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RESEARCH PAPER

Calculating the Knowledge-Based Economy in 54 Selected Countries

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Abstract

This research attempts to measure the knowledge economy by Combining Inductive and Deductive Approaches. In this essay, a comparison between different perspectives on the knowledge economy was done, and then the knowledge economy is defined as "achieving higher productivity levels by utilizing knowledge". After examining factors affecting productivity, these factors are classified into four categories including 1- Governance quality and business environment; 2- Quality of information and communication infrastructure; 3- Economic freedom and international relations quality; and 4- Level of knowledge and innovation. Subsequently, by calculating the productivity level for 54 countries and dividing the productivity of each country into these four factors above, the contribution of the fourth factor, and the role of knowledge and innovation in the knowledge economy were calculated and presented as the indicator of the knowledge economy. In each of these four categories, three or more indicators were placed, and fifteen indicators were used. The data of the 15 indicators were extracted in a panel containing information from 54 countries between 2000 and 2016. The weight of different productivity factors was estimated using the Bayesian Panel method. Results of the ranking of the selected countries indicate that the United States, Japan, and Germany are leading countries in a knowledge-based economy.

Keywords: Economic Growth, Knowledge-Based Economy, Productivity.
JEL Classification: H11, O47, O57.

Introduction

The limitation of primary resources in the economy leads to the importance of the role of knowledge in stimulating economic growth. Based on this, each school of economic thoughts aspires to explain the role of knowledge in economic growth. Since the 1990s, the term 'knowledge economy' has entered the economic literature of OECD countries and the World Bank, and global reports have been used to compute and rank countries based on their knowledge and innovation. However, the current practice of international reports in assessing the level of the knowledge economy has used an inductive approach. This way of calculating the knowledge economy suffers from numerous theoretical controversies. The most important problem is that in the inductive approach, the knowledge-based economy index consists of several sub-indicators, but the weight of the sub-indicators is not known. To solve this problem, it is necessary to introduce a method that can calculate these weights for each of the sub-indicators. Our answer to this problem is to use the deductive approach in combination with the existing inductive approach. The key question in the mostly used inductive approach to the calculation of knowledge-based economy is "what will lead to knowledge, technology,

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and innovation?" While in the deductive approach, the key question is what knowledge, technology, and innovation will lead to. The simplest answer is more production and higher productivity. However, is productivity promoted only through knowledge and technology growth? The answer is negative. Therefore, to calculate the volume of a knowledge-based economy, factors affecting productivity must be summarized, and the role of knowledge in productivity should be distinguished from the other factors. Calculation of productivity resulting from knowledge and technology will depend on computing the role of other factors affecting productivity such as appropriate business environment, infrastructures, quality of governance, etc. Therefore, studying global literature on this topic, this study seeks to provide an appropriate way of identifying factors affecting productivity and to address knowledge and innovation topics as one of the main drivers of productivity growth. Finally, using this method we calculate the share of knowledge and innovation in the productivity of different countries.

The remainder of this paper is organized as follows. Section 2 provides a brief review of the literature. In Section 3, the methodology of calculating the innovation is presented. Section 4 explains the deductive methodology in calculating the volume of the knowledge-based economy. Section 5 illustrates the method and the results of the model. Section 6 applies the results of the model for extracting the knowledge economy level in 54 countries. Finally, Section 7 concludes the paper.

Literature Review

The economy is defined as the allocation of limited resources to meet unlimited human needs. Knowledge is an understanding that is acquired through experience or education. Knowledge can refer from theoretical to empirical understanding, it can be implicit or explicit, and it can be more or less formal or systematic. As a result, the goal of a knowledge-based economy can be interpreted as achieving economic productivity by using knowledge. Innovation and the economy resulting from innovation are always integral parts of the knowledge economy. Innovation refers to any new ideas, tools, or processes that enter the market or are used in society. In the innovation economy, therefore, there has to be an invention or any new idea that requires the development of knowledge. In addition, this new idea or invention must reach the market and create value. Therefore, the innovation economy has the closest similarity to the knowledge-based economy. Thus, to examine the world literature in the field of the knowledge economy, innovation literature will be reviewed.

Knowledge Role in Economic and Growth Theories

For a period of two hundred years, labor and capital were recognized as production factors by the classical and neoclassical economists, and knowledge, education, and intellectual capital were all considered exogenous factors, meaning that they were determined outside of the system, and they could affect the system.

The new growth theory is based on the studies of Stanford economists, including Paul Romer and others, is attempted to explain the reasons for long-run growth. Following the work of well-known economists such as Joseph Schumpeter, Robert Solow, and others, Romer made a change in the neoclassical growth model by incorporating technology and knowledge as an endogenous factor in the economic system. Romer's growth theory differs from the common neoclassical growth theory in several aspects. These differences are as follows.

1- Economic growth arises from the accumulation of capital, and knowledge is considered as the main capital or the key factor in the production function (Romer, 1989).

2- Romer argues that the development of new technology can be the technological platform for further innovation, and the impact of this technological platform is the key to economic growth.

3- Technology can increase the return on investment. This explains why developed countries can have sustainable growth while developing countries cannot grow despite the abundance of capital and labor.

4- Investment can make technology valuable and vice versa.

5- Romer argues that patents' incomes resulting from inventions are important to motivate firms to invest in R&D for technological innovation (Romer, 1990).

Therefore, economic growth and development theories, in general, and neoclassical growth theories in particular, consider the role of education, technology, technical advancements, human capital, and general knowledge and innovation, essential for economic growth and development. Even in some cases, the importance of knowledge goes beyond the other factors of production in growth models.

Economic theories, with particular attention to the role of knowledge, can be divided into two general sections: economic development theories and economic growth theories. In this way, it is possible to examine the role of knowledge and its importance in each of the two dimensions of economic growth and development theory separately.

In Table 1, major ideas about the role of knowledge in the economy are described.

Table 1. List of Major Ideas about the Role of Knowledge in Economy

Economist	Main Idea	Idea Expansion
Adam Smith	Division of labor	The division of labor produces labor productivity in production (Smith, 1963).
David Ricardo	The role of technical progress in shaping increasing returns	Technical development in the industrial sector will adversely affect labor employment in the short run (Letiche, 1960).
John Stuart Mill	Introducing knowledge as one of the production factors	Referring to the role that is played by the accelerated rate of production through land and capital (from Mill's point of view, capital, is the reserve derived from the labor force) in the creation of a country's wealth, and the role that labor efficiency and skill play in the development and accumulation of a country's wealth, the role of knowledge in economic development is highlighted (Mill, 1871).
Schumpeter	Innovation theory and explaining the power of innovation and its role in the economy	Economic development involves using various combinations of events in the economic recession, these new combinations only arise through innovation (Malerba and Orsenigo, 1995).
Keynes	Outline of the science involved in growth theories	One of the main conditions for economic growth is the acceptance of "scientific advances and belief in the progress of science" (Keynes, 2010).
Rostow	Five-step growth theory	Rostow's three stages of growth development including preconditions to take off, take-off, and drive to maturity illustrate the role of knowledge in the transition from traditional to modern society and even suggests one of the most important factors for moving from a traditional society to modern society is the increasing adventure of research, innovation, and discovery that tangibly points to the importance of knowledge in economics and the knowledge-based economic dynamics (Pullman, 1966; Rostow, 1990).
Lewis	Labor surplus is the main condition for economic growth	The underlying cause of underdevelopment in developing countries is the lack of educational infrastructure and training of skilled workers in these countries, while knowledge is a major source of skill and initiative in countries (Lewis, 1954).
Meade	The gradual and relative impact of technical progress on GDP growth (Meade, 2013)	Rewriting the production function (Y GDP, K capital or reserve capital, L labor, N land, and natural resources, and T represents technical growth and progress over time): $y = f(K, L, N, T)$

Economist	Main Idea	Idea Expansion
Kaldor	Introducing the technical progress function instead of the regular production function	Taking factors such as the role of income, profits, capital, savings, and investment into account, and asserting that technical progress function is superior to conventional functions (Kaldor, 1957)
Romer	endogenous growth model	1. Knowledge is the main form of capital 2. Developing new technology can be a technological platform for further innovation 3. Technology can increase the return of investment 4. Investment can make technology valuable, and vice versa. 5. Patent's incomes resulting from inventions are important to motivate firms investing in R&D for technological innovation
Mankiw, Romer, and Weil		knowledge is the most important reason for a higher standard of living than in previous centuries (Mankiw et al., 1992).

Alvin Toffler emphasizes the role of knowledge as an important factor of production. In his opinion, while capital, land, and labor were the main factors of production in the "second wave of economics", knowledge, which in its broad definition, encompasses data, information, perceptions, symbols, culture, ideology, and values, is a major source of the "third wave of economics". In the third wave, Toffler also introduces knowledge as the primary raw material and the only never-ending matter (Toffler, 1980).

Recent studies have also paid particular attention to the role of knowledge as an important resource or factor in economic development. Peter Drucker acknowledges that in a "post-capitalist" society, capital and labor are not the only factors of production; the main factor of production in the economy is knowledge. In Drucker's view, knowledge has become the single most important source of today's economy. The traditional factors of production -land, labor, and capital- are not excluded, but are of secondary importance. Knowledge is recognized as an important resource. Knowledge forms the post-capitalist society and creates new economic social dynamics. Knowledge creates new policies, and the only long-term policy that leads to the success of an economy is the transformation of industries from labor-based industries to knowledge-based economies. Today, the economic value of production is created by 'productivity' and 'innovation', and both of them are the result of knowledge performance and its application in the economy.

For Drucker, therefore, the great economic challenge of the post-capitalist society will be 'labor productivity and 'knowledge worker' (Drucker, 2012).

Therefore, in general, theories of economic growth and development, especially neoclassical growth and development theories, consider the role of knowledge, education and technology, technical advancements, and general knowledge-based economy to be essential in economic growth and development. Even in some cases, the importance of knowledge goes beyond the other inputs of production and economic growth in growth models.

Explanation of Factors Affecting Productivity: Understanding the Effect of Knowledge on Productivity

The Role of Knowledge in Economics is not a new idea; Adam Smith points to a class of experts who play a key role in the production of useful economic knowledge (Smith, 1963). Friedrich List points to the structures and institutions like tariffs that play a major role in the development of long-run knowledge and productivity. He advocated imposing tariffs on imported goods while supporting free trade of domestic goods and stated the cost of a tariff should be seen as an investment in a nation's future productivity (Daastøl, 2011).

The innovation idea of Schumpeter is recognized as a powerful force behind economic dynamics. He states that capitalism can only be understood as an evolutionary process of continuous innovation and ‘creative destruction’ (Drechsler et al., 2009).

In addition, the New-Keynesian and New-Classic economists such as Romer have built their growth theories based on knowledge in response to the long-term economic growth factors (Romer, 1986).

We pointed out that knowledge and innovation are important factors in shaping productivity and productivity growth can be achieved through knowledge development. Now the question is that if a knowledge-based economy means achieving higher productivity through knowledge, what other ways, other than knowledge development, are there to improve productivity.

Taylor (2003) argues that governance quality, economic environment, and level of human resources education are considered as the main factors of productivity growth in countries (Taylor, 2003). Syverson (2011) divides the factors affecting productivity into two categories: factors affecting firm productivity and external drivers of productivity. He identifies productivity spillovers, competition, deregulation or proper regulation, and flexible input markets as key factors affecting productivity. Managerial practice, higher-quality of general labor and capital inputs, information technology, and R&D, learning-by-doing, firm structure decisions, and product innovation are among other effective factors (Syverson, 2011).

In addition to the above papers, numerous reports have been presented to compute innovation and the knowledge-based economy. Chen (2008) summarized various knowledge-based- economy (KBE) Indicators in international reports.

Table 2. The Various KBE Indicators Comparison

Organization	**Indicators Description**
Organization for Economic Co-operation and Development, 1999	Knowledge input, stock and flow of knowledge, knowledge output, knowledge network, knowledge learning
Progressive Policy Institute of the US, 1999	Changes in industry and employment structure, globalization, dynamics of competitiveness, information technical revolution, technological innovation ability
International Data Corporation, 1999	Computer, information, internet, society
Michael Porter and Scott Stern, 1999	Innovative construction, industry clusters, special innovative environment, connection quality
Marketing Information Center of Taiwan, 1999	The basic ability of information, information application ability, information regulation
Department of Trade and Industry of the UK, 2000	Human Resources, Science and Technology Innovation, Information and Communication application, Business Environment
Commission of the European Communities, 2000	Human resources, knowledge creation, knowledge spread, and application, innovative financial output, and market
Knowledge-Economy branch of Australian, 2000	structural change, knowledge output, knowledge proliferation (i.e. knowledge network, information infrastructure, internet, and e-commerce)
Ministry of Trade and Investment of Singapore, 2000	enterprise’s Economic Environment, Information Science and Technology, Innovation System, Human Resource Development
Asia Pacific Economic Cooperation (APEC), 2000	Innovation system, information, and communication technology infrastructure, human resource development, business environment
World Bank, 2002	Business environment, Innovation system, Human resources system, Information infrastructure, Performance index

Source: Chen, 2008.

The scope of the definition of the indicators and variables of the relevant categories seems to be perfectly consistent despite the apparent discontinuities. Therefore, we categorize the main factors affecting productivity as follows.

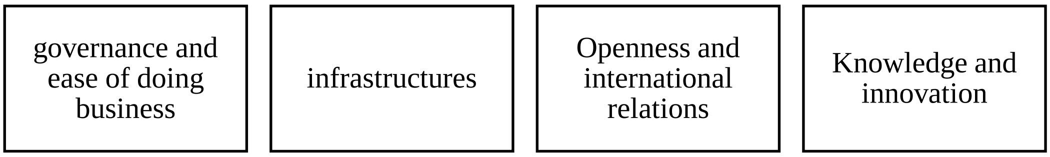

Figure 1. Factors Affecting Productivity
Source: Research finding.

Innovation Calculation Methodology: Crossing the Inductive Approach

From a methodological point of view, all reports related to the calculation of the knowledge-based economy, try to calculate different countries’ innovation levels focusing on the details of the innovation. The main weaknesses of the innovation computing approach are as follows.

1. Lack of meaningful relationship between the details presented in the reports and the concept of innovation (for example, although there is no relationship between the high number of landlines, or the number of videos uploaded to YouTube with the level of innovation in different countries, the level of innovation has been calculated by using them)
2. Relying on expert queries in calculating the reports sub-indicators (i.e. the ease of doing business in different countries is assessed by distributing a questionnaire among people familiar with the situation of those countries. Therefore, improving the indicators does not necessarily mean improving the situation but it means improving the insight of the elite community about the concerned country)
3. Reliance on the theoretical rationale for weighting sub-indicators to calculate a country-specific score and ranking countries (for example, the Global Innovation Index, by simply averaging the sub-indicators, measures the level of innovation in countries. The weight of different indicators should not necessarily be considered equal.)

To solve the above-mentioned problems, in the present study, it is suggested to use the deductive methodology. In the deductive approach (Figure 2), the concept of innovation is taken into account regardless of its details. In fact, unlike the inductive approach implemented in the global mainstream reports, in this approach, the question is not what constitutes innovation, or what features will lead to innovation. Rather, the main question is what innovation will be led by the deductive approach of calculating.

As stated in the definition of innovation, experts share the concept of market innovation, which means that higher innovation indicates higher production and sales levels (Dodgson and Gann, 2018). Therefore, assuming the stability of other conditions, an economy with higher innovation will also have higher per capita income. Therefore, countries with higher per capita incomes are likely to have higher levels of innovation. However, it should be noted that higher per capita income does not necessarily mean higher innovation. For example, oil countries and countries with a high level of natural resource rent also have high per capita income, but this higher per capita income is not due to greater innovation. Therefore, as will be explained below, in calculating the rate of innovation in countries, the natural resources rents should first be reduced from their per capita income.

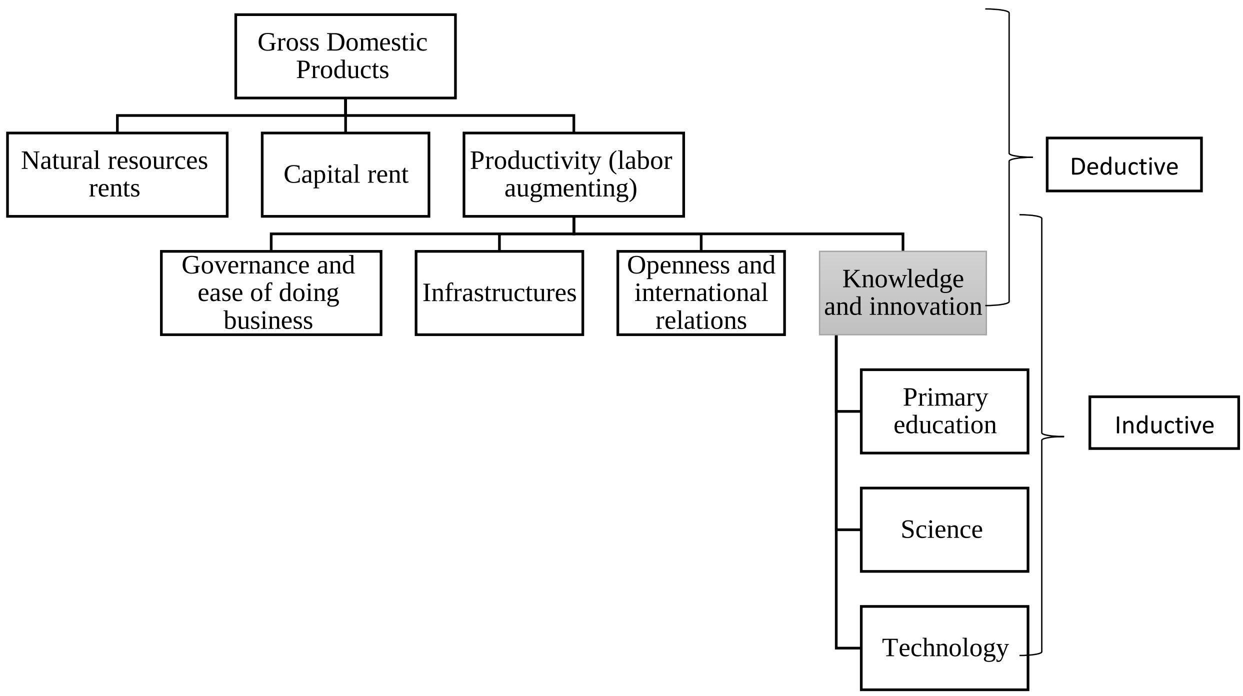

Figure 2. Comparison of Inductive and Deductive Approaches in Calculating Productivity
Source: Research finding.

Deductive Methodology in Calculating the Volume of the Knowledge-Based Economy

The main assumption is that productivity derives from the factors that influence it. Therefore, by calculating the level of total productivity in each country, a method must be provided for the partitioning of the efficiency achieved on its components. The approach used in this study to calculate productivity is based on solo work that was developed by Hall and Jones (1999).

Suppose the production function is as follows.

$$Y_i = K_i^{\alpha}(A_i L_i)^{(1-\alpha)}$$

where K_i is physical capital, L_i is labor, and A_i is Labor-augmenting productivity. It should be noted, given the results of Acemoglu's study, in the long run, both forms of capital-augmenting productivity and labor augmenting productivity can be estimated by labor augmenting productivity (Acemoglu, 2003).

According to the above production function, per capita production can be written as follows:

$$\frac{Y_i}{L_i} = A_i K_i^{\alpha}(A_i L_i)^{-\alpha}$$

Rewriting the above equation leads us to the following relation.

$$y_i = A_i\left(K_i^{(1-\alpha)}\right)^{\alpha/(1-\alpha)}\left((A_i L_i)^{(1-\alpha)}\right)^{-\alpha/(1-\alpha)}$$

where y_i is equal to $\frac{Y_i}{L_i}$.

With some simplification we have:

$$y_i = A_i(\frac{K_i^{(1-\alpha)}}{(A_iL_i)^{(1-\alpha)}})^{\alpha/(1-\alpha)}$$

$$y_i = A_i(\frac{K_i}{K_i^{\alpha}(A_iL_i)^{(1-\alpha)}})^{\alpha/(1-\alpha)}$$

$$y_i = A_i(\frac{K_i}{Y_i})^{\alpha/(1-\alpha)}$$

From the above relationship, assuming a broadly consistent neoclassical standard approach ($\alpha = 1/3$), labor augmenting productivity in different countries can be calculated.

$$y_i = A_i(\frac{K_i}{Y_i})^{1/2}$$

and hence:

$$A_i = \frac{y_i}{(\frac{K_i}{Y_i})^{1/2}}$$

Paying attention to A_i indicates that its dimension is the same as that of y_i or per capita income. A_i can be considered as per capita income derived from productivity.

It should be noted that in calculating productivity with this method, the rents in the economy must be eliminated first, and then the share of capital must be deducted from the per capita income according to the above-mentioned relation. It should be noted that GDP in different countries is calculated in terms of purchasing power parity.

Examining the indicators in the global reports and ranking their importance, in this study, we tried to derive the most important indicators affecting productivity by the following method (Figure 3).

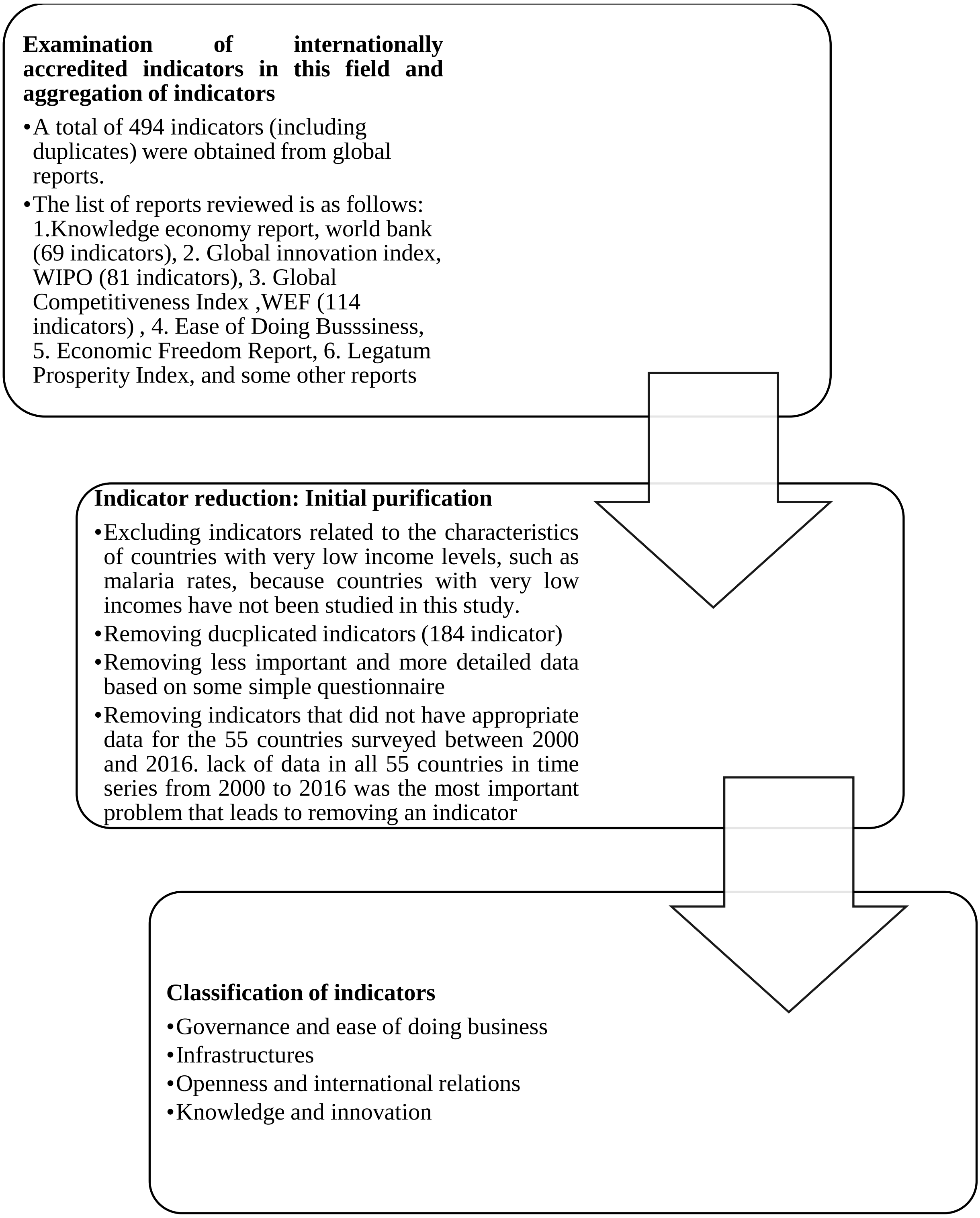

Figure 3. Method of Extracting Estimated Variables
Source: Research finding.

Finally, the sub-indicators in each of the four sub-categories were obtained as follows.

1. Governance and ease of doing business (Six sub-indicators: three sub-indicators related to governance and three sub-indicators representing business environment): Governance quality, political stability, and no violence, economic stability, inflation level, inflation fluctuations in the last five years, and unemployment

$$Gvrn\&Busi = a_1g_1 + a_2g_2 + a_3g_3 + b_1s_1 + b_2s_2 + b_3s_3$$

2. Infrastructures (three sub-indicators): per capita electricity consumption (kWh), internet access level, air passenger displacement rate

$$Infra = c_1f_1 + c_2f_2 + c_3f_3$$

3. Openness and international relations (three sub-indicators): FDI net inflows to GDP, FDI net outflows to GDP, and trade volume to GDP

$$Intr = d_1t_1 + d_2t_2 + d_3t_3$$

4. Knowledge and innovation (three sub-indicators): Number and quality of articles (total number of citations to total articles in the last five years), the ratio of government expenditure on education to GDP, and number of patent applications

$$Inno = e_1n_1 + e_2n_2 + e_3n_3$$

In addition to the above-mentioned factors, by looking at the data collected, the productivity levels in the countries were subject to the rate of natural resource rent in those countries. The increase in rents resulted in a decrease in the level of productivity and, in contrast, a decrease in the level of rents increased productivity.

Finally, productivity is a function of five factors: 1- rents level, 2- governance and business environment, 3- infrastructure, 4- quality of international relations, and 5- knowledge and innovation. In this case, the consequent form of productivity concerning its components is as follows. With six indicators, the coefficients can be calculated.

$$A = f(Rents, Gvrn, Infra, Intr, Inno) = \alpha Rents + \beta Gvrn + \theta Infra + \eta Intr + \lambda Inno + u$$

By replacing the above relations in the above equation and assuming the model is modeled as a panel data model, we have:

$$A_{it} = \alpha(Rents) + \beta(a_1g_{1it} + a_2g_{2it} + a_3g_{3it} + a_4g_{4it} + a_5g_{5it}) + \theta(c_1f_{1it} + c_2f_{2it} + c_3f_{3it}) + \eta(d_1t_{1it} + d_2t_{2it} + d_3t_{3it}) + \lambda(e_1n_{1it} + e_2n_{2it} + e_3n_{3it}) + u_{it}$$

We can simplify the above equation as follows:

$$A_{it} = \alpha(Rents) + (a_1g_{1it} + a_2g_{2it} + a_3g_{3it}) + (b_1s_{1it} + b_2s_{2it} + b_3s_{3it}) + (c_1f_{1it} + c_2f_{2it} + c_3f_{3it}) + (d_1r_{1it} + d_2r_{2it} + d_3r_{3it}) + (e_1k_{1it} + e_2k_{2it} + e_3k_{3it}) + u_{it}$$

Method and Model Estimation Results

Since the data are in the form of a panel, using a unit root test, data stationery was evaluated but not confirmed, so the first data difference was used for estimation. The stationary condition for the first difference of all the data was approved.

In the next step, using the F-Limer test, pooled or panel model was tested and the number of test statistics (Table 3) was obtained.

Table 3. Results of the F-Limer Test

Type of Test	T-Statistics Value	The Probability Value	Result
F-Limer test	1.14	0.2467	The model is pooled

Source: Research finding.

As can be seen in Table 3, the value of the T-statistic is equal to 1.14 and the probability value is 0.2467. Since the probability value obtained is greater than 0.05, the use of the pooled model was confirmed.

The necessity of using the first difference of data reduces the data quality. Therefore, to improve the estimation efficiency, Bayesian panel estimation with the following prior data is used:

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Priors:
                                        {dp:drt} ~ normal(0,10000000000) (1)
  {dp:dg2 dg3 df1 df2 df3 dr1 dr2 dr3 dk1 dk2 dk3} ~ gamma(1,10000)        (1)
                                {dp:dg4 dg5 dg6} ~ normal(-1000,1000000) (1)
                                     {dp:_cons} ~ normal(0,100)          (1)
                                       {sigma2} ~ igamma(.01,.01)
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As can be seen, some prior information, such as the rent coefficient, is non-informative because we had no sense of rents' effects on productivity. Since the model is estimated as the first difference, the y-intercept coefficient is chosen in such a way that the weight of the a priori information in the model is very high. In other cases, since all variables are normalized and exhibit the same behavior, it is attempted to use a priori estimator with the same mean and variance. Given the average productivity in 54 countries, and considering the normalization of all variables (between 0 and 1), as well as the fact that all a priori coefficients are assumed to be equal, the average a priori coefficients are equal to 1000. If the prior coefficient of 1000 is chosen for all variables, the average productivity obtained will be equal to the average productivity of all countries. Using 1000 for a standard deviation of the prior distribution reflects our expectations of the difference in the importance of the variables. Therefore, in all variables, the mean considered for the estimator was 1000 units and the standard deviation was 1000 units. It should be noted that in international studies such as the knowledge economy (Chen and Dahlman, 2005), the global innovation index (Wunsch-Vincent et al., 2015), and the global competitiveness report (Schwab and Sala-i-Martin, 2017), all coefficients have been taken into account with a constant weight.

In the case of the a priori distribution, the gamma distribution is used for all variables. Only for the three variables (inflation, inflation fluctuations, and unemployment) that harm production, given that we expected to encounter negative values, the normal distribution function was used.

The model is estimated and its coefficients are given in Table 4:

Table 4. Result of the Regression Model

$A_{it} = \alpha(Rents) + a_1 g_{1it} + a_2 g_{2it} + a_3 g_{3it} + b_1 s_{1it} + b_2 s_{2it} + b_3 s_{3it} + c_1 f_{1it} + c_2 f_{2it} + c_3 f_{3it} + d_1 r_{1it} + d_2 r_{2it} + d_3 r_{3it} + e_1 k_{1it} + e_2 k_{2it} + e_3 k_{3it} + u_{it}$			**Model**	
Median	**MCSE**	**Standard Deviation**	**Mean**	**Variable**
-19866.9	23.5	306.1	-19871.6	D.rt
Not included in the estimation				D.g1
1166.0	42.9	433.6	1175.5	D.g2
159.9	5.40	48.4	157.9	D.g3

Median	MCSE	Standard Deviation	Mean	Variable
-1106.3	93.7	666.6	-1094.8	D.s1
-1031.1	29.5	325.2	-1020.8	D.s2
-1856.3	28.6	301.7	-1827.1	D.s3
148.3	10.5	140.4	178.4	D.f1
1685.9	33.9	343.9	165702	D.f2
1195.7	31.4	241.1	1211.3	D.f3
1653.6	62.5	750.6	1674.5	D.r1
1125.4	37.1	273.3	1120.9	D.r2
88.2	5.9	113.5	120.4	D.r3
650.9	41.2	318.69	668.4	D.k1
187.0	20.3	179.6	228.7	D.k2
1389.4	59.2	644.7	1385.1	D.k3

Source: Research finding.

As shown in Table 4, the variable column refers to the names of the variables, and one column is dedicated to the standard deviation of results. **Monte Carlo Standard Error (MCSE)** is another measure of the accuracy of the chains. It is defined as the standard deviation of the chains divided by their effective sample size. The MCSE "provides a quantitative suggestion of how big the estimation noise is". After all, the median and the mean columns are important for the following calculations. As expected, the coefficients of inflation (D.s1), inflation fluctuations (D.s2), and unemployment (D.s3) are negative.

1 Applying Model Results in Practice: Extracting the Knowledge Economy Level for 54 Countries Using the Deductive Approach

By using the model results, the significance coefficient of each index can be obtained. The significance coefficient of each index is shown in Table 5. This coefficient indicates how each of the factors can contribute to each country's productivity.

Table 5. The Ratio of Coefficients Obtained from Model Results with the Deductive Approach

Variable	Mean	Significance Coefficient Index (Percent)
1. Political stability and no violence	1175	8.7
2. Macroeconomic fluctuation	157.9	1.2
3. Inflation level	1094.8	8.1
4. Inflation fluctuation	1020.8	7.5
5. The unemployment rate	1827.1	13.5
6. Electricity consumption	178.4	1.3
7. Internet access	1657.2	12.3
8. Air travels	1211.3	9.0
9. Trade volume to GDP	1674.5	12.4
10. Foreign direct investment	1120.9	8.3
11. Foreign investment	120.4	0.9
12. Government expenditure on education to GDP	668.4	4.9
13. Number of citations to scientific articles	228.7	1.7
14. Patent applications	1385.1	10.2

Source: Research finding.

To calculate the share of a knowledge-based economy, the following steps will be performed using the coefficients of the three indicators used in the Knowledge and Innovation section (Indicators 12, 13, and 14 of Table 5):

1. Multiplying the obtained coefficients by the values of the data for each country in each index
2. Normalizing the results so that the sum of the coefficients of a country equals one.
3. Calculating the knowledge share from productivity concerning the obtained coefficients

1.1 The Final Ranking of the Knowledge-Based Economy Level in Different Countries

According to the deductive model coefficients and level of indicators for each country in 2016, the final ranking of innovation level in different countries was obtained as Table 6:

Table 6. Final Research Results in 2016

No.	Country	Labor-augmenting productivity (US Dollar)	Knowledge-Based Economy Per capita (US Dollar)
1	United States	32,244	10,855
2	Japan	21,440	6,968
3	Germany	24,263	6,895
4	Sweden	25,034	5,002
5	South Korea	17,106	4,953
6	Denmark	24,264	4,815
7	France	19,016	4,742
8	Singapore	44,369	4,727
9	Israel	22,964	4,695
10	England	19,814	4,546
11	Saudi Arabia	24,441	4,484
12	Switzerland	32,561	4,410
13	Austria	23,438	4,346
14	Norway	21,292	3,916
15	Kuwait	42,382	3,859
16	Finland	20,343	3,772
17	Poland	18,941	3,769
18	Italy	15,508	3,739
19	Qatar	47,900	3,646
20	Russia	13,207	3,489
21	Netherlands	24,152	3,442
22	Canada	19,616	3,337
23	Australia	20,805	3,312
24	Belgium	21,285	3,312
25	Turkey	14,763	3,210
26	Iran	11,034	2,688
27	China	7,520	2,638
28	Malaysia	16,368	2,318
29	Spain	15,382	2,312
30	Czech Republic	15,531	1,995
31	Kazakhstan	16,870	1,958
32	Oman	16,029	1,870
33	Portugal	11,682	1,812
34	Mexico	9,575	1,794
35	Hong Kong	27,850	1,586
36	Brazil	6,511	1,496

No.	Country	Labor-augmenting productivity (US Dollar)	Knowledge-Based Economy Per capita (US Dollar)
37	Slovakia	16,636	1,438
38	Thailand	8,603	1,428
39	Egypt	8,849	1,386
40	Chile	12,108	1,358
41	South Africa	6,892	1,187
42	Greece	9,498	1,088
43	India	3,676	958
44	Bahrain	20,566	831
45	Azerbaijan	12,279	793
46	Indonesia	4,760	725
47	Turkmenistan	5,950	546
48	Vietnam	3,596	468
49	Pakistan	3,944	467
50	Georgia	7,048	434
51	Philippines	4,521	369
52	Lebanon	6,254	280
53	Emirates	30,718	140
54	Nigeria	3,572	5

Source: Research finding.

Results Analysis, Discussion, and Conclusions

Results are analyzed in the following categories:

1. labor-augmenting productivity
2. knowledge-based economy per capita

Labor-Augmenting Productivity

Figure 4 indicates Labor-augmenting productivity in understudied countries. As can be seen in Figure 4, the top ten countries are Qatar, Singapore, Kuwait, Switzerland, the United States, the United Arab Emirates, Hong Kong, Sweden, Saudi Arabia, and Denmark.

Resource-based countries such as Qatar, Kuwait, United Arab Emirates, and Saudi Arabia are among the top ten productive countries in this study, where oil and gas revenues in these countries are reduced from GDP, and then their productivity is calculated. Therefore, the high level of productivity in these countries cannot be attributed solely to the rent of natural resources. The question is if the productivity of these countries means that they are innovative? The answer is no. Because, as mentioned, productivity is not necessarily a result of knowledge and innovation, but the factors affecting productivity are divided into four categories.

Countries with a high level of natural resources rents generally have infrastructures with high quality and the role of knowledge and innovation in their productivity may not be very significant. In this study, we have attempted to answer this question by calculating the share of knowledge and innovation in labor augmenting productivity.

In the next section, we present the role of knowledge and innovation in improving productivity or the role of knowledge and innovation in economic growth.

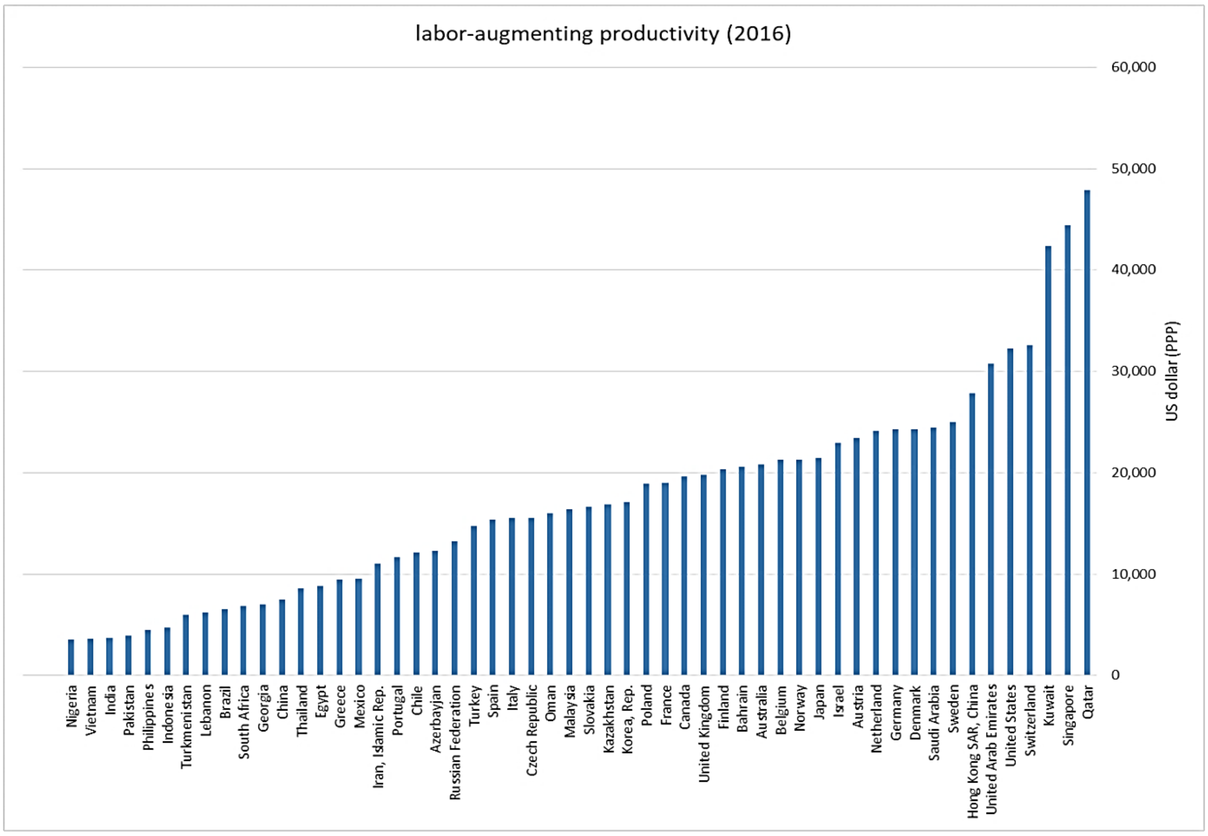

Figure 4. Labor- Augmenting Productivity in 2016
Source: Research findings.

Knowledge-Based Economy Per Capita

Figure 5 shows the share of knowledge and innovation in countries' productivity. As can be seen from Figure 5, the top ten countries that gain productivity through knowledge, or top ten knowledge-based economies are the United States, Japan, Germany, Sweden, South Korea, Denmark, France, Singapore, Israel, and the United Kingdom. Analysis of the results shows that in this ranking, developed countries are in the top ten. In addition, in this ranking, no country based on rents of natural resources is in the top ten.

The presence of the U.S, Japan, and Germany in the top three is very consistent with existing facts because these three countries are home to the world's largest tech companies.

Some of the results in figure 5 need to be explained. For example, Iran is better ranked than China, Malaysia, Spain, Hong Kong, Brazil, South Africa, and India. While such results seem inconsistent with the results of other global reports such as WIPO the global innovation index.

To explain this inconsistency, it should be noted that, the indicators in the WIPO World Innovation Index or the World Bank Knowledge Economy Report consider a wide range of indicators such as the quality of institutions, the quality of infrastructure, and knowledge indicators. For example, the Global Innovation Index consists of 8 institutional indicators and 10 infrastructure indicators. The World Bank Knowledge Economy Index also includes indicators in the economic and institutional regime and infrastructural indicators. In other words, the results of global reports, compared to the results of this study, indicate the level of productivity in the economy rather than the level of knowledge and innovation. Therefore, labor-augmenting productivity in Table 6 should be more consistent with the results of global reports. Based on the level of labor-augmenting productivity calculated in this study, Malaysia, Spain, Czech Republic, Portugal, and Hong Kong have higher productivity than

Iran. Therefore, the results of this study are highly consistent with the Global Innovation Index.

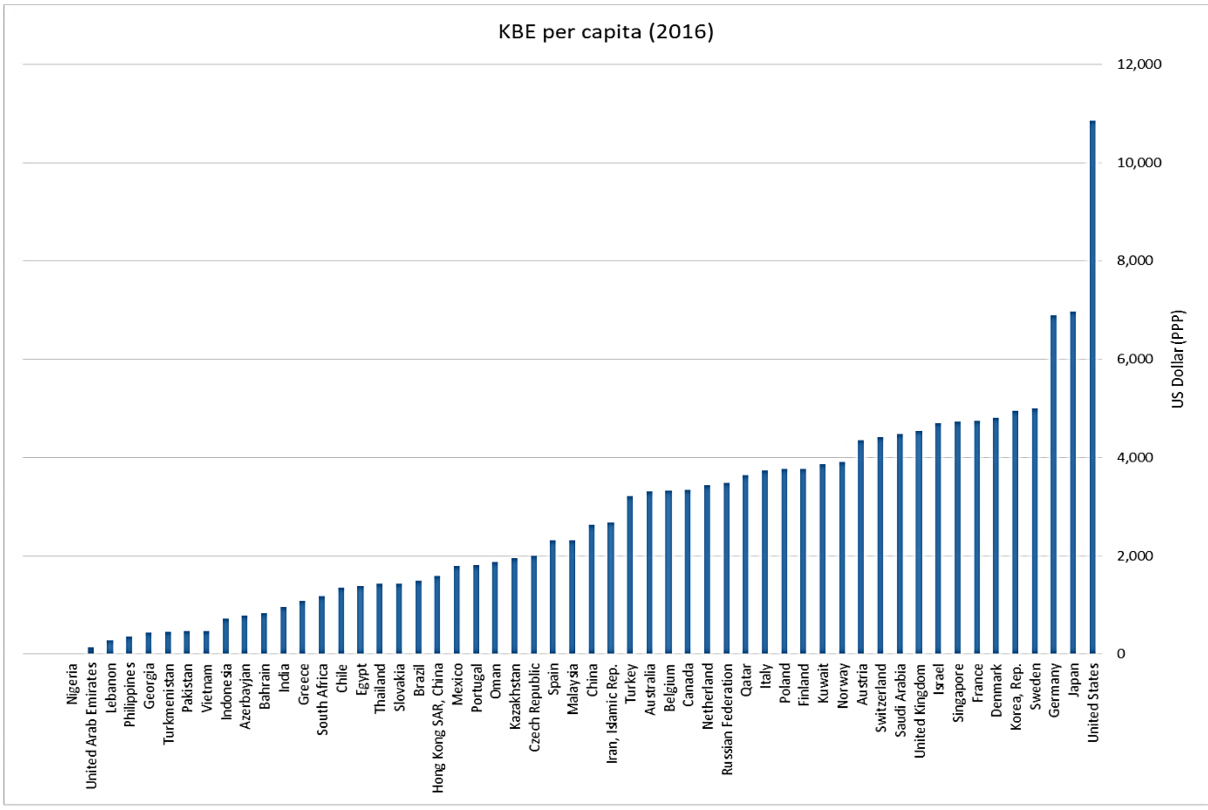

Figure 5. Knowledge-based Economy per Capita (PPP US Dollar)
Source: Research finding.

Given that labor-augmenting productivity is per capita, a lower level of productivity in China is acceptable compared to Iran. Although China has experienced high growth over the past three decades, due to its high population, its per capita productivity is lower than that of all developed countries, as well as that of Iran. China will rank much higher if the total output of the knowledge economy (not knowledge economy per capita) is taken into account.

Furthermore, the estimation method in this study justifies the results obtained. In fact, in this study, the level of productivity in different countries is divided into four sections. A country's high score on one section can mean that country is weak on other sections. In the case of Iran, due to the poor state of the country in terms of governance quality indicators and the level of international relations, a small level of productivity due to these two factors has been obtained and a higher share is allocated to knowledge and innovation. In the case of Hong Kong, although its productivity level is 2.5 times higher than in Iran, it has excellent sub-indices in three areas: quality of governance, quality of infrastructure and level of international relations, and intermediate sub-indices in science and technology. So it has led to excellent scores for this country in the other three sub-indicators and lower scores in the knowledge sector.

In addition to the above, the results of this study for developed countries, such as OECD countries, are highly correlated with the results of other international research and reports. Table 7 compares the results of this study with the results of the Global Innovation Index. The comparison shows that, firstly, the results of this study are highly correlated with the results of the Global Innovation Index; secondly, the U.S, Japan, and Germany in the top three ranks of the study are more in line with the public sense than the Global Innovation Index.

Table 7. Comparison of the Results of This Study with the Results of the Global Innovation Index

Rank	Global Innovation Index (2016)	Results of This Study (2016)
1	Switzerland	the United States
2	Sweden	Japan
3	the United Kingdom	Germany
4	the United States	Sweden
5	Finland	South Korea
6	Singapore	Denmark
7	Ireland	France
8	Denmark	Singapore
9	Netherlands	Israel
10	Germany	the United Kingdom

Source: Research finding.

It should be noted that in the Global Innovation Index (2016), Japan was not among the top ten innovative countries and Germany was in tenth place. Other differences in results are as follows:

In the Global Innovation Index, Switzerland (1), Finland (5), Ireland (7) and the Netherlands (9) were among the top ten countries, while in our results, Japan (2), South Korea (5), France (7) and Israel (9) have replaced them. In addition, the UK ranked third in the Global Innovation Index, which dropped to tenth in this study.

As can be seen, Ireland is ranked seventh in the 2016 Global Innovation Index, while Germany is ranked lower and Japan is not among the top ten countries. However, the results of this study show that the United States, Japan, and Germany are by far the top countries in the field of the knowledge economy. So at least in some cases, the results of this research are closer to our intuition.

Discussion and Conclusion

From a methodological point of view, reports on the computation of the knowledge-based economy, focusing on the details of innovation, try to calculate the level of innovation of different countries. The most important criticisms of this approach include doubts about the validity of the results, lack of a meaningful relationship between the details presented in the reports and the concept of innovation, and summing up the indicators is the same weight.

To solve these issues, using a deductive approach is suggested to calculate innovation. In the deductive approach, the concept of innovation, regardless of its details, is taken into account. In fact, in contrast to the inductive approach, which is commonly used before, in this approach, the question is not what constitutes innovation or what features will lead to innovation. Instead, the main question is what kind of innovation will be resulted in the deductive approach for computing. The answer is, innovation will lead to productivity and economic growth. Therefore, by identifying other components, which affect productivity and their importance, it is possible to calculate the rate of productivity resulting from knowledge and innovation with a more accurate estimation.

From the literature review, we remember that in almost all schools of economic thought, knowledge is the main factor influencing long-term growth. By analyzing global reports in this area, the factors affecting macro-level productivity were extracted as follows. 1- Governance and ease of doing business, 2- Infrastructures, 3- Openness and international relations, and 4- Knowledge and innovation.

Then, it was attempted to determine the contribution of the components of productivity through a macro approach and defining the concept of deductive productivity, and calculating the productivity resulting from knowledge and innovation. To some extent, this contribution represents the level of a knowledge-based economy in an economy.

For this purpose, factors affecting productivity were gathered from valuable resources and reports, and due to the practical inefficiencies in locating and computing the general productivity formula, the number of factors was reduced to the extent that they could be rationalized for calculation. Subsequently, in certain steps, the reduction of the factors affecting productivity was performed in several steps. In the first stage, there was an elite deduction, and in the second stage, a semantic deduction happened, and the third step deduction was based on the presence or absence of good, high quality and as firm as possible data. Finally, the factors were identified and located in the general productivity formula.

By identifying the appropriate estimation equation, this equation was estimated for 54 countries over the 15 periods using the Bayesian panel method. Results indicate that in terms of the knowledge-based economy per capita, the United States, Japan and Germany are leading countries out of 54 surveyed countries.

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