is observed to be the most developed, and Argentina with a development degree of 0.91 ( $fi = 0.91$ ) is marked as the least developed. Thenceforth, the United Kingdom and Japan appear to alternate as the most developed, while Argentina remains (alternating with Turkey only in 2012) the least developed in the years 2011 to 2016. Moreover, based on the GII data used in this research (setting aside the United States, China, EU, and India for homogenous grouping), it was explored that Germany, the United Kingdom, and Japan made the most progress in development during 2010–2016. However, as outlined in Tables 1, 2, 3, 4, 5, 6, and 7, the latter three are countries with higher GDPs and other indicators such as institutions, market sophistication, etc., contributing to innovation and prosperity.

Nevertheless, in the course of development degrees computations, shortest distances between the G20 economies were also generated. The results were yielded in Tables 23, 24, 25, 26, 27, 28, and 29 and Figs. 3, 4, 5, 6, 7, 8, and 9, which can be useful for benchmarking within the Group of Twenty.

Finally, for future research, use of the following indicators may be suggested:

- Human Development Index (HDI)—which includes GDP, education, and health
- Gini coefficient as a measure of inequality in society
- Environmental sustainability, including factors such as pollution, climate change, deforestation, etc.
- The United Nations’ Sustainable Development Goals
- Inclusion of the following forms of capital (as defined by the United Nations): human capital, social capital, and natural capital

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