Do Human Capital Investment and Technological Innovation Have a Permanent Effect on Population Health? An Asymmetric Analysis of BRICS Economies

Gang-Gao Hu and Li-Peng Yao

1 Business School of Ningbo University, Ningbo, China, 2 Ningbo College of Health Sciences, Ningbo, China

This study examines the asymmetric impact of human capital investment, and technological innovation on population health from the years spanning from 1991 to 2019, by using a panel of the BRICS countries. For this purpose, we have employed the PMG panel NARDL approach, which captures the long-run and short-run dynamics of the concerned variables. The empirical results show that human capital investment and technological innovation indeed happen to exert asymmetric effects on the dynamics of health in BRICS countries. Findings also reveal that increased human capital investment and technological innovation have positive effects on health, while the deceased human capital investment and technological innovation tend to have negative effects on population health in the long run. Based on these revelations, some policy recommendations have been proposed for BRICS economies.

Keywords: BRICS, human capital, NARDL, population health, PMG panel, technological innovation

INTRODUCTION

In its true essence, the demand theory suggests that consumers are used to ranking different mixtures of goods and services that they typically purchase on the basis of their individual utility function. According to this theory, consumers purchase those combinations of goods and services that increase their utility to the highest level, by optimally utilizing their income. Therefore, it can be affirmed that this theory is suitable for predicting the consumers’ demand for goods and services. However, the demand function in medical economics puts forth the argument that when consumers acquire medical treatment or services, they actually expect and subsequently demand better to good health conditions and not only the services that are being provided. According to Bentham (1), the feeling and emotion of pain was included as one of the fifteen “simple pleasures” in a person’s utility function, as early as the year 1789.

Positive investment in education is one of the primary sources of development of human capital for any nation. Education is defined as human capital primarily because it develops the productive capacity and increases the skill level of the people (2, 3). Researchers have suggested that formal education promotes and modifies the general skills and abilities of the people, rather than focusing on a specific purpose. When a person attains formal education, this process helps them in acquiring the mind-set that makes them much psychologically stronger in tough situations, and helps them solve problems that come in their way in a more informed and calculated manner. Among these
problems, some are related to productivity, which is the main
disciplinary focus of proprietors and economists. Some of these
problems are related to basic personal needs, and one such critical
need is health and healthcare (2, 3).

Education is a primary source of developing the real expertise
of an individual, their capabilities, and skills, and is known as
the most basic proxy that can be considered to calculate human
capital. Hence, theory suggests that an enhanced level of human
capital will lead to better health conditions, mainly because the
advancement in human capital will alter the lifestyle of humans
by changing their habits, mind-sets, skills, abilities, training, etc. Moreover, along with the development and enhancement
of education, people's realization about better health conditions
also tends to increase. Furthermore, education not only helps
to make people aware of different health issues, but also serves as
a means through which better health standards can be achieved
(4). Through superior training courses that are focused toward
enhancing the knowledge and skills attained by doctors and
medical staff, the general health conditions of people can be
improved, and this can effectively be attained by investing heavily
in health-related infrastructures.

The empirical literature available on the education-health
nexus also suggests that education is the main driver of improved
health conditions. In addition to this, education in various
different fields of study, on one side, improves the physical
working and individual health of the people of all ages and at the
same time also helps to decrease the rate of sickness, incapacity,
and death that are related to aging and other related factors (5–
9). Moreover, studies pertaining to researchers such as Wilkinson
and Spurlock (10), and Doornbos and Kromhout (11) actively
argue that it is education that exerts a positive impact on health
and healthcare related disciplines, and it is essentially not health
that improves the level of education in people.

Among the other aspects of human capital that can be
taken under consideration, the most significant ones pertain to
the spending on research and development, and technological
innovations (12). These two areas of study are increasingly
becoming popular, especially in their role in collecting empirical
evidence based on the impact of human capital, on all sectors of
the economy. Investment in research and development has done
wonders in emerging economies and is actively considered as a
key driver of economic growth (13–17). Eventually, this increased
investment in research and development will lead the nations
toward technological innovations that can affect the economy
through various channels. In this regard, we can dwell a little
deeper into these effects. Firstly, it will improve the competitive
position of the country in the global market and will lead to a
boost in the exports of a country. Secondly, innovations will help
countries to develop more advanced financial systems. Thirdly,
the overall infrastructure of the countries will improve, and as
a result, people will enjoy higher standards of life and living
(18). Similarly, more spending on research and development will
help in creating sophisticated infrastructure that can be directly
proportional to the enhancement of health care services i.e.,
hospitals, testing laboratories, medical equipment, and medicines
etc. In addition to this, investment in research and development
initiatives provides the society with better trained and highly
qualified doctors and paramedical staff, who will eventually prove
to be catalysts in improving the health standards of the people
that they treat (19, 20).

The investment in human capital (education, research and
development, and technological innovations) can also affect
the health status of people, albeit through an indirect channel i.e.,
environment. However, though, as the investment in human
capital spurs economic activity, this can also harm the quality of
the environment (21, 22), which will deteriorate the health status
of the general public as well. Contrariwise, human capital can
also improve the environmental quality of society through better
and more sophisticated techniques of production, efficient use of
energy, increased use of environmentally friendly products, and
creating awareness about the greener and cleaner environment
(23). Several studies show that a cleaner and greener environment
certainly tends to have a positive impact on people's health—be it
physical, emotional or psychological in nature (24, 25).

In this study, our basic goal is to analyze whether the
investment in human capital actually matters when it comes
to the health condition of the people belonging to BRICS
(Brazil, Russia, India, China, South Africa) economies. It must be
noted that the BRICS economies are among the fastest-growing
economies of the world, and are home to about 3.2 billion people
of the world. It must also be noticed that the collective GDP of
these economies is about 20.81 trillion US$. Hence, it is safe
to affirm that these economies are capable of serving as an ideal
case study, in order to analyse the impact of investment in
human capital, on the health status of the people. This study
is more important because average life expectancy in BRICS
stands a fraction below the average of global (26). The BRICS
economies are facing a lot of challenges in achieving sustainable
development goals.

Few empirical studies identifying the important factors of
BRICS health outcomes, such as health spending (27, 28);
health system (29); health care financing (30, 31); GDP (26);
none of these studies examined the impact of human capital
investment and technological innovation on BRICS health
outcomes. Previous literature assumed the linear impact of
health expenditure on health efficiency. These previous studies
cannot assess the impact of technological and human capital
shocks on health outcomes. For this purpose, we used the panel
non-linear ARDL-PMG method of estimation for analysis. This
methodology is easily captured the positive and negative shocks
of technology and human capital investment on health outcomes.

To the best of our knowledge, this is the first-ever study
that has included three different aspects of human capital, i.e.,
education expenditures, research and development expenditures
(R&D), and technological innovations. Moreover, this study
also aims to successfully perform a comparative analysis of
these indicators on the health condition of the people living
in BRICS countries. More importantly, the analysis is based
on the non-linear ARDL model, which has the benefit of
providing information regarding whether the health status
of people in these economies responds to the variables of
human capital symmetrically, or asymmetrically. Furthermore,
the results of this study have not suffered from the problem of
aggregation bias. The findings of this study are supportive for
academicians, development practitioners, health institutions, and international organizations.

This study is comprised of various sections. Section two of the study writes the model and discusses the methodology of the paper in detail. Moreover, in section three, we have elaborated upon the results, while the study is concluded in the fourth section of the paper.

MODEL AND METHODS

By analyzing the extant literature in-depth, in order to capture the impact of human capital on the life expectancy of the people living in the BRICS economies, we have borrowed the following model:

$$\text{Life expectancy}_it = \varphi_0 + \varphi_1EE_{it} + \varphi_2TI_{it} + \varphi_3X_{it} + \varepsilon_{it} \quad (1)$$

In the above model (1), the life expectancy in BRICS economies depends on the education expenditure (EE), technological innovation (TI), and a set of control variables (GDP, education, internet) as denoted by the symbol X. The methodology adopted in this study is the linear and non-linear panel ARDL-PMG. However, the asymmetric version is the extension of the linear model, hence; we have initiated our discussion from the linear ARDL-PMG model. Therefore, the relationship described in Equation (1) will go on a temporal route before attaining a long-run equilibrium route. Hence, Equation (1) needs to be stated in the form of the ARDL model, as suggested by (32–34).

$$\text{Life expectancy}_it = \omega_0 + \sum_{k=1}^{n} \beta_{1k}\text{Life expectancy}_{i,t-k}$$

$$+ \sum_{k=0}^{n} \beta_{2k}\Delta EE_{i,t-k} + \sum_{k=0}^{n} \beta_{3k}\Delta TI_{i,t-k}$$

$$+ \sum_{k=0}^{n} \beta_{4k}\Delta X_{i,t-k} + \omega_1\text{Life expectancy}_{i,t-1}$$

$$+ \omega_2\Delta EE_{i,t-1} + \omega_3\Delta TI_{i,t-1} + \omega_4\Delta X_{i,t-1} + \varepsilon_{it} \quad (2)$$

Equation (2) is formerly known as the ARDL model of (32–34). In this model, the estimated attached to first difference operator, i.e., A, represent the short-run results, whereas, the long-run results are signified by the coefficient estimates of $\omega_2 - \omega_4$, normalized on $\omega_1$. In this regard, in order to prove that our long-run results are valid, we need to prove the co-integration among the long-run estimates. To that end, the error correction term ($ECT_{-1}$) has been developed by using the estimates from Equation (1), and the estimate of $ECT_{-1}$ should be negative and significant in nature. Moreover, most of the macroeconomic variables have become stationary after differencing only once, hence, the leading benefit of applying this methodology is that it capable of performing well, even if the variables are I(0), I(1), or a mixture of both.

The basic aim of this study is to observe the asymmetric impact of the variables of human capital, on the life expectancy in BRICS countries. Therefore, we needed to divide the variables of our interest i.e., education expenditure (EE) and technological innovation (TI), into their positive ($EE^+_{it}$, $TI^+_{it}$) and negative ($EE^-_{it}$, $TI^-_{it}$) parts, by using the partial sum technique as proposed by Shin et al. (35). This has been presented below as:

$$EE^+_{it} = \sum_{n=1}^{t} \Delta EE^+_{i,t} = \sum_{n=1}^{t} \max (\Delta EE^+_{i,t}, 0) \quad (3a)$$

$$EE^-_{it} = \sum_{n=1}^{t} \Delta EE^-_{i,t} = \sum_{n=1}^{t} \min (\Delta EE^-_{i,t}, 0) \quad (3b)$$

$$TI^+_{it} = \sum_{n=1}^{t} \Delta TI^+_{i,t} = \sum_{n=1}^{t} \max (\Delta TI^+_{i,t}, 0) \quad (3c)$$

$$TI^-_{it} = \sum_{n=1}^{t} \Delta TI^-_{i,t} = \sum_{n=1}^{t} \min (\Delta TI^-_{i,t}, 0) \quad (3d)$$

In the above equations the functions, $EE^+_{it}$ and $TI^+_{it}$, signify the positive changes or shocks, whereas, the functions $EE^-_{it}$ and $TI^-_{it}$ signify the negative changes or shocks. After breaking down the respective variables, the next step was to substitute these partial sum variables in the space of the original variables that were mentioned in Equation (2). When the substation takes place, the new equation tends to look like as shown below:

$$\Delta \text{Life expectancy}_it$$

$$= \alpha_0 + \sum_{k=1}^{n} \beta_{1k}\Delta \text{Life expectancy}_{2,t-k}$$

$$+ \sum_{k=0}^{n} \beta_{2k}\Delta EE_{i,t-k} + \sum_{k=0}^{n} \beta_{3k}\Delta TI_{i,t-k}$$

$$+ \sum_{k=0}^{n} \beta_{4k}\Delta X_{i,t-k} + \omega_1\text{Life expectancy}_{i,t-1}$$

$$+ \omega_2\Delta EE_{i,t-1} + \omega_3\Delta TI_{i,t-1} + \omega_4\Delta X_{i,t-1} + \varepsilon_{it} \quad (4)$$

This shows that Equation (4) has now transformed into a non-linear panel ARDL-PMG. It is noteworthy that the estimation procedure of this equation is the same as the linear model. Moreover, the same test of co-integration is applicable in the non-linear panel ARDL-PMG, as this is an extension of the linear ARDL. However, this model provides us the luxury of detecting the impact of positive and negative shocks, separately, on the dependent variable as well. In this regard, the questions pertaining to the non-asymmetric and asymmetric causality between human capital investments, technological innovation, and population health are also addressed in this study, primarily by using the teachings of Dumitrescu and Hurlin (36), and Hatemi-j (37) panel causality tests.

DATA

The analysis for this study has been conducted exclusively for BRICS economies that pertain to Brazil, Russia, India, China, and...
and South Africa, and cover the data collection period from 1991 to 2019. The dataset of all variables has been collected from the World Development Indicators (WDI) that are compiled and updated by the World Bank. Moreover, life expectancy has been considered as a dependent variable, while government education expenditure (EE), and technology innovation (TI), as a proxy of patent applicants, are considered to be the independent variables. In addition to this, the GDP per capita (GDP), the average year of schooling (education), and the number of users of the internet (Internet) have been considered as the control variables in the analysis. Moving on, the transformed technology innovation and GDP data have been considered in terms of the natural logarithm. In Table 1, the mean values of the life expectancy, EE, TI, GDP, education, and internet users are 67.2 years, 4.35%, 8.95, 8.39$, 12.3 years, and 20.2%, respectively, while the standard deviations are 5.93 years, 1.52%, 1.93%, 0.93$, 2.06 years, and 23.5%, respectively.

**RESULTS AND DISCUSSION**

Before applying any regression techniques, it was necessary to test the stationarity properties of the considered data. For this purpose, the study has used the Levin–Lin–Chu (LLC) test, the Im–Pesaran–Shin (IPS) test, and the Fisher-ADF tests. The statistical outcomes of the LLC test, IPS test, and ADF test have been presented in Table 2. The findings of these tests show that only a few variables are level stationary, and while a few are stationary at the first difference. The study also opts for the ARDL and NARDL models, in order to investigate the symmetric and asymmetric nexus among the variables in the short-run and long-run, in the panel of BRICS countries. Moreover, Table 3 delivers the findings of the short-run and long-run estimates of the ARDL and NARDL models, along with the outcomes of various diagnostic tests.

The long-run findings of ARDL show that the government sector education expenditure tends to positively affect the life expectancy in BRICS economies. It also demonstrates that a 1% increase in government sector education expenditures results in increasing the life expectancy by 3.717% in these economies. In addition to this, GDP and education have a significant and positive impact on the life expectancy in BRICS economies, specifically in the long-run. It shows that due to a 1% upsurge in the GDP per capita and education, the life expectancy increases by 4.851 and 8.557% in the BRICS countries. However, it is noteworthy that technological innovation and the number of internet users have no effect on the level of life expectancy in BRICS economies, as shown by a statistically insignificant coefficient estimate of both variables. The short-run findings of ARDL show that technological innovation, GDP per capita, and internet users positively affect the life expectancy index in BRICS economies. However, the impact of the government sector education expenditure and education on the general life expectancy is statistically insignificant in the short-run. For diagnostic testing, a certain number of tests have also been applied. These include the log-likelihood test, LM test, F-test, and the ECM test. The significant coefficient estimate of the log likelihood test confirms the goodness of fit of model. Moreover, the statistically significant coefficient estimates of F-statistics and ECM confirm the existence of the long-run cointegration among the variables. Other than that, the ECM term holds a negative sign with a value 0.221, which states that almost 22% convergence toward the equilibrium level is likely to occur in period of one year. Moreover, the coefficient estimate of LM shows there is no issue of serial correlation in the data that has been taken into account.

The long-run outcomes of the NARDL show that the positive component of the government sector education expenditure has a significant and positive impact on the life expectancy in BRICS economies. It reveals that in response to a 1% increase in the positive component of the government sector education expenditure, life expectancy in BRICS economies increases up to 0.804%. On the other hand, the negative shocks in the government sector education expenditure result in decreasing life expectancy in BRICS economies in the long-run. In more precise terms, a 1% decrease in the negative component of the government sector education expenditure leads to a reduction in the life expectancy by 3.143% in the BRICS economies. The positive shocks in technological innovations tend to have a significant positive impact on the life expectancy in the long-run, which propagates that a 1% upsurge in technological innovation leads to a 2.608% increase in the life expectancy in the BRICS economies. Conversely, the negative shocks in technological innovation negatively affect the life expectancy, as a 1% decrease in the negative shocks in technological innovation result in a 1.168% reduction in the life expectancy in BRICS economies, specifically in the long-run.

These findings are also consistent with Oster et al. (38), who noted that human capital investment is one of the key inputs of health outcomes. The results revealed that human capital investment raises awareness and information about good health, in return, the human capital improves the level of life expectancy. Moreover, the human capital theory predicts a longer life expectancy, primarily because human capital is a key input of the health outcomes. In addition to this, these findings are also supported by Manton et al. (39), who noted that technology innovation is more responsive to health care efficiency. The average life expectancy of humans can increase with improvements in education, affordable housing, sanitation, and the effective advancements in medical treatments. In this context, it is observed that the progress in the technological sector permits everyone to improve his/her health individually, which helps in improving the life expectancy on an individual basis. In many countries, the level and percentage of life expectancy has reached up to seventy years and above. These significant gains are achieved due to better healthcare services and facilities, better nutrition, improved public health, and, most significantly, due to the application of technological innovations. The growth in technological innovations benefits longevity and healthy aging, primarily by empowering people to spend gratifying and healthier lives at all age groups. Technological innovations contribute in several ways when keeping people more physically active, and enabling them to spend an independent living style. For instance, by adopting smart home technology, the detection
and management of disease conditions at the initial stages, continuous involvements in the workforce, and maintaining social relations by dropping social isolation, etc., the contribution of technological innovations can be fathomed. In order to ensure the maximum benefits of technological innovations on longevity and aging, there is also a need to design such inclusive technologies that benefit every one of the direct and indirect stakeholders.

As far as the findings of the other control variables are concerned, all three variables (i.e., GDP, education, and internet) have a significant and positive impact on the life expectancy in BRICS economies, particularly in the long run. In this regard, due to a 1% increase in the GDP, education, and internet users, the life expectancy increases by 7.747, 1.804, and 0.075%, respectively, in the long run. The short-run outcomes of NARDL also show that only the positive component of technological innovation has a significant and positive impact on the life expectancy. In the case of the control variables that are taken into account, the GDP per capita and the internet users, positively and significantly, influence the life expectancy in BRICS economies.

Moving on, the findings of the diagnostic tests reveal that the log-likelihood test result is statistically significant, confirming the goodness of fit of the model. Moreover, the F-statistics and the ECM results are statistically significant, which confirms and validates the existence of the element of long-run cointegration among the considered variables. It must also be noted that the ECM term is observed to be negative, with a value of 0.423, which shows that an almost 42% convergence toward equilibrium will occur in a time span of 1 year. The coefficient estimate of the LM also confirms that there was issue of the serial correlation in the data. Other than this, the Wald test confirms the presence of an asymmetric relationship between the government sector education expenditures, technological innovation, and the life expectancy in BRICS economies in the long-run. However, the Wald test does not establish any asymmetry between these variables in the short run.

Table 4 reported the non-symmetric and asymmetric causality relationship among the concerned variables for BRICS economies. In this regard, the non-asymmetric causality analysis outcomes for BRICS indicate that there exists a bidirectional causality from the education expenditure to the life expectancy, and technology innovation to the life expectancy. However, the asymmetric causality test findings confirm the bidirectional causality relationship in the positive and negative shocks of the education expenditure, to the life expectancy for BRICS. These revelations imply that an increase and decrease in human capital investment is affected by life expectancy, and alternatively, an increase in life expectancy promotes an increase in human capital investment. Our findings also show evidence of bidirectional asymmetric Granger-causal relationship between technology innovation and life expectancy. The shocks of the technology innovation also seem to affect the life expectancy of the population of BRICS economies.

**CONCLUSION AND POLICY IMPLICATIONS**

The level of global life expectancy has widened by almost 20 years over the past five decades. In this context, researchers have actively been inspecting the key factors that determine the life expectancy and health performance indicators of nations. Thus, this study has been aimed toward identifying the asymmetric impact of human capital investment and technology innovation

**TABLE 1 | Variables definition and data descriptive.**

| Variables                      | Symbol     | Variables                                      | Mean   | Std. Dev. | Min   | Max   |
|--------------------------------|------------|------------------------------------------------|--------|-----------|-------|-------|
| Life expectancy at birth       | Life expectancy | Life expectancy at birth, total (years) | 67.2   | 5.93      | 53.4  | 76.9  |
| Education expenditure          | EE         | Government expenditure on education, total (% of GDP) | 4.35   | 1.52      | 1.44  | 8.59  |
| Technology innovation          | Ti         | Patent applications, residents                 | 8.95   | 1.93      | 4.93  | 14.1  |
| GDP per capita                 | GDP        | GDP per capita (constant 2010 US$)             | 8.39   | 0.93      | 6.36  | 9.39  |
| Year of schooling              | Education  | Average year of schooling                     | 12.3   | 2.06      | 7.70  | 15.6  |
| Internet users                 | Internet   | Individuals using the Internet (% of population) | 20.2   | 23.5      | 0.00  | 80.8  |

**TABLE 2 | Unit root tests.**

| Variables | LLC I(0) | LLC I(1) | IPS I(0) | IPS I(1) | ADF I(0) | ADF I(1) |
|-----------|----------|----------|----------|----------|----------|----------|
| Life expectancy | -4.825*** | l(0) | -3.654*** | l(0) | -3.434*** | l(0) |
| EE        | -0.340   | -1.925*  | l(1)     | -0.123   | -3.546*** | l(1) |
| Ti        | -3.086***| -2.121** | l(1)     | -1.044   | -5.740*** | l(1) |
| GDP       | -0.531   | -2.516***| l(1)     | -0.704   | -3.371*** | l(1) |
| Education | -1.082   | -3.516***| l(1)     | -0.678   | -3.617*** | l(1) |
| Internet  | -0.160   | -4.384***| l(1)     | -0.684   | -2.589*** | l(1) |

***p < 0.01, **p < 0.05, and *p < 0.1.
on the life expectancy in BRICS countries. This study also implements a panel non-linear autoregressive distributed lag (NARDL) model, in order to examine the long-run and short-run dynamics of human capital investment and technology innovation for the health outcomes that are taken into account. Other than that, the study also employs an asymmetric causality test in the context of the variables proposed by (37).

One of the primary purposes of this study was to examine the dynamic impact of human capital investment and technology innovation, on the health outcomes for BRICS countries from 1991 and 2019. The findings of the study revealed an asymmetric impact of human capital investment, and technology innovation on the health of individuals. However, we have found that a positive shock in human capital investment and technology innovation helps to increase life expectancy, while a negative shock in the human capital investment and technology innovation leads to a reduction in life expectancy. Most importantly, a positive technology innovation shock improves the life expectancy in the BRICS in short run. Furthermore, we also find that a negative shock in technology innovation has an insignificant impact on the life expectancy, in the short run. Findings also indicate that positive and negative education expenditure has insignificant short-run asymmetric effects on the life expectancy in BRICS. Moreover, the revelations of the asymmetric causality analysis for BRICS indicate that there exists a bidirectional asymmetric causality from education expenditure to life expectancy, and technology innovation to life expectancy.

When taking into consideration the implications of the study, it is suggested that the government should raise the level of public financing for the education and healthcare sector of the

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**TABLE 3** | Panel ARDL and NARDL PMG estimation.

| Variable | Coefficient | Std. error | t-Stat | Variable | Coefficient | Std. error | t-Stat |
|----------|-------------|------------|--------|----------|-------------|------------|--------|
| **Long run** | | | | EE | 3.717*** | 1.080 | 3.442 | EE_POS | 0.804*** | 0.101 | 7.964 |
| | | | | Ti | 0.836 | 0.730 | 1.146 | EE_NEG | 0.905*** | 0.101 | 8.942 |
| | | | | GDP | 4.851*** | 1.051 | 4.599 | Ti_POS | 2.608*** | 0.336 | 7.759 |
| | | | | Education | 8.557*** | 2.598 | 3.293 | Ti_NEG | −1.168 | 0.601 | 1.943 |
| | | | | Internet | 0.030 | 0.024 | 1.224 | GDP | 7.747*** | 0.524 | 14.78 |
| **Short run** | | | | D (EE) | −0.091 | 0.130 | 0.705 | D (EE_POS) | 0.014 | 0.049 | 0.283 |
| | | | | D [EE (−1)] | 0.007 | 0.062 | 0.116 | D [EE_POS (−1)] | 0.004 | 0.049 | 0.283 |
| | | | | D (Ti) | 0.259* | 0.155 | 1.671 | D (EE_NEG) | −0.665 | 0.708 | 0.940 |
| | | | | D [Ti (−1)] | 0.312 | 0.318 | 0.980 | D [EE_NEG (−1)] | 0.620 | 0.432 | 1.433 |
| | | | | D (GDP) | 0.399* | 0.224 | 1.781 | D [Ti_POS (−1)] | 0.530* | 0.311 | 1.709 |
| | | | | D [GDP (−1)] | 0.585 | 0.854 | 0.685 | D [Ti_POS (−1)] | 0.204 | 0.186 | 1.098 |
| | | | | D (Education) | −0.040 | 0.056 | 0.715 | D [Ti_NEG (−1)] | −0.636* | 0.365 | 1.744 |
| | | | | D [Education (−1)] | −0.125 | 0.082 | 1.525 | D (GDP) | 0.919* | 0.542 | 1.695 |
| | | | | D (Internet) | 0.008** | 0.004 | 2.000 | D [GDP (−1)] | −0.032 | 0.463 | 0.068 |
| | | | | D [Internet (−1)] | 0.004 | 0.003 | 1.166 | D (Education) | −0.186 | 0.234 | 0.793 |
| | | | | C | −0.339 | 1.414 | 0.240 | D [Education (−1)] | −0.065 | 0.041 | 1.608 |
| | | | | | | | | D (Internet) | 0.008*** | 0.003 | 2.666 |
| | | | | | | | | D [Internet (−1)] | 0.004 | 0.005 | 0.925 |
| | | | | | | | | C | 0.062 | 0.217 | 0.284 |

| Diagnostic | Log likelihood | 369.6*** | Log likelihood | 456.95*** |
|-----------|---------------|----------|---------------|-----------|
| LM | 1.458 | LM | 1.979 |
| F-test | 5.698*** | F-test | 6.988*** |
| ECM (−1) | −0.221 | 0.117 | 1.888 | ECM (−1) | −0.423* | 0.210 | 2.014 |
| Wald-EE-L | 5.988*** | Wald-EE-L | 1.326 |
| Wald-EE-S | 7.612*** | Wald-EE-S | 1.326 |
| Wald-Ti-L | 0.123 | Wald-Ti-L | 0.123 |

***p < 0.01, **p < 0.05, and *p < 0.1.
### TABLE 4 | Symmetric and asymmetric Granger causality.

| Null hypothesis | Symmetric | Asymmetric |
|-----------------|-----------|------------|
|                 | W-Stat.   | Zbar-Stat. | Prob. | W-Stat.   | Zbar-Stat. | Prob. |
| EE → Life expectancy | 25.88*** | 21.72 | 0.000 | EE_POS → Life expectancy | 20.07*** | 16.22 | 0.000 |
| Life expectancy → EE | 10.63*** | 7.758 | 0.000 | Life expectancy → EE_POS | 9.270*** | 6.425 | 0.000 |
| TI → Life expectancy | 8.840*** | 6.105 | 0.000 | EE_NEG → Life expectancy | 25.68*** | 21.33 | 0.000 |
| Life expectancy → TI | 4.505* | 2.119 | 0.034 | Life expectancy → EE_NEG | 5.371*** | 2.877 | 0.004 |
| GDP → Life expectancy | 42.64*** | 37.18 | 0.000 | TI_POS → Life expectancy | 23.81*** | 19.60 | 0.000 |
| Life expectancy → GDP | 5.702*** | 3.220 | 0.001 | Life expectancy → TI_POS | 4.227* | 1.835 | 0.067 |
| EDUCATION → Life expectancy | 31.60*** | 27.07 | 0.000 | TI_NEG → Life expectancy | 6.686*** | 4.073 | 0.000 |
| Life expectancy → EDUCATION | 7.277*** | 4.667 | 0.000 | Life expectancy → TI_NEG | 6.215*** | 3.644 | 0.000 |
| INTERNET → Life expectancy | 20.17*** | 16.57 | 0.000 | GDP → Life expectancy | 42.64*** | 37.18 | 0.000 |
| Life expectancy → INTERNET | 7.597*** | 4.962 | 0.000 | Life expectancy → GDP | 5.702*** | 3.220 | 0.001 |
| TI → EE | 6.795*** | 4.225 | 0.000 | EDUCATION → Life expectancy | 31.60*** | 27.03 | 0.000 |
| EE → TI | 7.125*** | 4.528 | 0.000 | Life expectancy → EDUCATION | 7.277*** | 4.667 | 0.000 |
| GDP → EE | 6.099*** | 3.585 | 0.000 | INTERNET → Life expectancy | 20.17*** | 16.52 | 0.000 |
| EE → GDP | 4.479** | 2.095 | 0.036 | Life expectancy → INTERNET | 7.597*** | 4.962 | 0.000 |
| EDUCATION → EE | 1.677 | 0.481 | 0.631 | EE_NEG → EE_POS | 3.086 | 0.797 | 0.426 |
| EE → EDUCATION | 5.819*** | 3.327 | 0.001 | EE_POS → EE_NEG | 7.544*** | 4.854 | 0.000 |
| INTERNET → EE | 3.457 | 1.156 | 0.248 | TI_POS → EE_POS | 5.048** | 2.582 | 0.010 |
| EE → INTERNET | 6.026*** | 3.517 | 0.000 | EE_POS → TI_POS | 4.871** | 2.421 | 0.016 |
| GDP → TI | 5.056*** | 2.626 | 0.009 | EE_NEG → EE_POS | 3.822 | 1.467 | 0.142 |
| TI → GDP | 2.694 | 0.454 | 0.650 | EE_POS → TI_NEG | 3.132 | 0.839 | 0.402 |
| EDUCATION → TI | 2.314 | 0.105 | 0.916 | GDP → EE_POS | 5.917*** | 3.373 | 0.001 |
| TI → EDUCATION | 4.525** | 2.138 | 0.033 | EE_POS → GDP | 5.190*** | 2.712 | 0.007 |
| INTERNET → TI | 1.704 | 0.456 | 0.649 | EDUCATION → _POS | 1.235 | 0.888 | 0.375 |
| TI → INTERNET | 7.010*** | 4.422 | 0.000 | EE_POS → EDUCATION | 4.748** | 2.308 | 0.021 |
| EDUCATION → GDP | 4.722** | 2.319 | 0.020 | INTERNET → EE_POS | 3.429 | 1.109 | 0.268 |
| GDP → EDUCATION | 6.192*** | 3.670 | 0.000 | EE_POS → INTERNET | 6.083*** | 3.525 | 0.000 |
| INTERNET → GDP | 1.681 | 0.477 | 0.634 | TI_POS → EE_NEG | 4.281* | 1.885 | 0.060 |
| GDP → INTERNET | 9.908*** | 7.086 | 0.000 | EE_NEG → TI_POS | 4.292* | 1.895 | 0.058 |
| INTERNET → cause EDUCATION | 5.212*** | 2.769 | 0.006 | TI_NEG → EE_NEG | 83.62*** | 75.79 | 0.000 |
| EDUCATION → INTERNET | 9.382*** | 6.603 | 0.000 | EE_NEG → TI_NEG | 8.716*** | 5.921 | 0.000 |
| GDP → EE_NEG | 2.988 | 0.708 | 0.479 | GDP → EE_NEG | 3.094 | 1.569 | 0.117 |
| EE_NEG → GDP | 2.257 | 0.042 | 0.968 | EDUCATION → EE_NEG | 2.818 | 0.553 | 0.580 |
| EE_NEG → EDUCATION | 1.468 | −0.676 | 0.499 | INTERNET → EE_NEG | 5.372*** | 2.876 | 0.004 |
| EE_NEG → INTERNET | 13.96*** | 10.65 | 0.000 | TI_NEG → TI_POS | 2.636 | 0.387 | 0.699 |
| GDP → TI_POS | 3.988 | 0.899 | 0.369 | GDP → TI_POS | 3.198 | 1.568 | 0.117 |
| TI_POS → GDP | 1.794 | −0.379 | 0.705 | EDUCATION → TI_POS | 5.376*** | 3.263 | 0.001 |
| TI_POS → EDUCATION | 1.712 | −0.453 | 0.650 | INTERNET → TI_POS | 6.475*** | 3.882 | 0.000 |
| GDP → TI_NEG | 3.649 | 1.310 | 0.190 | TI_NEG → GDP | 3.552 | 1.220 | 0.222 |
| TI_NEG → EDUCATION | 5.234*** | 2.752 | 0.006 | TI_NEG → EDUCATION | 1.759 | −0.411 | 0.681 |
| INTERNET → TI_NEG | 8.522*** | 5.744 | 0.000 |

(Continued)
economy. Moreover, the government should more allocate more public funds toward proper research and development. BRICS economies should ideally lay more emphasis on technological innovation in the healthcare sector. Other than that, the government should raise health awareness among people, through smart technology. Governments should also encourage innovation in the healthcare sector. Other than that, the economies should ideally lay more emphasis on technological development. In addition to this, the federal and local governments should promote a healthy lifestyle (exercise, diet, behavior) and protect and preserve the environment (air, soil, water), via social media and smart technology.

This study has certain limitations as well. Moreover, this study does not cover the health systems and physical environment of BRICS regions, which are equally important for health efficiency. Further work is called for, in order to examine the relationship between the health systems, physical environment, and the health status of women and men.

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**DATA AVAILABILITY STATEMENT**

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

**AUTHOR CONTRIBUTIONS**

L-PY: conceptualization, software, data curation, and writing—original draft preparation. G-GH: methodology, visualization, investigation, writing—reviewing, and editing. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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