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Technological innovation is considered as being one of the major driving forces in fostering economic growth. However, in the current economic situation, where matters related to environmental protection and conservation play a key role, technological innovation can also be used as a driver of new production alternatives to reduce the harmful impacts of industrial development on society and nature. Within this context, this paper aims to analyze, through econometric tools, the relationship between investments in technological innovation and the sustainable development of G7 and BRICS countries. The results demonstrate that for the BRICS group, technological innovation has been significant for the three pillars of sustainable development. However, for the G7 group, technological innovation was considered significant only for social development, showing no statistical significance for economic and environmental development. The results indicate that technological innovation can cause different types of impacts, depending on the development stage of the analyzed country or region.

Keywords: BRICS; economic growth; G7; sustainable development; technological innovation

1. Introduction

The economic growth of many countries is often accompanied by the excessive use of natural resources, and the negative environmental and social impacts that derive from it. This paper defends the view that economic growth, albeit very important, should not be regarded as the prime parameter for development, and that environmental considerations should be part of the equation.

For some time, technological innovation has been viewed as a guaranteed means to achieve economic growth. However, in the current context of high economic growth with little regard to environmental issues, technological innovation should not be used only as a means to further accelerate production and spur economic growth. Primarily, technological innovation should be a driver of new production alternatives, especially those which have a lesser impact on nature and which allows countries to continue producing without posing a threat to the planet.

1.1. Research question and hypotheses

There is an important research question that directly relates to the scope of this investigation, formulated as follows: Can technological innovation bring sustainable development to a nation, in its three dimensions?

As a result of the extensive analysis of the literature performed in the preparation of this paper, in order to try to answer this question, two distinct hypotheses were formulated as part of this research:

(1) Technological innovations partially promote sustainable development;
(2) Technological innovations promote sustainable development in its three dimensions: economic, social and environmental.

On the first hypothesis, sustainability is considered in a more classic and conservative manner. This hypothesis argues that technological development is an important input for industrial and economic growth. However, it can also result in social and environmental degradation.

Such a view indicates that technological innovation only partially promotes sustainable development, since it only addresses one of the pillars of sustainability: economics. Authors such as Meadows et al. (1972) and Freeman and Soete (1997) corroborate this view, and have argued that technological innovation can bring social and environmental degradation, even though these authors consider technological innovation as a major driver of industrial development.

Regarding the second hypothesis, it became more heavily defended from the 1970s, especially due to the increased attention paid to issues related to sustainability (Sachs 2004). Environmental issues have become part of

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the development agenda of countries and sustainability has become a normative regulation for contemporary society, which includes an ethical relationship of current generations to future generations (Scholz 2011).

To Franceschini and Pansera (2015), the discourse on sustainable development has invigorated the idea that technological innovations are inevitable to sustain economic development, while simultaneously ensuring environmental sustainability. Thus, awareness of environmental problems has been emerging (one example can be taken from the area of cleaner technologies), which Paredis (2011) considers as a way to simultaneously solve environmental and development problems.

In addition, an understanding that technological development should be aligned to social development has guided research in the area, addressing some thematic gaps. More than the promotion of social development, technological development should lead to structural changes as well. Sabadie (2014) argues that sustainable technological solutions should also catalyze social and behavioral changes. For the author, the human capital and new social behaviors are critical and must be combined with economic competitiveness and sustainability, as technology alone is no longer able to solve global challenges.

To Sabadie (2014), sustainability and innovation are among the key elements of the European Union's Research and Innovation Framework Programme. In this context, the European Institute of Innovation and Technology (2012) argues that radical technological changes can only occur if the social context is also changing. The individual must be prepared for an environment (economic, social and environmental) that is sustainable. The study by the European Institute of Innovation and Technology states that in the European Union, increased competitiveness and industrial production, resulting from technological development, should also generate sustainable jobs. This, in turn, is important in order to establish a solid basis for a smart growth (European Comission 2013). Consistent with this view, Kinnear and Ogden (2014) state that efforts should be made to include innovation in the programming of regional policies, in order to diversify the economy, and to unleash opportunities to do better in the socio-cultural and environmental spheres.

In this sense, technological innovation can be considered as a key factor for sustainable development, assuming a catalytic role in the economic, social and environmental fields (Fokkema et al. 2005; Constantinescu & Frone 2014).

Considering this context, according to the Brundtland Report, elaborated by the World Commission on Environment and Development (1987), technology can increase productivity and the quality of life, improve health and conservation of the resource base, but can also bring new risks, since they are not all inherently benign.

In fact, it should be noted that the positive integration of the three pillars of sustainability is needed to facilitate the achievement of sustainable development. Nonetheless, the integration of economic, environmental and social dimensions is also frequently associated with conflicts between these aspects that tend to hinder the achievement of sustainable development (Hansmann et al. 2012).

1.2.   Objectives of the investigation

Based on the background here provided, the overall goal of this paper is to analyze the relationships between investments in technological innovation and the sustainable development models of BRICS and G7 countries.

The study was conducted via an econometric analysis of two groups of countries. The first group, the BRICS, was composed of Brazil, Russia, India, China and South Africa, and the second group, the G7 group, was composed of France, Italy, Germany, the United Kingdom, Japan, the United States of America and Canada.

The relevance and innovative nature of this study are based on the current gap related to empirical research and comparative studies that analyze the relationship between technological innovation and sustainable development of countries. In general, what is put into question is the perhaps mistaken assertion, that technological innovation per se can support economic growth without limits.

The timely nature of this study can be ascertained if one considers the projections by O'Neill (2001), who in 2001 and 2002 predicted that the real GDP growth of the BRIC countries would be higher than the G7 countries. This author also stated that in each of the four scenarios he projected, the GDP increase of the BRICs would be led by China, although India, Russia and Brazil would also contribute significantly to the overall growth.

According to Yang et al. (2012), the countries that are members of the G7 group have a high scientific and technological development level and the countries of the BRIC group, which had a lower economic level, have achieved an astonishing development speed in the last 10 years, especially in science and technology. Thus, G7 and BRICS countries can be used to study two types of countries with different development levels in science and technology.

2.   Economic growth and sustainable development: understanding the connections

Authors such as Moraes and Barone (2001) have pointed to the possibility that the era of economic theory, which significantly contributed to the quantitative growth, is ending, mainly due to the fact of not satisfactorily meeting the simultaneity of economic, social and environmental objectives. The authors have claimed that the economic theory, especially from neoclassical studies, overstresses economic growth, disregarding the fact that natural resources are finite. However, considering that these resources are finite, and that growth could be limited by this factor, another way to measure progress was needed.

In addition to the considerations presented earlier, Gadotti (2000) added that the globalized capitalist

development form, which prioritized economic growth over human development, determined the concentration of power and resources, thereby promoting inequalities and devastating the environment.

Meadows et al. (1972), in the world-famous report entitled *The limits to growth*, presented the discussion about the incompatibility between the current development model and environmental protection. According to these authors, the planet would reach a catastrophic situation if developing countries consumed natural resources at the same level as the developed ones.

Thus, the idea of limits to growth, supported by Meadows et al. (1972), came to be viewed with greater interest, since the continued exponential growth of the world economy would lead to the structural loss of the natural foundations of life, and in less than 100 years, the limits to growth would be reached, as can be seen from the results obtained in more recent studies by Moussiopoulos et al. (2010). According to him, the anthropogenic pressure on the urban environment has reached critical levels worldwide.

Sachs (2004) acknowledged that it was after the 1970s that the concern with environmental issues became a determining factor for a new definition of the term development. All of this, according to him, is a result of the United Nations Conference on the Human Environment held in Stockholm in 1972, where the idea of eco-development was first proposed.

Bellen (2006) believed that the term eco-development had emerged as a new alternative to the classical idea of development, adding that it meant a significant advance for the notion of interdependence, which involved consolidating between development and environment.

It should be emphasized that the term sustainable development was initially discussed by the *World Conservation Union* in the document entitled *The World Conservation Strategy*, which states that 'for development to be sustainable it must take into account aspects relating to social and ecological dimensions, as well as economic factors, the living and non-living resources and the advantages of alternative actions in the short and long term' (Bellen 2006, p. 23).

Thus, the definition of the term sustainable development has been presented in the Brundtland Report of World Commission on Environment and Development (1987), as being the development modality that seeks to meet the needs of current generations without compromising the ability of future generations to meet their own needs.

In this scenario, in a study by Cracolici et al. (2010), it was suggested that quantifying the performance of a nation could not be restricted to only economic aspects or to any non-economic aspect, not by articulating them. More than that, these aspects should be taken into consideration simultaneously and consistently. Sachs (2004) pointed out that only the activities that took into account social and environmental sustainability and economic viability deserve being designated as development.

The explanation made along this section leads to a questioning of the fact that sustainable development is in the opposite direction to economic growth. In this sense, Sachs (2001) emphasized that economic growth, if properly reconsidered, remains a necessary condition for development given that high rates of economic growth are necessary to accelerate social rehabilitation, and since it is easier to operate with increases in the Gross National Product than distributing goods and income in a stagnant economy.

This demystification of the opposing idea between growth and development allowed Cracolici et al. (2010) to conclude that the GDP per capita increase of a country should be considered as a fundamental prerequisite for improving the quality of life of its population, since it can provide better-quality healthcare services, greater access to education, safety, leisure and better working conditions, in addition to providing a sustainable environment. Furthermore, the authors added that these factors related to improved living standards, mentioned above, are the foundations for productivity, and consequently to increase the GDP.

In order to address the non-economic dimensions, Cracolici et al. (2010) concluded that they are significantly explained by GDP per capita. However an inverse relationship, in other words, the explanation of GDP per capita by non-economic dimensions, is not always accurate. In this sense, Cracolici et al. 2010, p. 350) argued that 'the positive and significant effect of GDP on all social and environmental dimensions highlights that a good level of the economic dimension is a basic condition to achieve a good social–environmental performance'.

3. Technological innovation and economic growth

In relation to business growth, Schumpeter (1937/1989) noted that within economic systems, there is a strong dynamic and changes often take place. Within this perception, Fagerberg (2002) found that Schumpeter's objective was to develop a theory about economic evolution complementing the theory of static equilibrium, with no intention of replacing it.

Also according to Schumpeter (1939), the term Economic Evolution referred to changes in the economic process brought about by innovation, together with all its effects and impacts. In this regard, Fagerberg (2002) identified that the dynamic view attributed to the works of Karl Marx exerted a significant influence on Schumpeter's ideas, since Marx adopted the view that capitalist firms, in order to remain competitive, would need to increase productivity through the continuous introduction of new machines.

Schumpeter (1943) emphasized that the most important modality of competitiveness is the one driven by new goods, new technology, new resources and a new type of organization. Thus, according to Fagerberg (2002), Schumpeter can be considered as being among the ones responsible for the broader notion of innovation.

Within this perspective, Fagerberg (2002) found that Nelson and Winter (1982) continued advocating Schumpeter's idea by considering capitalism as an engine of change, although sharing the view that the neo-Schumpeterian term was the most appropriate name for the evolutionary approach.

Recognizing that these authors had something in common with Schumpeter, Fagerberg (2002) noted they suggested that firms reinvest their profits in new technologies and in more productive equipment, thus bringing along the rewards of high profits and growth, as opposed to the companies that did not put this into practice.

Thus, Ruffoni et al. (2004) stated that although the relationship between technological progress and economic growth has not always been included in the theoretical models of economic growth, it can be argued that this is a positive relationship. According to these authors, the pioneering studies on economic growth only took into account the two main categories: capital and labor, as determining variables. However, they pointed out that these variables alone cannot explain economic growth.

Fagerberg and Srholec (2008) pointed out that the work that gained prominence for having regarded technological progress in the economic theory was that of Solow, in 1956. However, the model developed by Solow had the characteristic of adding in the production function the technical progress factor only, as a residual variable, but which better explained GDP variations.

According to Fagerberg and Srholec (2008), economists such as Lucas (1988) and Romer (1986) began to develop growth models with a focus on technology as the driving force of growth and development; technological innovation began to be considered as an essential variable, initiating the 'new era of growth'. This initiative complemented the neoclassical models and their basic postulates, and helped defend the thesis of the need for strict protection of intellectual property rights. Scholars who sought to relate the technological innovations with economic growth, such as Romer (1986), argued that knowledge, whether in the form of technology or human capital, was an important source of growth.

The role played by technological innovation acquired greater visibility by using data on technological activities (R&D and patent statistics), based on the Schumpeterian notion of innovation as a driving force for economic change. All of this caused technological innovation to be considered as a main factor of international trade and economic performance (Fagerberg 2002).

In the field of international competitiveness, Fagerberg and Verspagen (2003) based their investigations on various previous studies (e.g. Nelson & Phelps 1966; Fagerberg 1987; Barro & Sala-i-Martins 1995) to consider that innovation and technology diffusion were the driving forces in what was regarded as the different growth rates of countries. The authors concluded that this fact led to the hypothesis that many countries and regions would reduce their international competitiveness, if they did not consider the appropriate technological development.

The study conducted by Fagerberg (1987) helped prove the hypothesis of a positive relationship between the level of economic growth and the level of technological development of a country, since it confirmed the existence of a close correlation between economic development, represented by GDP per capita, and the level of technological development, measured by R&D data and patents in a group of 25 countries. Moreover, the author concluded that, for those countries studied, the differences between their growth rates could be largely explained by differences in the types of technological models adopted.

In a study by Ruffoni et al. (2004), it was observed that high R&D expenditures led a country to achieve and maintain high income levels. However, those that had lower technology investments were the ones that demonstrated greater potential to transform this kind of investment into economic growth. Thus, a perception emerged that there would be a limit where this type of investment could increase the economic growth potential.

Considering what has been presented in this section, it is reasonable to add that, according to the OECD (2005), technological development and innovation are key factors for increased productivity and also for employment and economic growth. Thus, in order to understand the influence of technological innovation on sustainable development, the next section presents the theoretical background on the subject.

4. Technological innovation and sustainable development

Based on the information obtained in the literature review presented in the previous section, it can be stated that technological innovation has been a key factor in promoting economic growth (OECD 2005).

The idea that was the guiding notion of this research was based on another dimension that goes beyond growth. Although economic aspects have been described in depth and have so far prevailed, the social and environmental aspects promoted by technological innovation were also considered.

Freeman and Soete's (1997) study on the potential harms and benefits of technological innovation has shown that while technological innovation is recognized as a driver for industrial development, it is also seen as a factor of social and environmental degradation.

With regard to the business aspect, Hall and Vredenburg (2003) stated that on the one hand technological innovations can be considered as providing competitive advantages. However, they can also, on the other hand, be considered as a source of risk, competitive degradation and business failure.

Meadows et al. (1972) also warned about the dangers of technology on the environment, bearing in mind that a given technology developed and implemented to increase the welfare of society can also have undesirable effects.

Authors such as Viotti and Macedo (2001) recognized that science, technology and innovation comprised the

fundamental tripod for development and competitiveness between companies and countries, and furthermore, it had a direct participation in achieving the quality of life for the population, in addition to the possibility of contributing to solving social and environmental problems. Accordingly, Constantinescu and Frone (2014) showed that technological innovation is crucial to advance sustainable development, through its effects on the three pillars of sustainability, and with decisive influence on the efforts to promote economic vitality, environmental sustainability and social progress.

With a more focused view on the social and environmental dimensions of economic growth, Fokkema et al. (2005) stated that technology was a key factor for sustainable development. According to the authors, based upon the need to ensure a qualitative leap in environmental efficiency and the production of goods and services, technological changes should be at the center of concerns to ensure sustainable development.

The development of new technology is considered in studies such as Paredis (2011), Sabadie (2014), Kinnear and Ogden (2014) and Franceschini and Pansera (2015), as one of the ways to address social, environmental and development problems. It is important to quote, in this context, Barbieri's (2004) statement concerning the fact that advances in science and technology bring along the possibility of products and processes that entail the efficient use of resources, as well as may reduce the emission of pollutants.

This is consistent with the views expressed by Hall and Vredenburg (2003), who stated that technological innovation – when directed to sustainable development – is incompatible with the conventional idea of innovation. They defend the view that conventional technological

innovation is market-oriented, while technological innovation directed toward sustainable development requires using social and environmental pressures, assimilating them while considering future generations and their survival, with the overall quality of life. Thus, according to Freeman (1996), social and environmental pressures have made innovation for sustainability more complex than exclusively market-oriented innovations.

The ideas developed by Hall and Vredenburg (2003), illustrated in Figure 1, point out that technological innovation can be seen as an opportunity to create new sustainable competitive advantages (quadrants 1 and 3), as well as can be a source of competitive disruption, business failure and social and environmental disorders (quadrants 2 and 4). Additionally, technological innovation can also undergo market influences (quadrants 1 and 2) and public policy influences (quadrants 3 and 4).

This schema was used by Hall and Vredenburg (2003) to confirm that companies traditionally focus on quadrants 1 and 2, whereas policymakers tend to focus on quadrants 3 and 4. However, the technological innovation that sustainable development strives for should consider the four quadrants, and in doing so a competitive advantage can be achieved.

Interestingly, the idea of sustainable technological innovation has not yet been fully explored, and this results in elaborating new hypotheses and alternatives, without taking into account its intrinsic dimensions. In the synthesis presented by Nobelius (2004), it is noted that the perspective of sustainable development is not included in their analysis, given that its concepts and principles are not addressed. Thus, according to the author, leaving out the environmental and social variables in alternative technologies may pose a limiting factor to the proposed models.
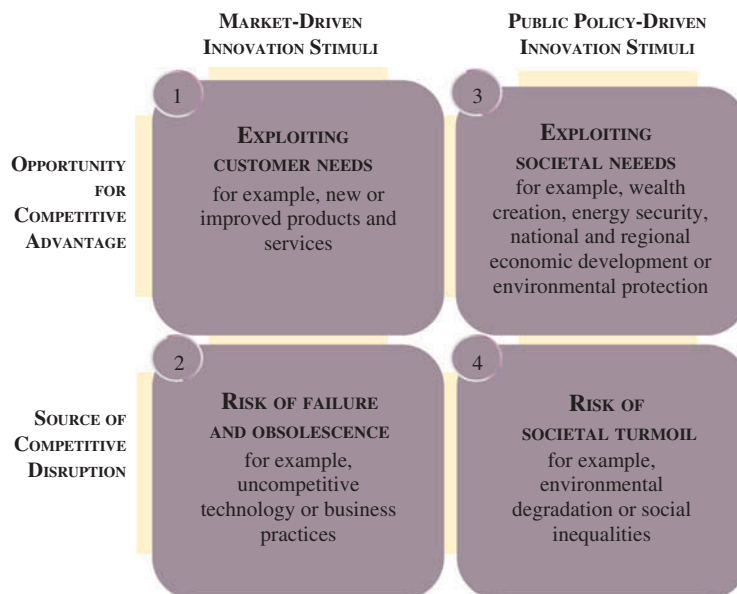

Figure 1. The 'two-sided situation' of innovation.
Source: Hall and Vredenburg (2003).

According to Kemp and Soete (1990), there are some obstacles to the supply and demand of this type of technology, some of which regard the uncertainty about demand, automated markets and the exclusion of environmental issues, when the question at hand is about maximizing profits. Thus, the authors believe that disseminating environmental technology has been demanding more support from decision makers, than the traditional production technologies. In India, there are examples that support this (e.g. Puyravaud & Davidar 2014).

The transition to sustainability, according to Martens and Rotmans (2005), requires a due emphasis to the complexity of social processes. According to Fokkema et al. (2005), the process of sustainable technological innovation involves all stakeholders of a company, from the beginning of the technological design process, starting with the formulation of the problem to be solved.

In summary, it is perceived that technological innovations, assumed within the scope of firms and directly related and committed to sustainable development, should take into account other previously absent dimensions in its planning. This deliberate action should especially consider the roles played by both the market forces and the public policy forces, which take into account the social and environmental dimension and can ensure that sustainability accompanies technological innovation in its current stages of development.

5.   Methods used in the study

In this study, the emerging countries that constitute the BRICS group and the developed ones (which constitute the G7 group) were selected in order to analyze the relationship between technological innovation investment and economic, environmental and social development. Hence, the analyzed units were Brazil, Russia, India, China, South Africa (BRICS), as well as Canada, France, Germany, Italy, Japan, the United Kingdom and the United States of America (G7). The choice for studying these countries is justified by the possibility of comparing the major economic powers, against the group of emerging countries.

This research included the use of an unbalanced panel. The data collection and analysis for the BRICS countries contemplated the beginning of 2000 to 2007. As for the countries of the G7 group the period was more extensive, covering data from 1996 to 2008.

Initially, a modified F test for structural stability (the Chow test) was performed, to observe whether the two groups of countries have similarities and differences. Since both groups of countries cannot be classified as similar, the econometric analysis has been performed separately, with the regressions for each group being considered.

5.1.   Identifying the variables

As the overall goal of this study included composing a relationship between technological innovation and

sustainable development within the BRIC and G7 groups of countries, the selected variables sought to portray these issues, in order to allow the set-up and subsequent analysis of the model.

To define the theoretical model adopted in this study, one of the first steps regarded the use of a modified Cobb–Douglas production function by including the variable technological innovation as shown in Equation (1),

$$q = AK^\alpha \, L^\beta \, IT^\gamma \qquad (1)$$

where q is the product, K is capital, L is labor and IT is the variable representing technological innovation.

Table 1 lists the selected variables.

Regarding the independent variables, the variable 'gross fixed capital formation' was chosen to represent the variable capital, of the original Cobb–Douglas production function; the selection of the variable 'employed population' represents labor, also from the original Cobb–Douglas production function; finally, the choice of the third independent variable, 'expenditure on R&D', represents the technological innovation of countries, and it was chosen because it is considered in the Oslo Manual as an indicator of technological innovation ([OECD] Organization for Economic Co-operation and Development 2005).

In the set of dependent variables, the selection of the variable 'GDP' was to indicate the economic development of the countries, and it justified this variable as it is in studies evaluating the sustainability of regions, such as in Shi et al. (2004) and Zhen et al. (2009).

The second dependent variable chosen to translate the environmental development of the countries was the indicator 'carbon dioxide emissions (CO_2)'. This indicator has been widely used in studies evaluating the environmental sustainability of regions, as for instance in Lee and Huang (2007), Tamazian et al. (2009), Zhen et al. (2009), Boggia and Cortina (2010) and Pao and Tsai (2010), among others. Furthermore, the use of 'CO_2 emissions' as a variable of environmental development is justified by the *Environmental Kuznets Curve*, elaborated by Grossman and Krueger (1991), to show the relationship between pollution emissions and GDP per capita of the countries. Thus, as CO_2 is the main gas responsible for the intensification of the greenhouse effect, the emission of this pollutant was adopted as an example to develop the work described herein.

Finally, the selection of the third dependent variable, which represents social development, was 'life expectancy at birth'. This variable was chosen because it has been used

Table 1.   Variables selected.

Independent	Dependent
Gross fixed capital formation	GDP
Employed population	CO_2 emissions
Expenditures on R&D	Life expectancy

in works such as Mahlberg and Obersteiner (2001), Despotis (2005), Gisbertt and Palleja (2006), Ramathan (2006), Lee and Huang (2007), Zhen et al. (2009) and also in the work of Sen (1998), which showed life expectancy as a decisive indicator to verify the full success of a society.

5.2. Collecting and organizing data

The data of the variables were collected in the databases of two major international bodies:

(1) *United Nations Educational, Scientific and Cultural Organization* (UNESCO);
(2) *World Bank.*

The data collected were organized in a panel of 12 countries. The BRICS group was observed in eight periods ($t = 8$), from 2000 to 2007, and the G7 group was observed in 13 periods ($t = 13$), from 1996 to 2008, resulting in a total of 131 observations.

5.3. Definition of the econometric model

A three-function econometric model was tested, in which one refers to economic development, the second to environmental development and the last to social development of countries, thus portraying the three dimensions of sustainability as dependent variables.

In the first functions, GDP was used as a dependent variable that reflects the economic performance of the units – as shown in Equation (2).

$$ECO_{it} = AK_{it}^{\alpha_1} L_{it}^{\alpha_2} IT_{it}^{\alpha_3} e^{\varepsilon_{it}} \qquad (2)$$

To analyze the influence that technological innovation has on the environmental development of the countries, CO_2 emission was used as the dependent variable.

Thus, the equation that relates to environmental sustainability dimension is given by Equation (3).

$$AMB_{it} = AK_{it}^{\beta_1} L_{it}^{\beta_2} IT_{it}^{\beta_3} e^{\varepsilon_{it}} \qquad (3)$$

Finally, to analyze the influence of technological innovation on social performance, life expectancy at birth was used as a measure of social performance. The formulation is shown by Equation (4):

$$SOC_{it} = AK_{it}^{\gamma_1} L_{it}^{\gamma_2} IT_{it}^{\gamma_3} e^{\varepsilon_{it}} \qquad (4)$$

It should be noted, however, that the functions proposed here are not linear, a fact that required the use of logarithms for the linearization of the functions, which enables the estimated parameters' interpretation in terms of elasticity, and also reducing heteroscedasticity.

Thus, using a log–log model in Equations (2), (3) and (4), shown above, the model of three equations to be estimated was elaborated.

$$\ln ECO_{it} = \ln \alpha_0 + \alpha_1 \ln K_{it} + \alpha_2 \ln L_{it} + \alpha_3 \ln IT_{it} + \varepsilon_{it} \qquad (5)$$

$$\ln AMB_{it} = \ln \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln IT_{it} + \varepsilon_{it} \qquad (6)$$

$$\ln SOC_{it} = \ln \gamma_0 + \gamma_1 \ln K_{it} + \gamma_2 \ln L_{it} + \gamma_3 \ln IT_{it} + \varepsilon_{it} \qquad (7)$$

Another important aspect is regarding the analysis of the error structure. The availability of panel data allows greater flexibility for its specification. In general, the specification is given by Equation (8).

$$\varepsilon_{it} = \eta_i + \mu_{it} \qquad (8)$$

where μ_{it} is the assumed error and η_i is the individual unobserved heterogeneity of the production function of each country.

These unobserved characteristics are constant over time, and for this study they can be factors such as location, climate, natural resource endowments and a mix of other factors that materialize in productivity differences between countries (Woodridge 2002).

If these unobserved differences or individual effects exist, and are not explicitly recognized in the model, then the estimated coefficients of the explanatory variables included can be biased and inconsistent. Therefore, greater care was exercised here.

In order to consider the problem of individual heterogeneity, the fixed effects and random effects models are mentioned. It should be noted that in the fixed effects model, the individual effects can be freely correlated with the other regressors, while in the random effects model, it is assumed that there is no correlation between individual effects and other explanatory variables.

When the fixed effects approach is used, the individual effect is considered as a specific constant term of a group, controlling its presence through the use of intercept dummy variables, so that the model can be estimated by ordinary least squares (OLS) known as the Least Squares Dummy Variable Model (LSDV). On the other hand, it is specified in the random-effects approach that the individual effect is a specific concept for each group, similar to error, thereby inducing an autocorrelation between them, and the model must be estimated by generalized least squares (GLS).

The STATA 9.2 software was used to perform these analyses, and after determining the econometric model and its equations, some post-estimation procedures should be followed, such as autocorrelation and heteroscedasticity tests in the functions. Then, if non-spherical disturbances were observed, the three-equation panel-data linear model will be fitted using feasible generalized least squares (FGLS).

6. Results – presentation and discussion

Before presenting the econometric results, the formulation of the two hypotheses of Chow's test for parameter stability should be demonstrated.

(1) H0: Stability (BRICS = G7);
(2) H1: Instability (BRICS ≠ G7).

The purpose of this test was to identify similarities or differences between the BRICS and G7 groups. Hence, with 99% of confidence a critical F of 3.48 was found, so the null hypothesis of parameter structural stability was rejected, as seen in Table 2.

Accordingly, with Chow's test, it was seen that in the three equations mentioned, the BRIC group is different from the G7 group. Thus, the econometric analyses of these two groups of countries were performed separately for the three proposed functions.

After completing Chow's test for defining the model and its equations, the Drukker (2003) tests were performed for autocorrelation, and the Breusch–Pagan for heteroscedasticity.

From the results of the Drukker (2003) tests and the Breusch–Pagan, it was possible to state that all three functions of the econometric model showed autocorrelation and heteroscedasticity. Thus, the estimation by FGLS was chosen, allowing the estimation in the presence of AR (1) autocorrelation within panels and cross-sectional correlation and heteroscedasticity across panels.

The first estimation carried out was for the economic equation that considered the GDP as the dependent variable. Second, the environmental equation was estimated, which used CO_2 emission as the dependent variable. Note that the lower the CO_2 emission level in a region, the better it is for its environmental development. Finally, the social equation was estimated, which used life expectancy as the dependent variable.

Table 3 shows the results obtained from the estimation with their respective coefficients and *p*-values for all equations (economic, environmental and social).

6.1. Separate results for investments in technological innovation

As the objective of this study was to mathematically model the variables used in the analysis of the BRICS and G7 groups, focused on the variable technological innovation, the results regarding the variable expenditure on R&D are highlighted.

Table 2.   Results of Chow's test.

	F calculated	Conclusion
Economic equation	7.57	BRICS ≠ G7
Environmental equation	56.02	BRICS ≠ G7
Social equation	36.48	BRICS ≠ G7

Table 3.   Econometric results.

	BRICS		G7	
	Coefficient	*P*-value	Coefficient	*P*-value
Economic equation				
Gross fixed capital formation	.6449086	0.000	.5471857	0.000
Employed population	.0002504	0.837	.3176664	0.183
Expenditure on R&D	.0952782	0.000	−.029377	0.864
Environmental equation				
Gross fixed capital formation	.0733177	0.399	−.0844879	0.259
Employed population	.0006095	0.637	1.325.701	0.000
Expenditure on R&D	.600412	0.000	−.105434	0.255
Social equation				
Gross fixed capital formation	.0533732	0.000	.0542992	0.000
Employed population	.000151	0.408	−.1209447	0.000
Expenditure on R&D	−.016959	0.081	.0338415	0.000

Thus, with the results presented in Table 3, Table 4 was constructed, which shows the summary of results of the variable expenditure on R&D in both groups of the countries studied.

It can be seen that, for the BRICS group, the variable expenditure on R&D was significant for all the proposed functions. That said, and based on the data in Table 3, the results indicate that:

(1) If the investments in technological innovation of this group of countries increased by 1%, the GDP of the member countries would see an increase of 0.0953%.
(2) If the investments in technological innovation of this group of countries increased by 1%, the CO_2 emissions of the member countries would see an increase of 0.0006%.
(3) If the investments in technological innovation of this group of countries increased by 1%, life expectancy of the member countries would see a decrease of 0.0169%.

Table 4.   Summary of econometric results.

	Economic function	Environmental function	Social function
BRICS	Significant, positive	Significant, positive	Significant, negative
G7	Not significant	Not significant	Significant, positive

It should be noted that the investments in technological innovation, made by the countries in the BRICS group, resulted in a positive change in their economic development. However, for environmental and social development, the values of the coefficients showed that increasing the investments in technological innovation would bring an increase in CO_2 emission and a decrease in the population's life expectancy.

The increase in investments in technological innovation, associated with the increased levels of CO_2, enabled the assumption that this type of investment, adopted by the BRICS group, does not help them meet their sustainable development targets, and are geared to meet the market pressures, anticipating the consumer needs, as discussed by Hall and Vredenburg (2003). This confirms earlier results by Santana et al. (2014), who stated that the investments in technological innovation made by the BRICS may not be focused on sustainable technologies that can reduce levels of CO_2 emissions. It is also consistent with the results of Amiolemen et al. (2012), who affirmed that most emerging countries do not have the conventional technology to combat environmental pollution. Finally, it supports the view from Constantinescu and Frone (2014), who argued that developing countries still lack the technology to handle environmental pollution and their consequences.

As for the increase in investments in technological innovation, associated with the population's decreased life expectancy, it may be assumed that in the countries of the BRICS group, the type of technological innovation adopted, geared to meet the market pressures and production growth, is not committed to social welfare and regional development.

With regard to the G7 group, it was seen that technological innovation was not significant, neither for economic development nor for environmental development. However, for social development, the variable technological innovation was significant and positive.

With regard to economic development, it is observed that the investments in technological innovation of the G7 group no longer potentialize the goal of economic growth, meaning that they may have reached the limit, as shown by Ruffoni et al. (2004). From this, the lack of significance of the variable technological innovation for the economic development of these countries can be justified. A similar analysis can be made with respect to the lack of statistical significance of technological innovation for environmental development. Given that in these circumstances technological innovation no longer enhances economic development, it may not entail increased production and hence the change in the CO_2 emissions.

A factor that should be highlighted in the analysis of sustainability in industrialized countries, according to Scheel and Vazquez (2011), concerns the fact that they have economic growth often at the cost of other countries, which bear the resulting socio-environmental problems. In this regard, Amiolemen et al. (2012) showed that serious consequences are seen with respect to high mortality, food shortages and epidemics due to industrial production, which are most evident in developing countries, than in the developed countries.

Finally, the social development of the G7 countries has benefited by investments in technological innovation, represented by a positive correlation between these and the life expectancy of the member countries. It is possible that, contrary to what was observed for the BRICS group, the nature of technological innovation specifically adopted by the G7 group has reached a stage that is geared more to the needs of society and only not to meet the needs of consumers, as discussed by Hall and Vredenburg (2003).

7.   Conclusions

The motivation for developing this investigation originated in questions about outcomes of probable achievements of countries that excel in the global economic scene. According to O´Neill (2001), the GDP growth of the BRICS countries may exceed the GDP growth of the G7 countries in some years. But how can one monitor this to see the aspects that can be improved in the growth and economic development of the new emerging actors? Can the evolution of science, through new analysis tools, anticipate these growth-related problems?

In this context, and considering the importance of technological innovation for the economic growth of countries, the work reported herewith analyzed the relationship between the investments directed to technological innovation, and the sustainable development prospects of the BRICS and G7 groups. The initiative to study this relationship stemmed from the idea that economic growth no longer guarantees a nation's social welfare and environmental quality.

Through the results here gathered, it was found that the investments made in technological innovation from the BRICS countries in the analyzed period resulted in positive changes in their economic growth. In contrast, with regard to environmental and social development, the investments in technological innovation of the BRICS group showed they were directly associated with increased CO_2 emissions and decreased life expectancy. This enables the conclusion that investments in technological innovation by this group of countries do not seem to be committed to a qualitative leap in socio-environmental efficiency, but is rather focused on meeting market pressures. Reflecting this state of affairs, Wang and Ying (2014) stated that the participation of the BRIC countries in the international innovation scenario has grown in recent decades, but this participation is still quite low.

The results obtained from the analysis of the G7 group pointed toward a lack of statistical significance, in terms of technological innovation for economic growth and environmental development. This could be justified, since this group of countries is at an advanced development stage,

where possible investments in technological innovation do not necessarily have economic growth as a main driving force, which in these circumstances may not result in increased production and hence variation in CO_2 emissions. On the other hand, the differentiated nature of technological investments, acquired by the G7 group, is reflected in the increase in the population's life expectancy.

Comparing the results achieved, it can be suggested that while the G7 group may have reached the limit of technological innovation for economic growth, the BRICS group demonstrates its potential for this transformation. Moreover, it is possible that, over time, the G7 group has implemented sustainable technologies, while the BRIC group has not yet done so, according to the data analysis of the variable CO_2 emissions. Finally, it is possible that the type of technological innovation adopted by the G7 group is at the stage of anticipating the needs of society, striving to create social welfare and regional development, as suggested by Hall and Vredenburg (2003), unlike the BRICS group, which seems to be focused on innovation exclusively on the market, anticipating consumer needs.

If on the one hand the G7 group represents the seven most industrialized and economically developed countries in the world, the BRICS countries represent the five emerging countries, with the fastest growth rate tendency in their economies. Based on the perception about the differences in the development stage of each of these groups, it was found that the result of the innovation effort was also different for each one.

Based on the results of the work presented herein, together with the proposal of Hall and Vredenburg (2003), the G7 group has demonstrated it is situated at the innovation stimulus stage by public policies, anticipating the needs of society by the creation of social welfare, environmental quality and regional development.

The BRICS group, however, has shown to be situated at the innovation stimulus stage by the market forces, anticipating the needs of consumers, the development of new products/services and the definition of new markets.

Paredis (2011) stated that all countries have responsibilities for achieving sustainable development, but that the industrialized countries should take the lead. To Blohmke (2014) advances in the technology frontier are often made in developed economies, and the diffusion of technology extends slowly to the developing world. In this sense, Amiolemen et al. (2012) highlighted that the concept of sustainable development in developing countries has received little or no attention and, in addition, these countries have failed to understand that sustainability is a synonym of wealth and development. For the authors, these countries need to look inward to adopt and develop technologies that are appropriate and necessary for self-sufficiency and sustainable development.

In this context, one can conclude that the current and future differences in the real GDP growth of the BRIC and G7 countries should be closely monitored, and here investments in technological innovation should deserve a special attention. The question that remains is 'what should the BRIC countries do to direct investments in technological innovation in order to achieve positive results as of now, not only in respect of economic growth, but also in terms of environmental and social development?'

The study presented here is not intended to exhaust the discussion. Additional in-depth analyses should be performed, especially the role of technological innovation as a tool to promote sustainability.

Disclosure statement

No potential conflict of interest was reported by the authors.

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