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A New Index Measure of Technological Capabilities for Developing Countries

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A New Index Measure of Technological Capabilities for Developing Countries

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Abstract: This study is conducted to develop a new measurement tool to analyze the extent of innovation by developing nations. The role of science and technology in enhancing the rate of innovation is also investigated. The existing methods for measuring innovation such as Technology Index (WEF), Technology Achievement Index (UNDP), Industrial Development Scorecard (UNIDO), ArCo (Archibugi and Coco) and Science and Technology Index (RAND Corporation) are compared and based on their limitations a new tool with higher advantage is developed. The new index labeled as Technology Creation Index (TC-index) is decomposed into six distinct components. The index is estimated for 61 developing countries from Asia, North and South America and Africa. The countries are classified into three groups based on their extent of innovation derived from principal component analysis to assess the country group heterogeneity. The results suggest that in construction of the TC-index patents granted, human development index, local availability of specialized training and resources, foreign direct investment inflows, number of citations per science and education articles, secondary gross enrollment rate and science and education journals are identified as the main contributors to the higher rate of innovation in developing nations.

Keywords: Innovation measurement, Technological infrastructure, Diffusion of innovations, Human skills, Economic and social indicators.

JEL Classification Numbers: C19, C49, I32, J24, O30, O32.

1. Introduction

The definition of innovation has evolved over time. In [1] innovation is defined as the specific tool of entrepreneurs and the means for exploiting the change as an opportunity for a different business or services, while [2] defines innovation as any practice that is new to organizations, including equipment, products, services, processes, policies and projects. More recently, [3] proposed that innovation is the use of new technical and administrative knowledge to offer a new product or service to customers. It is a process of coming up with new ideas leading to higher convenience for human existence.

In other words, innovation is a gradual process of converting the opportunity into new ideas which will be further employed for development of new practices leading to technological advancement [4]. The inter-relationship between science and technology and innovation is significant and they both positively influence each other. The existing literature suggested that the rate of innovation and contribution from science and technology has not been satisfactory in several developing nations in Asia, Middle East, South America and Africa [5] [6] [7]. Though some types of methodologies were used for measuring the extent of innovation in few studies, they lack the clarity in identifying the extent of innovation in developing countries and their relative status with that of developed nations. Moreover, the role of developing science and technology in enhancing the rate of innovation were not focused specifically in those studies.

For example, the technology index developed by World Economic Forum [8], and the technology achievement index (TAI) developed by United Nations Development Program [9] concentrate much on the extent of advancement in technology rather than creativity and innovation. Similarly, the industrial development scoreboard developed by United Nations Industrial Development Organization [10] emphasizes more on the rate of industrial growth which is not fully linked with the rate of innovation.

All these methods did not take science and technology development as a major component of measuring the technology indices. Very few studies were concentrated on measuring science and technology development and growth rate like science and technology capacity index by Rand Corporation [11]. However, its interrelation with the rate of innovation is yet lacking. Though some efforts were made by researchers to come up with a better measurement tools relative to that of the above said methods, they too could not integrate the various factors affecting science and technology and innovation in an integrated manner. Hence, there is a necessity for identification and standardization of new means of estimating the extent of contribution made by science and technology for the innovation in developing nations and accordingly the policy initiatives can be taken.

There is a strong need for increasing the extent of innovation through better focus on science and technology and research to promote and strengthen development in developing countries. Developing nations should try to match their rate of development with that of the newly developed nations like South Korea. For achieving the same development, there is a need for identifying the present rates of innovation and extent of contribution made by the science and technology towards the process of innovation. As mentioned earlier, the existing measurement tools lack some key factors of science and technology such as average number of citations per science and education article and local availability of specialized training and resources affecting innovation rate and hence the formulation of future strategies for enhancing the innovation rate becomes a major challenge.

There is an urgent need to develop a new measurement tool for innovation that accounts for the contribution from science and technology in an integrated manner. Keeping these points in view, the present study has been conducted to answer questions such as “what is the most efficient way of measuring innovation rate and technological capabilities in developing nations?” or “whether there is a scope for further development of an integrated innovation index that measures the rate of innovation more accurately than the existing methods”.

Hence the present study focused on development of new measurement tool of innovation i.e. TC-index which is multidimensional and more effectively accounts for the factors underlying innovation and technological capability of developing nations than the existing methods. Based on the identified factors affecting innovation rate derived from TC-index, future management strategies have been suggested for the achievement of a higher growth rate of science and technology and innovation in developing nations. The new index through its better coverage of underlying development is superior to the existing indices and as such it makes a contribution to the literature.

Rest of this study is organized as follows. Section 2 is a review of the literature on factors affecting the rate of innovation and existing measurement methods. The theoretical framework and methodology in the design of the proposed TC-index is outlined in Section 3. Empirical results and its discussion accounting for country group heterogeneity found in Section 4. Section 5 concludes and provides policy recommendations.

2. The Review of Literature

2.1. Factors Affecting the Rate of Innovation

The existing literature on technology and innovation indices used in assessment of development is relatively new and developing but yet with major limitations. A number of factors are identified to impact the rate of innovation at the micro and macro levels. These include firms innovation ability and capacity, industry level collective capability and networks, innovations friendly environment, global economic system and trade related intellectual property rights protection, state support in interacting learning and technological capability, multinational corporation role in organizational and geographical mobility of innovation, indigenization of learning capability, global and regional innovation networks and systems, and coordination between public and private agencies.

The ability to innovate is generally accepted as a critical success factor to growth and future performance of firms. [12] investigated how firms can influence their innovation capacity. The author proposed a ‘3P’construct of innovation measurement at the micro level, Posture, Propensity and Performance related to a firm’s innovation capabilities.[13] revealed that there exists a fundamental change in the process of innovation in developed countries. They found that the origin of innovation has been changed from centralized system to decentralized mode. It was also found that the 'organizational decomposition of the innovation process' changes the global distribution of innovation of activities which may also influence innovation in the developing world.

[14] studied the major types of innovation, like product innovation and process innovation and [15] by correlating the knowledge creation and innovation suggested that today’s global environment requires different types of knowledge and innovative capabilities from the side of the developing countries.

[16] studied the relationship between innovation and wellbeing based on the British Household Panel survey. It was concluded that the higher subjective wellbeing contributed to higher level of creativity, and working in an innovative friendly environment also results in higher level of innovation.

[7] studied the important of the innovation system in development of small economies. Results based on firm level data across 43 developing countries, revealed that exporting and importing activities are important channels for the transfer of technology and utilization of scale in innovation [5]. The international agreement has also impact on the level of innovation and science and technology in developing countries like India [17]. They found that India’s signing the TRIPs (Trade Related Intellectual Property Rights) agreement in 1994 affected Indian firms’ growth rate in their product innovation and science and technology in particular among the more innovation intensive industrial firms. [18] investigated the Greek innovation system and identified important asymmetries prevalent in the system which explains the low performance of the Greek innovation system.

[19] analyzed the main institutional mechanisms that foster the emergence and performance of firms in knowledge intensive sectors in South Africa and Malaysia. They illustrate the linkages between interactive learning and technological capabilities and how state support plays a critical role in enabling this. In the other hand, [20] explained about the current state of innovative capacity in South Africa. They identified sets of policies at national and international level that have contributed to the promotion of innovative capacity in health R&D and establishes the indicators and drivers of innovative capacity. The development of technological capability has also been analyzed by [21] in the Brazilian subsidiaries of multinational vehicle assemblers.

These played a role in building up local technological capabilities in product development in Brazil. [22] explained how innovation off-shoring gives rise to Global Innovation Networks (GINs) in the field of electronics industry. They explained about the forces that are responsible for the organizational and geographical mobility of innovation within GINs emphasizing their systemic nature.

Some researchers emphasized the link between the innovation strategies and promotion of science and technology and industrial development. [14] stressed on the necessity to reduce the barriers of innovation in public sector and to encourage the drivers of the innovation in public sector in developing nations by developing technological, social and financial innovations in public sector. In this regards [23] emphasized on the indigenization of learning capabilities to become part of comprehensive innovation strategy in economic development. The concept of Regional Innovation System (RIS) which developed by [24] and study by [25] suggest strategic lines to achieve a regional innovation strategy to develop innovative clusters In Portugal. [26] reported that Malaysia has mounted notably comprehensive efforts to build a national innovation system and despite efforts to promote Science and Technology policies, the challenges remained affecting successful innovation strategy. They suggested establishment ordination between public sector technology agencies and private enterprises.

2.2. A Comparison of Existing Index Measures

Several researchers investigated the status of innovation and technology development, however, few studies were conducted on the role science and technology played in enhancing the rate of innovation. The compute indices which are mainly based on the human development index methods of calculation with different dimensions to rank countries and to make inference about their state of science and technology and polices.

[6] compared several new measures of national technological capabilities. A new methodology called ArCo was developed and it was compared with the methodologies for measuring innovation and technology development designed by the World Economic Forum (WEF), the UN Development Program (UNDP), the UN Industrial Development Organization (UNIDO), and the RAND Corporation. These five methodologies to measure technological capabilities which include are reported in [4] [8] [26] [27] [9] [29] [10] [30] [11]. ArCo was estimated for 162 nations by considering three dimensions of technology into account (see Table A.1), innovative activity (based on patents registered at US patent office and scientific publications); technology infrastructure (based on internet, telephone mainlines and mobile and electricity consumption); and human capital (based on scientific tertiary enrolment, years of schooling and literacy rate).

In the other hand, WEF considered two main measures for competitiveness and economic development, the first devoted to the medium-term growth and the second to the short-term current competitiveness index. The growth component was estimated on the basis of a battery of variables linked to growth grouped in three components: the level of technology, the quality of public policies, and the macroeconomic environmental conditions. Similarly, the current component was estimated on the basis of variables that concentrate on microeconomic aspects, such as the business environment around a firm, and the strategy and organization inside a company. These were estimated for a set of 75 countries, divided into two groups, core and non-core, according to the number of patents produced.

The UNDPs TAI index was estimated for 84 nations and considered four dimensions of technology achievement: creation of technology (based on patents registered and royalty and license fees); diffusion of newest technologies (based on internet hosts and medium-and high-technology exports); diffusion of oldest technologies (based on telephone mainlines and electricity consumption); and human skills (based on years of schooling and tertiary science enrolment).

The UNIDOs Industrial Development Scorecard was estimated for 87 nations and it considered four categories: technological effort (based on patents and enterprise financed R&D); competitive industrial performance (based on manufactured value added and exports and medium-and high-technology sectors shares); technology imports (based on FDI, foreign royalties payments, and capital goods); and skills and infrastructures (based on tertiary technical enrolment and telephone mainlines).

Science and Technology Capacity Index was developed for 76 nations by RAND Corporation which was based on eight indicators which in turn are aggregated and divided into three categories: enabling factors (based on GDP and tertiary science enrolment); resources (based on R&D expenditure, number of institutions and scientists and engineers); embedded knowledge (based on patents, Science and Technology publications and co-authored papers). A synthetic index is created through a standardized formula, with different outcomes occurring according to the weights assigned to the three index components.

A few studies suggest improvement of the abovementioned indices. For instance a conceptual framework for approaching the promotion of technological innovation and its diffusion is developed by [31]. It took into constraints of innovation climates like poor business and governance conditions, low educational levels, and mediocre infrastructure which affect diffusion of technologies and related practices. [31] suggested strategies for better innovation rate like provision of the necessary package of support related to technical, financial, commercial and legal aspects, as well as attention be paid to administrative and cultural traditions. [32] in relation with innovative approaches for suggested eLearning in particular, the methodology applied to measure innovation in eLearning projects. They focused on the concept of innovation and three key aspects, i.e. technological innovation, sociological innovation and service customization.

[33] also describes different forms of innovations that can be explored in developing countries. The study was made on product innovation, process innovation, organizational innovation and marketing innovations. It was also opined that the infrastructure and institutional framework, public research system and education pattern play crucial role in growth of innovation in developing nations. Recently [16] explained the process of how innovation takes place in the public sector. Two stages in public sector innovation i.e. invention based and diffusion based are identified. They also examined three key differences specific to the public sector that strongly affects how government organizations operate in terms of innovations. Table A.1 in the appendix is a summary of the comparison between the existing indexes.

In sum, though these studies explain the several specific factors that influence the rate of the innovation, they lack required parameters to draw an accurate conclusion on the specific factors affecting the rate of innovation in developing nations. Hence, the present study has been initiated to develop most innovative method of measuring innovation.

3. Theoretical Framework and Methodology

3.1. Technological Innovation and Indices

The somewhat different definitions of innovation by [1], [2] and [3] are related to specific tool of entrepreneurs to exploit changes as an opportunity for business or services, any practice that is new to organizations and use of new technical and administrative knowledge to offer a new product or service to customers. Innovation intensity differs across countries [28]. The firms' technological innovation environment can be divided broadly into internal and external parts.

National innovative capacity can be defined as the ability of a country to produce and commercialize a flow of innovative technology over the long term. The strength of a nation's common innovation infrastructure is affected by the national innovative capacity and the internal environment for innovation in firms. It was also found that there exist a close relation between international patenting and variables associated with the national innovative capacity framework. Some internal factors like structures, climates, and cultures of organizations, will influence the adoption of innovation [34] [35]. [36] found that the management skills, organizational encouragement for innovation, and support in form of innovation resources would help the improvement of innovation. In this regards, [37] suggested that an organization with higher quality (skills) of human resources such as better education or training will have higher abilities in technological innovation.

Similarly, the external environment in which a firm is operating will also influence the innovative capability [39] [39]. Governmental support is another important environmental characteristic for technological innovation. Government through effective regulation can play positive or negative role in the adoption of innovation [2]. [37] found that environments with high uncertainties have positive influences on the relationship between organizational structures and organizational innovation. The patent protection and regulation system and patent application has positive effect on innovation [40]. In other words, the patent number and innovation rate are positively correlated, and hence the patent number can be considered as one important factor influencing the rate of innovation in developing nations [41] [42].

Foreign direct investment (FDI) can benefit innovation activity in the host country through spillover channels like reverse engineering, skilled labor turnovers, demonstration effects, and supplier customer relationships [43]. [44] reported the positive effect of internet access on the rate of innovation. It was found that the internet is a new information and communication technology that has a big potential to improve the relationships and networks among various enterprises and hence it will allow firms to interact with distant partners more easily and as a consequence, innovation networks get enhanced. Hence, internet and computer use along with FDI have been used as the important variables that affect the rate of innovation in this study. Based on the theoretical considerations about the meaning of innovation and various factors affecting innovation, an attempt has been made to develop a more integrated approach for development of new index of innovation, i.e. TC-index.

The above theoretical considerations suggest that several internal and external factors affect the rate of innovation in developing nations. Though the existing methods address the innovation rate to some extent, there is still a scope to improve the index which will be more integrated in nature. Keeping this in view, the present study has been made to develop a better technology innovation index. The information related to the development of science and technology and innovation in developing nations under study was collected through review of literature from standard international journals, reference books and reports. The literature was studied and analyzed based on the objective of the study i.e. identifying the extent of contribution made by the science and technology towards the innovation rate in these developing nations, while comparative interpretation was made with that of developed nations. The existing measures of innovation index were reviewed and their advantages and disadvantages assessed.

Based on the pros and cons of existing methods listed above, the new TC-index was developed which attempts to take into consideration of all the prioritized factors affecting science and technology and innovation in an integrated manner. According to the score obtained by the TC-index, a new classification for categorizing the nations based on the present level of resources for science and technology is made available with them and is consistent in reflecting the actual rate of innovation. The TC-index construction is described below in the next section.

3.2. Data and Estimation of the New Technological Capability Index

The strategy for construction and computation of the proposed technological capability index (TC-index) is by utilizing data contains 28 indicators of technology and innovation. The data consists of 61 developing countries from different continents observed during 2003-2008. The data is obtained from the World Banks World Development Indicators, Telecommunication Union and other international data sources. The sample is limited to developing countries to focus on the technology innovation capability of these countries as group and in line with the objective of this study and limitations of the literature. The sample is further distinguished by the level of index into three groups.

The indicators were subjected to a principal component analysis (PCA) methodology using ones as prior communality estimates. The PCA is defined as a mathematical procedure that helps in transforming a number of correlated variables into a smaller number of uncorrelated variables known as principal components [44]. It also implies that the first component will represent maximum variability in the data as possible. The indicators of rate of innovation are further categorized as 6 principal components. It is the simplest of the true eigenvector based multivariate analyses and it reveals the internal structure of the data in a way which best explains the variance in the data. The principal component analysis was applied to extract the components, and this was followed by a varimax or orthogonal rotation.

Despite the large number of indicators and multidimensional nature of the problem, the overall TC-index index helps to rank the countries in one single way while accounting for the differences in the sub-index or principal components. A main advantage of the index compared with many other indices is that it is parametric and in aggregation of the different indicators the weight are not selected on an ad hoc basis but estimated parametrically.

All the six principal components displayed with Eigenvalues greater than 1, and the results of a screed plot also suggested that the six components were meaningful and then were retained for rotation (see Table A.2 and Figure A.1 which presents a fictitious screed plot from a principal component analysis). Combined, the components 1 and 2 accounted for 75% of the total variance in the data. Parameters (items) and corresponding factor loadings are presented in Table 2 and Table 3, respectively. In interpreting the rotated factor pattern, an item or indicator was said to load on a given component if the factor loading was 0.30 or greater for that component, and was less than 0.30 for the other. Using these criteria, we identify the contributing factors to a principal or sub-index components and their contributions by the size and sign of the factor loading.

In total six principal components or sub-indices are distinguished. For instance, three items were found to load on the first component, which was subsequently labeled as the computer and internet index. Three items also loaded on the fourth and fifth components, which were labeled as the researcher and technician index, respectively.

The summary above is giving the weight associated with each of the principal components. The principal component 1 has 0.3129 weights, principal component 2 has 0.3064, and so on, and the cumulative weights for the first six principal components form 0.8290 weight, in other words, interpreted as around 83% of the variance in the data can be explained by the five principles components. Moreover, all Eigenvalues greater than 1 here is considered. It indicates that the principal component 1 contributes around 38% of the variation in the rate of innovation which is very important in deciding the future innovation policies for the developing nations.

The governments in their policies must emphasize much on this principal component in promoting innovation as it significantly affects the rate of innovation in developing nations. The rationale for this criterion is straightforward. Each observed variable contributes one unit of variance to the total variance in the data set. Any component that displays an eigenvalue greater than 1 is accounting for a greater amount of variance than had been contributed by one variable. Such a component is therefore accounting for a meaningful amount of variance, and is worthy of being retained. Other principal components have little representation of variation of data and hence they were discarded from using in the analysis.

3.3. Decomposition of the Index

According to the results obtained from principal component analysis applied to the 28 indicators (see table A.2 in the appendix), the following table illustrates the six principal components or sub-indices:

Table 1. The principle components of sub-indices

Sub-Indices	Components
Technology creation	X2, X5, X10, X15, X16, X18, X27, X28
Technology diffusion	X8, X9, X12, X13, X14, X21, X22, X23, X24
Researcher and technician	X19, X26
Patent and scientific journal	X4, X7, X11
Science and education research	X1, X6, X20
Technology export	X3, X4, X17

The aggregate TC-index, which is an integrated methodology for estimation of innovation rate, is an index for measuring innovation rate in any nation based on the performance of important indicators of science and technology, technology diffusion, skilled human capital, research and its outcome and cross border technology exchange. The variables like foreign direct investment (FDI), internet users, and number of computers would be completely decided by the national policy of the governments in developing nations and these parameters have significant effect on the rate of innovativeness and innovation and hence the TC-index would provide a solid advantage over other methods previously used in estimation of innovation.

The TC-index takes into consideration of several weighting factors related to science and technology, policy making and human capital development in most integrated manner. Though some methodologies were developed for assessment of innovation rate in developing and developed nations, they are fragmented in approach and hence integration of all the important weighting factors is non-systematic and simplistic.

For example, the technology achievement index developed by United Nations Development Program takes into consideration of several weighting factors related to technology development, and it lacks the inclusion of human capital development and policy making indicators which also play significant role in innovation.

Similarly, the technology index developed by World Economic Forum takes into consideration of level of technology and some policy issues, but it does not cover the human capital development and science capacity indicators. The industrial development scorecard developed by United Nations Industrial Development Organization covers mainly the indicators of industrial technological aspects, however it lacks in weighting factors related to science and technology and human capital development.

The accurate method of assessment of rate of innovation is highly essential for developing nations so that they would be in a position to review their present status of innovation and to develop future strategies for enhancing the role of science and technology in innovation. Technological capability and innovativeness certainly helps them to catch up with the developed nations. Keeping this in mind, the concept of TC-index has been developed.

TC-index is an integrated innovation index whose score ranges from negative to zero and to positive values. The range depends on the way the index is normalized. The overall index is a weighted aggregation of six principal components or sub-indices which were further derived from 28 indicators of innovation and technology (see Table A.2). As weights in aggregation of the six components into a multidimensional index we use the share of the total variance explained by each principal component. A parametric estimation of the weights and their aggregation based on their contribution to the explanation of the variation in the data together with a better data quality and coverage suggest that the index is superior to the existing index measures. TC-index is a unique way of measuring innovation rate in developing nations compared to previous methods because of its broader coverage of several numbers of variables which accurately predict the rate of innovation. For example, the local availability of specialized training and resources and average number of citations in science and education journals have been included in calculation of TC-index which were not focused well in the previously computed innovation measurement indices. Hence TC-index gives an accurate measurement of innovation compared to the other existing innovation measurement approaches.

4. Empirical Results and Discussion

4.1. Analysis of the TC-index

The TC-index has been estimated by taking into consideration of six principal components i.e. technology creation index, technology diffusion index, patent and journal index, researcher and technician index, education and science index and science export index. These principles have included 28 indicators of technology and innovation forming 6 sub-indices as presented in Table A.5.

Among the 61 developing nations studied, China as an emerging economy recorded the highest TC-index value of 3.19 which reflects that it is having the highest potential for innovation in science (see Table A.6). Moreover, the TC-index value is mainly contributed by highest patent, internet and foreign direct investment indicators. China was followed by Estonia (1.25) and Malaysia (1.02) in terms of TC-index value reflecting the scope of higher status of innovation in science and technology. On the other hand, the lowest TC-index value (-0.56) was recorded for Iran due to the lower values of patent, FDI, literacy and education indicators.

Bangladesh, Tadzhikistan and Cambodia also registered lowest level of TC-index value which shows that these nations have less favorable conditions for innovations. One important aspect of this study is that the innovation rate by TC-index was more decided by the specific factors such as patent, science and engineering and FDI indicator whereas the previous methods mostly stressed on human development index. As the human development index covers the only three broad factors (life expectancy, year of schooling and GDP per capita) affecting innovation, it may not be considered as accurate method of estimating innovation rate like TC-index. The differences in values of TC-index and HDI for the 61 nations under the present study can be found in Table A.6. In terms of HDI value Estonia leads the table followed by China and Malaysia.

Though China ranks first in TC-index value, it ranks second in HDI value. This is due to the fact that the rate of innovation is more determined by the specific determinants used in our study which decides the rate of innovation better than the HDI where the general factors for human development are involved. For example, the diffusion of technology and innovation is facilitated more by specific parameters like patenting [46] [47] whereas HDI is mainly affected by health and literacy leading to the differences in values of HDI and TC-index for same nation.

China again leads in the specific indicators’ contribution that determines the TC-index value. However, as far as the general factors for human resource development are taken into consideration, the effect has not been that good relative to other developing nations. Estonia recorded first rank in Human development index where as it ranked second in TC-index value. This difference is due to the variation between the specific indicators affecting the rate of innovation like patents, internet, computers, scientific journal access, and FDI (one of the main sources of technology transfer). These indicators are the main consideration for TC-index value and the generalized parameters like literacy and education as main components of HDI. Malaysia recorded third place both in HDI and TC-index. HDI seem to be a good indicator of both human development and also innovative capacity of developing nations.

As it is revealed from several primary and secondary sources of literature that the rate of innovation is more in China than Estonia and Malaysia and other developing nations, hence TC-index can be considered as more accurate method than previous methods of measuring innovation in developing nations.

The correlation matrix revealed that the highest correlation was found between pairs of majority of the indicators (see Table A.8 for details). Some indicators like X6, X7, X9, X11, X12 and X13 did not show strong correlation with other variables. The strong correlation between human development index and average number of citations per science and education article, FDI inflows, FDI outflows and gross secondary enrollment rate is due to the significant allocation of resources in terms of foreign direct investment towards the secondary enrollment and scientific journal papers which is directly proportional to the innovation rate and science development.

Similarly, the higher level of correlation between the local availability of specialized training and resources with that of foreign direct investment towards the secondary enrollment and scientific journal papers is due to the direct proportional relationship between the training at local level and science development and FDI which is also encouraging innovation development. The correlation between the adult literacy rate and gross enrollment ratio is due to the interdependency of both of these factors on each other.

The strong correlation between the number of computers and the internet connectivity is also due to interdependency on each other. Moreover, the correlation between the human development ratio and gross secondary enrolment ratio is due to the main fact that the literacy is one of the main indicators of the human development ratio for estimation of its net value. The positive correlation between the local availability of average number of citation in Science and Education journals and FDI inflows is due to the higher extent of investment towards the development of scientific journals which is directly proportional to the innovation rate [48].

4.2. Country Group Heterogeneity

The developing nations under study have been classified into three distinct groups based on the overall TC-index score as follows:

- Group 1: This group consists of scientifically high potential nations where TC-index score is greater than 0.5. Seventeen nations have been categorized under this category begin from China and ended with Croatia. Although literacy percentage is remarkable, the efforts must be made by policy makers to elevate the status of research by spending higher share of the state budget on R&D, and by encouraging scientists for filing more number of patent applications.
- Group 2: Consists of scientifically moderate potential nations where TC-index score ranges from 0 to 0.5. Twenty nations were categorized under this group starting with Latvia and ended with Ukraine. Policy makers should emphasize on enhancing the literacy level and education enrollment shares in these countries. The government policy to eradicate poverty would help in this regard as several people do not get access to education due to the cost involvement. The policy making should facilitate higher budget for research institutes and laboratories.
- Group 3: Labeled as scientifically low potential nations where TC-index score is less than 0. Thirty nine nations were categorized under this group starting

with Brazil and ending with Iran. This group of countries is far behind. The intensified efforts must be made to enhance the literacy share and education enrollment percentage and to reduce the unemployment and poverty rates. The policy making should allocate a higher of the state budget for university education and schemes for encouraging scientists for filing more number of patents.

5. Conclusion and Recommendations

The present study developed a new measurement tool, TC-index, to analyze the extent of innovation for developing nations. It is far superior to the existing methods for measuring innovation such as technology index (WEF), technology achievement index (UNDP), industrial development score card (UNIDO), ArCo (Archibugi and Coco) and science and technology index (RAND corporation) which were basically measurement tools for technology rather than innovation. In case of TC-index, the specific factors are more influencing innovation in developing nations like patent, internet and computer and foreign direct investment were taken into consideration along with science and engineering and education. Hence the new index reflects the accurate measurement of innovation.

The new measure of innovation was estimated for 61 developing countries around the world observed during 2003-2008. The highest growth rate of innovation was noticed in China followed by Estonia and Malaysia among the developing nations under study. The lowest innovation rate was reported in Iran, Bangladesh, Tadzhikistan and Cambodia.

The differences existed in the ranking of some nations like China when we compare HDI and TC-index values. This is due to the summation of several general factors or indicators for estimating HDI where specific indicators of innovation were considered in computation of the TC-index. Since the TC-index proved to be a better measurement tool for innovation in developing countries which can also be used for estimating the innovation rate in other developing nations. Based on the results, a number of recommendations are to be made. These are aimed to enhancing the rate of innovation, competitiveness and development in these nations. The bulk of policy recommendations include the followings:

First, the specific indicators which determine the rate of innovation more accurately like the number of computers, number of internet users, local availability of specialized training and resources, science and technology, scientific journal, number of patents, foreign direct investment inflows have to be better reflected and focused on well in the national policy of all the developing nations. The combination should be determined by the initial condition of the individual nations.

Second, the emphasis must be paid to allocate significant share or proportion of their annual budgets towards the science education, gross enrollment rate and internet connectivity. These factors enhances technological capability and facilitates the faster rate of innovation in developing nations by identifying and accessing for their local needs and ability adaptable foreign technology and technology information.

Third, the policy of national awards for the scientists and technicians who make sound breakthroughs in science and technology be established. This will be useful in promoting researchers and technicians to get motivated and encouraged to do more research for generating innovative technologies in developing countries. Fourth, the international relations with other nations must be bettered in the social, economic, cultural and scientific spheres. All of the spheres are quite interrelated and correlated in affecting the fate of the foreign direct investments flowing in to the domestic educational sector.

Fifth, the efforts must be made sincerely towards the modification of school curriculum and syllabus so that higher emphasis is given to the creativity and spontaneity of the children and problem solving exercises. This would make impeccable effect on the mindset of the children who may opt for the field of research in future which in turn would certainly lead to higher rate of innovation.

Sixth, the companies or corporate houses must be encouraged in the form of relaxation of considerable portion of corporate taxes for developing an innovative way of product and production processes which are environmentally friendly and economically viable. The firms who come up with most innovative production processes may be given a tax holiday incentive for specific period so that other companies would also be motivated to develop new practices.

Finally, the special focus must be given to the encouragement of local organizations to conduct the specialized training programs to promote innovation activities, innovation cooperation within and between public and private organizations and their foreign collaborators in R&D activities.

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Appendix

Table A.1. Comparison of existing measurement devices of technology and innovation.

No	Existing measurement index	Developed by	Methodology used	Advantages	Disadvantages	No. of countries
1	Technology index	WEF(2003) [8]	Innovation sub index was computed based on patents at USPTO, survey data and tertiary enrolment	Assessment of technological advancement	Measurement of innovation as part of technology development is meager	75
2	Technology Achievement index	UNDP(2001) [9]	Technology creation was assessed through national patents and payment of royalty	Assessment of technological advancement	Measurement of innovation as part of technology development is meager	72
3	Industrial development score board	RAND Corporation (2001) [11]	Technology creation was assessed through patents at USPTO, international scientific journal articles and allocation towards scientific research and development	Focus on industrial development	Not much emphasis on science and technology	87
4	Science and technology capacity index	UNIDO(2002) [10]	Technology index was computed based on patents at USPTO and enterprises financed Research & Development	Focus on science and technology development	Not much emphasis on innovation	76
5	ArCo	Archibugi and Coco (2004) [6]	Technology creation was assessed through patents at USPTO and international scientific journal articles	Focus on technology and industrial development	Not much emphasis on innovation	162

6	i-AFIEFL	Crosta and Prieto (2009) [32]	i-AFIEFL methodology Innovative Approaches for full inclusion in e-learning	Focus on sociological innovation, technological innovation and service customization	Only applicable for e-learning only	3
7	Conceptual framework for innovation	Aubert (2004) [31]	Developed conceptual framework based on problems of diffusion of innovation in developing countries	Focus on identification of problems for innovation in developing nations and development of effective strategies and conceptual framework	Science and technology role in innovation was not specifically studied. More generalized approach	>15
8	Innovation in government organizations, public sector agencies and public sector NGOs	NESTA (2008) [16]	National Endowment for Science and Technology and Arts followed methodology for computing innovation index in public sector agencies which is composed of 54 indicators belonging to 10 different dimensions	Innovation index was developed for government organizations and identified both invention based and diffusion based innovations in public sector	Focus on public sector enterprises only Lacks application for private organizations	>12
9	TC-Index	Khayyat and Lee(2009)	Estimated by taking in to consideration of five principles i.e. patent and journal index, science and education index), FDI index, researcher and technician index and computer and internet.	Takes in to consideration of most specific parameters or factors affecting the process of innovation and technology compared to any existing method of measuring innovation.	The computation of FDII and II may not reflect the status of innovation in some nations where their practice is not common.	61

Source: Author’s Collection

Table A.2. The indicators of TC-index and data sources.

No.	Label	Indicator	Source
1	X1	Patents Granted by USPTO / Mil. People, avg 2003-2007	(USPTO)
2	X2	Patents Granted by USPTO, avg 2003-2007	(USPTO)
3	X3	Intertiol Internet Bandwidth (bits per person), 2007	
4	X4	Intellectual Property Protection (1-7), 2008	
5	X5	Foreign direct investment, net inflows (BoP, current US$)	UNCTAD
6	X6	Public Spending on Education as % of GDP, 2007	DDP
7	X7	Availability of e-Government Services (1-7), 2008	
8	X8	Internet Users per 1000 People, 2007	ITU
9	X9	Internet Access in Schools (1-7), 2008	UNESCO
0	X10	Human Development Index, 2005	UNDP Human Development Report 2007/2008
1	X11	Quality of Science and Math Education (1-7), 2008	
2	X12	S&E Journal Articles / Mil. People, 2005	DDP
3	X13	GDP per Capita (in/l current $ PPP), 2007	DDP World bank and OECD national account data
4	X14	Computers per 1000 People, 2007	ITU
5	X15	Local availability of specialized research and training services(1-7), 2008	
6	X16	Average number of citations per S&E article, 2005	Special tabulations: Average number of citations per S&E article, 2005 Citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI).
17	X17	Adult Literacy Rate (% age 15 and above), 2007	DDP
18	X18	Gross Secondary Enrollment rate, 2007	UNESCO
19	X19	Exports of Goods and Services as % of GDP, 2007	
20	X20	High-Tech Exports as % of Manuf. Exports, 2007	
21	X21	Mobile Phones per 1000 People, 2007	
22	X22	Total Telephones per 1000 People, 2007	
23	X23	Internet users (per 100 people)	ITU
24	X24	Mobile cellular subscriptions (per 100 people)	
25	X25	S&E Journal Articles, 2005	
26	X26	S&E articles with foreign co-authorship (%), 2005	
27	X27	FDI Inflows as % of GDP, 2003-07	UNCTAD
28	X28	FDI Outflows as % of GDP, 2003-07	UNCTAD

Table A.3. Eigenvalues of the correlation matrix (weighted parameters).

Principles	Eigen value	Difference	Proportion	Cumulative
1	8.762	0.183	0.312	0.312
2	8.578	6.767	0.306	0.619
3	1.811	0.152	0.064	0.684
4	1.658	0.344	0.059	0.743
5	1.313	0.225	0.046	0.790
6	1.088	0.200	0.038	0.829
7	0.887		0.031	0.860

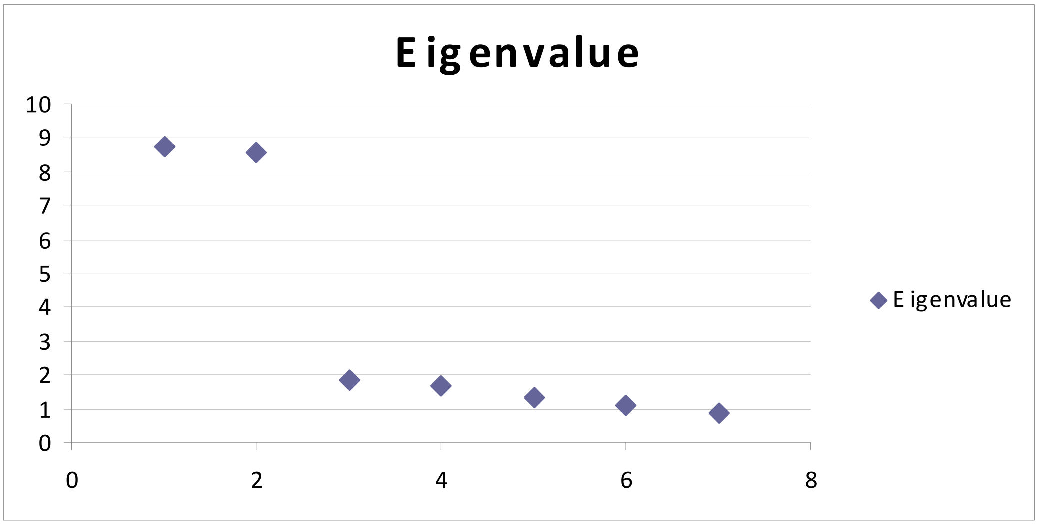

Figure A.1. Eigenvalue scree plot.

Table A.4. Principal component analysis, eigenvectors.

Indicators	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	Comp 7
x1	-0.016	0.248	-0.038	0.130	0.429	0.014	-0.079
x2	0.296	0.042	-0.247	0.054	0.062	-0.019	0.077
x3	-0.032	0.164	0.174	-0.162	-0.104	0.548	0.509
x4	0.021	0.223	-0.056	0.383	-0.298	0.055	-0.094
x5	0.317	0.053	-0.090	-0.028	0.030	-0.023	0.073
x6	-0.094	-0.008	-0.029	0.180	0.238	0.598	-0.426
x7	-0.084	0.185	-0.200	0.255	-0.251	0.116	0.385
x8	-0.072	0.292	0.056	-0.152	0.179	0.128	0.079
x9	0.052	0.281	-0.044	0.271	-0.167	-0.039	0.041
x10	0.333	0.029	0.086	-0.012	0.001	-0.007	-0.017
x11	0.040	0.171	-0.053	0.469	-0.205	-0.033	-0.216
x12	-0.043	0.250	-0.105	-0.123	0.042	0.233	-0.188
x13	-0.068	0.245	0.033	-0.194	-0.095	-0.212	-0.322
x14	-0.051	0.281	0.082	-0.077	0.222	-0.005	-0.140
x15	0.334	0.028	0.086	-0.011	0.000	-0.005	-0.018
x16	0.333	0.027	0.091	-0.009	0.006	0.012	0.009
x17	-0.195	0.142	0.040	-0.144	0.136	-0.242	0.151
x18	0.321	0.075	0.079	-0.056	0.009	-0.058	0.001
x19	-0.117	0.191	0.275	0.173	0.007	-0.152	-0.012
X20	-0.033	0.088	-0.013	0.384	0.566	-0.248	0.320
X21	-0.101	0.284	0.036	-0.151	-0.190	-0.130	0.037
X22	-0.102	0.292	0.024	-0.186	-0.122	-0.132	0.019
X23	0.190	0.249	0.113	-0.090	0.164	0.141	0.050
X24	0.024	0.314	0.061	-0.105	-0.088	-0.022	-0.034
X25	0.017	0.028	-0.678	-0.091	0.053	0.028	0.132
X26	-0.086	-0.162	0.476	0.218	-0.030	0.061	0.151
X27	0.332	0.034	0.095	-0.008	-0.009	0.001	-0.009
X28	0.333	0.030	0.089	-0.011	-0.002	0.000	-0.012

Table A.5. TC-index and its principal components compared with HDI.

TC-index Rank	Country	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	TC-Index	HDI
1	China	7.585	0.621	0.890	-0.109	0.001	-0.039	3.192	12.465
2	Estonia	-0.431	3.484	0.341	0.186	0.400	2.540	1.252	14.726
3	Malaysia	-0.217	2.001	0.110	2.828	3.149	-0.675	1.027	12.128
4	Lithuania	-0.339	1.902	0.276	-0.075	-0.428	0.373	0.566	11.194
5	UAE	-0.480	2.500	0.876	-0.597	-2.095	-2.023	0.563	12.055
6	Croatia	-0.261	1.707	-0.332	-0.414	0.817	0.701	0.536	10.410
7	Latvia	-0.161	1.180	1.259	-0.915	1.171	0.146	0.478	9.569
8	Costa Rica	-0.233	0.553	0.527	1.764	3.393	-0.558	0.468	9.066
9	Jamaica	-0.200	0.901	1.108	-1.469	-0.510	3.345	0.313	9.087
10	Kuwait	-0.327	1.369	0.398	-1.331	0.321	-0.915	0.297	9.421
11	Thailand	-0.212	0.723	-0.088	1.234	-0.173	-1.273	0.213	8.882
12	Chile	-0.170	0.920	-0.355	-0.249	-0.444	0.212	0.203	8.850
13	Tunisia	-0.167	0.475	-0.325	1.661	-1.298	0.650	0.148	7.911
14	Saudi Arabia	-0.319	0.832	-0.159	-0.034	-0.761	0.042	0.121	8.451
15	Mauritius	-0.202	0.455	0.527	0.469	-0.481	-0.492	0.121	7.858
16	Panama	-0.341	0.476	1.532	-0.348	-1.406	1.843	0.119	8.663
17	South Africa	-0.023	0.432	-1.064	0.050	0.166	0.024	0.076	7.807
18	Mexico	0.112	0.286	-1.347	-0.457	1.054	-0.183	0.061	7.721
19	Philippines	-0.155	-0.189	0.219	1.486	1.775	-1.779	0.046	7.045
20	Uruguay	-0.195	0.421	0.118	-0.346	-0.528	-0.310	0.021	7.697
21	Jordan	-0.054	0.415	-0.030	0.365	-1.555	-1.465	0.014	7.077
22	Ukraine	-0.157	0.481	-0.454	-0.301	-0.542	-0.457	0.009	7.984
23	Brazil	0.152	0.455	-2.987	-0.747	0.835	0.541	-0.006	8.208
24	Oman	-0.240	0.510	-0.056	0.445	-1.828	-0.652	-0.008	7.628
25	Argentina	-0.142	0.477	-0.863	-1.208	0.399	-0.079	-0.018	7.837
26	Morocco	-0.048	-0.224	-0.014	0.571	-0.240	0.776	-0.048	6.323
27	Colombia	-0.073	0.061	-0.117	-0.154	-0.473	0.175	-0.049	7.137
28	Kazakhstan	-0.220	0.035	-0.018	0.685	-0.261	-1.486	-0.087	6.978
29	Mongolia	-0.199	-0.549	1.067	0.469	0.681	-0.204	-0.121	6.290
30	Vietnam	-0.131	-0.317	0.860	0.376	-0.487	-1.058	-0.132	6.215
31	Turkey	0.013	0.456	-2.580	-1.102	-0.663	0.154	-0.154	7.351

32	Georgia	-0.121	-0.252	-0.011	0.053	-0.051	-0.651	-0.160	6.136
33	Venezuela	-0.196	0.000	-0.044	-1.116	0.136	-0.423	-0.166	6.667
34	Indonesia	-0.015	-0.560	0.135	1.006	-0.349	-0.648	-0.167	5.993
35	Senegal	0.011	-0.729	-0.075	1.535	-0.957	0.942	-0.181	5.268
36	Peru	-0.132	-0.349	0.530	-0.927	0.098	0.125	-0.192	6.203
37	Botswana	-0.222	-0.391	0.213	0.136	-0.286	0.641	-0.196	6.126
38	Kyrgyz	-0.157	-0.619	0.530	0.244	0.189	0.203	-0.206	5.780
39	Lesotho	-0.301	-1.015	0.694	1.129	0.619	2.513	-0.226	5.730
40	El Salvador	-0.212	-0.317	0.387	-0.330	-0.641	-0.548	-0.245	6.336
41	India	0.580	-0.323	-4.907	0.901	-0.355	0.034	-0.249	6.446
42	Kenya	-0.118	-0.864	0.055	0.862	0.076	1.026	-0.254	5.348
43	Ecuador	-0.199	-0.359	0.856	-0.914	-0.063	-1.610	-0.260	6.160
44	Egypt	0.041	-0.435	-0.930	-0.438	-0.370	0.308	-0.263	5.217
45	Armenia	-0.046	-0.687	-0.089	-0.405	0.475	-0.316	-0.287	4.988
46	Guatemala	-0.134	-0.611	0.292	-0.054	-0.629	-0.090	-0.294	5.636
47	Burkina Faso	0.054	-1.270	0.060	1.180	-0.189	1.095	-0.326	4.191
48	Bolivia	-0.213	-0.913	0.745	-0.339	0.667	0.319	-0.328	5.407
49	Paraguay	-0.309	-0.647	0.985	-0.852	0.406	-0.554	-0.330	5.896
50	Algeria	-0.072	-0.463	0.312	-0.981	-0.711	-1.612	-0.338	5.270
51	Pakistan	0.095	-0.773	-0.768	-0.146	-0.584	0.132	-0.349	4.177
52	Nicaragua	-0.122	-0.962	0.618	-0.137	-0.040	-0.234	-0.367	5.007
53	Uganda	-0.096	-1.142	-0.017	0.418	0.435	0.504	-0.381	4.513
54	Cameroon	-0.043	-1.049	0.018	0.290	-0.221	0.235	-0.381	4.405
55	Ethiopia	0.092	-1.350	-0.083	0.673	-0.189	1.118	-0.388	3.713
56	Madagascar	-0.034	-1.161	0.334	0.546	-0.350	0.003	-0.390	4.338
57	Mozambique	-0.006	-1.242	0.171	0.143	0.091	0.733	-0.401	3.874
58	Cambodia	-0.101	-1.112	0.796	-0.036	-0.160	-0.665	-0.413	4.377
59	Tajikistan	-0.087	-0.870	-0.092	-0.407	-0.219	-0.460	-0.415	4.582
60	Bangladesh	0.040	-1.394	0.229	-0.652	0.200	0.077	-0.507	3.455
61	Iran	-0.140	-0.986	-0.264	-4.116	2.981	-0.068	-0.560	3.930

Table A.6. Summary statistics of the indicators.

Indicators	Mean	Median	Std Dev	Minimum	Maximum
x1	0.569	0.180	0.951	0	4.320
x2	32.587	1.800	113.211	0	758.200
x3	1384.639	164.000	3511.686	0	19151
x4	3.269	3.200	0.888	0	5.300
x5	3790894184	84740000	10582114696	-238620000	79126730000
x6	4.131	4.000	2.077	0	13.000
x7	3.477	3.480	1.178	0	6.600
x8	185.705	130.000	162.367	0	640.000
x9	3.125	3.200	1.028	0	6.400
x10	3.329	0.760	20.394	0.370	160.000
x11	3.602	3.700	0.967	0	5.600
x12	33.140	13.360	53.823	0.39	326.090
x13	8815.702	6079.000	9547.312	4.800	53212
x14	88.556	70.000	95.703	0	520.000
x15	91.916	3.800	688.745	0	5383.000
x16	2.172	1.200	7.541	0.180	60.000
x17	82.465	90.300	19.725	4.500	99.790
x18	86.662	83.500	112.024	15.510	926.480
x19	40.934	36.000	21.443	0	110.000
X20	7.262	4.000	11.266	0	54.000
X21	632.812	630.000	393.300	1.500	1770.000
X22	770.656	760.000	470.251	0	2090.000
X23	14.552	10.514	16.405	0.219	93.310
X24	39.786	35.637	29.648	0.550	127.506
X25	991.533	179.890	2467.867	0.770	14622.260
X26	65.971	65.660	21.023	18.640	100.000
X27	10.880	3.670	53.333	0.180	420.000
X28	12.222	0.200	89.551	-0.210	700.000

See Table A.2. for glossaries of the indicators.

Table A.8. Summary statistics for TC-index and its sub-index components.

Variable	No. of Obs.	Median	Std Dev	Minimum	Maximum
Comp 1	61	-0.140	1	-0.480	7.585
Comp 2	61	-0.252	1	-1.394	3.484
Comp 3	61	0.110	1	-4.907	1.532
Comp 4	61	-0.054	1	-4.116	2.828
Comp 5	61	-0.189	1	-2.095	3.393
Comp 6	61	0.003	1	-2.023	3.345
TC-index	61	-0.154	0.544	-0.560	3.192

Table A.9. Pearson correlation coefficient for the TC-index and its sub-indices.

	Comp 1	Comp 2	Comp 3	Comp 4	Comp 5	Comp 6	TC-index
Comp 1	1						
Comp 2	0	1					
Comp 3	0	0	1				
Comp 4	0	0	0	1			
Comp 5	0	0	0	0	1		
Comp 6	0	0	0	0	0	1	
TC-index	0.738	0.6696	0.1495	0.1346	0.1095	0.0601	1

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