Centro Unversitário Santo Agostinho

revistafsa

www4.fsanet.com.br/revista
Rev. FSA, Teresina, v. 19, n. 1, art. 6, p. 104-129, jan. 2022
ISSN Impresso: 1806-6356 ISSN Eletrônico: 2317-2983
http://dx.doi.org/10.12819/2022.19.1.6

Do Expenditures on Research and Development (R&D) Cause Externalities in the Environment? Empirical Evidence for Brazil

Gastos em Pesquisa e Desenvolvimento (P&D) causam externalidades no meio ambiente? Evidências empíricas para o Brasil

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Editor-Chefe: Dr. Tonny Kerley de Alencar Rodrigues

Artigo recebido em 30/08/2021. Última versão recebida em 09/09/2021. Aprovado em 10/09/2021.

Avaliado pelo sistema Triple Review: a) Desk Review pelo Editor-Chefe; e b) Double Blind Review (avaliação cega por dois avaliadores da área).

Revisão: Gramatical, Normativa e de Formatação

ABSTRACT

Recognizing investments in Research and Development (R&D) can contribute to the development of Brazil, considerable and important investments that were made available since the 1940s. To leverage the economy from the 1990s, they were implemented as policies of Science, Technology and Innovation (CT&I) releasing resources that must guarantee, over time, a development process in accordance with the objectives and standards of economic, social and environmental sustainability. In this context, this article aims to analyze the impact: of resources in Research and Development (R&D) for the public and private sectors; and economy (credit payments made by BNDES and GDP per capita) on how the CO2e of the agricultural sector (CO2Agro) in Brazil, between periods between 2000 and 2015. For the analysis procedure, two models were used distinct, the first with R&D from the public and private sectors in a linear and quadratic way, to investigate or impact CO2e emissions in the agricultural sector in Brazil. And, without a second model, in addition to public and private sector R&D, credit disbursements from the National Bank for Social Economic Development - BNDES and GDP per capita were included. The application method uses an economical approach to time series data. A dependent variable of the two models is how CO2 in the agricultural sector (CO2Agro) in Brazil. The results of the suggested models for which resources with R&D generate positive externalities for the environment and are permitted, show the effects on CO2e emissions in the agricultural sector. In the linear analysis of the impact of R&D investment objects on the private sector, it was found that they corroborate with the increase in CO2e and Agricultural emissions. However, in the analysis of non-linear impact there is a suggestion of the presence of a maximum point, and from this point, as the use of Agricultural CO2 starts to lose each unit invested in R&D in the private sector. The variable disbursements with BNDES credit promotes a reduction in the use of agricultural CO2 with low statistical significance. However, a variable GDP per capita strongly corroborates the increase in CO2 emissions and the agricultural sector. In this way, the results suggested for the development of the country, and from public resources, clean technologies are generated over time, aiming at reducing CO2 emissions in the agricultural sector, which is a very important sector of the Brazilian economy.

Keywords: Economic growth. Greenhouse gases. Research and Development. GDP per capita. Agricultural sector.

RESUMO

Reconhecer os investimentos em Pesquisa e Desenvolvimento (P&D) pode contribuir para o desenvolvimento do Brasil, investimentos consideráveis e importantes que foram disponibilizados desde a década de 1940. Para alavancar a economia a partir da década de 1990, foram implementadas como políticas de Ciência, Tecnologia e Inovação (CT&I) liberando recursos que devem garantir, ao longo do tempo, um processo de desenvolvimento de acordo com os objetivos e padrões de sustentabilidade econômica, social e ambiental. Nesse contexto, este artigo tem como objetivo analisar o impacto: dos recursos em Pesquisa e Desenvolvimento (P&D) para os setores público e privado; e economia (pagamentos de crédito feitos pelo BNDES e PIB per capita) sobre como o CO2e do setor agropecuário (CO2Agro) no Brasil, entre os períodos entre 2000 e 2015. Para o procedimento de análise, foram utilizados dois modelos distintos, o primeiro com P&D de os setores público e privado de forma linear e quadrática, para investigar ou impactar as emissões de CO2e no setor agropecuário no Brasil. E, sem um segundo modelo, além da P&D dos setores público e privado, foram incluídos os desembolsos de crédito do Banco Nacional de Desenvolvimento Econômico Social - BNDES e PIB per capita. O método de aplicação usa uma abordagem econômica para dados de séries temporais. Uma variável dependente dos dois modelos é a forma como o CO2 no setor agropecuário (CO2Agro) no Brasil. Os resultados dos modelos sugeridos para os quais recursos com P&D geram externalidades positivas para o meio ambiente e são permitidos, mostram os efeitos nas emissões de CO2e no setor agropecuário. Na análise linear do impacto dos objetos de investimento em P&D no setor privado, verificou-se que eles corroboram com o aumento das emissões de CO2e e Agropecuárias. No entanto, na análise de impacto não linear há a sugestão da presença de um ponto máximo, e a partir deste ponto, à medida que o uso de CO2 Agrícola passa a perder cada unidade investida em P&D no setor privado. A variável desembolso com crédito do BNDES promove a redução do uso de CO2 agrícola com baixa significância estatística. No entanto, uma variável PIB per capita corrobora fortemente o aumento das emissões de CO2 e do setor agropecuário. Dessa forma, os resultados sugeridos para o desenvolvimento do país, e a partir de recursos públicos, tecnologias limpas são geradas ao longo do tempo, visando a redução das emissões de CO2 no setor agropecuário, que é um setor muito importante da economia brasileira.

Palavras-chave: Crescimento econômico. Gases de efeito estufa. Pesquisa e desenvolvimento. PIB per capita. Setor agrícola.

1 INTRODUCTION

Developed economies are increasingly investing in Research & Development (R&D). These investments come from government resources and private institutions, the last one representing the major part in countries such as the USA, Australia and Japan, while in developing countries the funding is mainly carried out by the Federal Government (GRIFFIN, 2012).

In Brazil, investments in Science, Technology and Innovation (ST&I) that includes resources with Research and Development, are called expenditures, and are divided between the public and private sectors. These expenditures are sources of founds and foster the economy for technological innovation, aiming to increase competitiveness and development (GRIFFITH *et al*., 2004; GRIFFIN, 2012).

There is a consensus in the literature that R&D expenditures have a positive impact on the economy and play a fundamental role in the development process, especially in the scientific and technological aspects. These investments were answers to Malthusian theory and the green revolution proved that the technology provided by technological progress by Romer, allowed to increase production with lower natural factors such as land and human capital (HESHMATI AND LÖÖF, 2005; COCCIA, 2009, 2010; SHAARI *et al*., 2016).

In this context, Brazil, with an economy based on agricultural production, made important investments over time from the 1940s on ST&I policies, increased its agricultural productivity indices and transformed its economic matrix, which was beyond the production of corn and soybeans. From this scenario, this research was motivated by the question: Do R&D expenditures generate positive or negative externalities[1] to the environment? And what are these externalities specifically on the agricultural sector? For the reason that, this is a sector that has an enormous importance among the productive sectors and deserves special attention from the public policies of development.

In this follow-up, the objective of the study was to analyze the impact of: spending on research and development (R&D) for the public and private sectors; and the economy (credit disbursements made by the National Bank for Social Economic Development (BNDES); and the per capita Gross Nacional Product (GNP-per capita) on CO_2e[2] emissions from the agricultural sector (CO_2Agro) in Brazil between the period since the year 2000 until the year 2015.

2 LITERATURE REVIEW

2.1 Technology and Innovation in the Economy

Technological resources must ensure over time a development process in accordance with the objectives and standards of economic, social and environmental sustainability. According to Gaspar (2015) technologies evolve and provide more and better results for the benefit of humanity. These technological developments may in the future help or harm the survival of all life on planet earth. Thus, technologies influence the changes that occur in humanity (GASPAR, 2015).

The Industrial Revolution, which began between the late eighteenth and early nineteenth centuries, promoted technological developments that enabled economic advancement and enhanced great innovations.

Humanity in its activities demands constant technological innovations to assist its consumption. In a consumption-based economy, technological innovations are the main drivers of the market rise, because promotes the emergence of new needs in humans and

[1] - Externalities refer to the impact of a decision even on those who did not participate in the decision, and may have positive or negative effects, in another words, they may represent a cost to society, or may generate benefits. (PERO, 2018).

[2] - The *carbon dioxide equivalent* (CO_2eq ou CO_2e), it is an international accepted measure, and expresses the amount of various greenhouse gases (GHGs) based on the amount of carbon dioxide (CO2) that would have the same global warming potential. Equivalently, it considers all GHGs to be emitted in proportion to carbon dioxide (CO2).

presents itself as the main factor of progress and development (SILVEIRA; BASSO, 2005; GASPAR, 2015).

According to Griffin (2012) technology is a collaborative factor to increase the economy, the production and services and the good use of the most diverse resources in order to promote the sustainability of humanity.

Nelson and Phelps (1966) and Romer (1990) state that technological evolution corroborates the increase in production. In the same context, Rattner (1967) points out that increased production plays an important role in economic development and growth.

Technology and innovation are important to the economy, and are fundamental to the social process, closely linked to history, culture, education, institutional and political organizations, and the economic base of society. The technological process of innovating is not a unique role attributed to companies, but also to a very broad collective skill set, channeled to generate, absorb and diffuse the new (MCTI & C, 2001; MCTI & C, 2002).

Verspagen (2000) analyzed a model of evolutionary growth and noted that convergence based on assimilation of foreign technology was becoming a more active process. He noted that R&D is crucial for catching up with nations and is no longer an activity unambiguously associated with changing the world's technological frontier. It also found that differences between countries in terms of pure technological skills are important in explaining growth differentials.

2.2 Research & Development

Differences in economic performance between countries, according to the neoschumpeterian[3] perspective, are mostly explained by the complex interaction of public and private institutions participating in the National Innovation System (NIS) and the coordination between them. Recognizing that investments in Research and Development (R&D) can contribute to Brazil's development, science, technology and innovation (ST&I) policies have been implemented since the 1990s to leverage the economy.

For Mazzucato and Penna (2016) all countries in the world seek to achieve smart (innovation-subsidized), inclusive and sustainable economic growth. To this end, innovation policies must strategically develop, implement and monitor an innovation program based on

[3] - The neoschumpeterianos understand the innovation as a primordial determinant of the economic dynamics, because it is fundamental to define the patterns of economic competitiveness, especially in this process of contemporary globalization (FELIPE, 2008).

the strengths of the innovation system in order to overcome the nation's weaknesses, addressing the challenges, taking advantage of the potentialities and opportunities available in terms of resources in the country. Also, Mazzucato and Penna (2016) stated that public investments in R&D and innovation are resources that generate better multiplier effects on the economy compared to other government spending. These investments promote the inclusion of innovative technologies that maximize production and consequently the creation of new job openings and quality of human life.

For Tuna *et al*. (2015) sustained growth in developed nations is attributed by most contemporary economists to their intensive R&D activities. Metcalfe (2005) claims that the main objective of scientific policy is to manage and finance the production and accumulation of knowledge regarding about the natural phenomenon through the creation and support of appropriate organizations - research laboratories and universities.

On Science, Technology and Innovation, Salami and Soltanzadeh (2012) points out that there are diferences between the objectives of technological policy and scientific policy. These policies represent broader philosophical considerations for a more instrumental focus on national prestige and economic objectives. Innovation policies are approached by both as an infrastructure to help organizations and institutions involved in science and technology (S&T) policy making.

Mazzucato and Penna (2016) studied Brazilian explicit innovation policies (policies formulated by the Ministry of Finance and the Ministry of Science and Technology (MCTI) and included in science, technology and innovation policy plans) so that they can suggest policy initiatives that allow the National Innovation System (SNI) to be better informed to pursue purposive state-sponsored policies in direct partnership with the private sector. In this study the authors concluded that the innovation policies implemented in the last decades of the twentieth century were flawed because they were based on a restrictive perspective of market failure, and that for the coming years, with targeted innovation policies, it will become efficient in defining the direction and ambitions about its technological trajectory in favor of economic development.

Mendes *et al.* (2013) examined the possible impacts of the National Policy on Science, Technology and Innovation in Brazil, especially in terms of its regulatory framework, on the indicators of the innovative process. They analyzed the probable relationships between the laws: Innovation Law and the Good Law and also analyzed private R&D expenditures during the initial period from 2005 to 2009. The results confirmed that there were significant developments in the innovation indicators after Laws: Innovation and Good, and verified that there has been a positive evolution of private R&D expenditures.

Even with the positive evolution of private spending on R&D according to Mendes et al. (2013), the productivity growth of Brazilian companies has not yet been significant. In the study by Zuniga *et al.* (2016), which aimed to identify ways to promote a more effective National Innovation System (NIS), and to propose a better performance of innovation by the private sector, was an examination of the Brazilian situation with regard to its research activities and technology transfer and innovation to compare with similar economies and also with some developed countries. In this context, the authors stated that there have been significant economic and social progress in Brazil in recent decades, which has contributed to the reduction of poverty and inequality, and pointed out that, despite considerable economic progress, Brazil has experienced low productivity growth in the last six decades in the manufacturing and service industries.

However, even with low productivity growth, as claim by Zuniga *et al.* (2016), Brazilian companies still seek to innovate to better compete in the market. According to Resende *et al*. (2014) who evaluated innovation policies in the context of Brazilian industry in 2003. They focused on complementarity and substitutability tests for obstacles to innovation. They found evidence that international competition promotes companies to be more prone to innovation and yet found evidence that suggests and favors the adoption of more innovation-oriented incentive policies.

In international markets, most competitors innovate and remain competitive, a fact not observed in Brazil. In this context, Erber (2004) claims that companies located in Brazil invest only in R&D and import technology to introduce in their new products and processes.

Brazilian companies to invest in R&D need stimulation. Thus, according to Quadros *et al.* (2001), who analyzed data collected from more than 10,000 industrial companies in the state of São Paulo in 1996, found that companies wholly or partially controlled by foreigners are more likely to introduce new processes and products, in addition to being the companies most employ scientists and engineers to carry out R&D activities.

But in the case of Brazilian companies they are not motivated to invest in R&D by some factor, a large part of these companies acquire innovations to stay more competitive. According to Quadros *et al*. (2001) Transnational corporations from industrialized countries that maintain R&D centers transfer their product and process innovations to the South American market in order to adapt them to local market needs or technical constraints to the supply of materials and components.

Part of the existing problems in Brazil related to the inefficiency of government R&D expenditures are described in the arguments of Gupta *et al*. (2013). Other authors stated that public resources invested in R&D do not benefit the private sector. They stated that basic research carried out by universities is not being transferred to the private producing community, a fact that makes the benefits of research impact the economy.

Gupta *et al*. (2013) also pointed out that innovations in Brazil are largely adapted to local and regional demands and not shared globally. Even so, Brazil has a strong manufacturing sector, dominates the South American region as a regional leader, and has maintained a growing economy.

The adaptation of international technologies in Brazil is observed by Ribeiro (2016). The author studied the transfer of techniques to the semi-arid branch of the Brazilian Agricultural Research Corporation (Embrapa) from the early 1990s. It identified gaps and areas of concern, in particular a fragmentation of macro- and micro-level cooperation that requires effective management in the event of S&T collaboration to consolidate Brazil's international role and geopolitical interests.

Erber (2004) states that in Brazil the majority of investments in scientific and technical research are made by government funds, and more than 40% of R&D expenditures are spent on maintenance and expansion of the postgraduate system. Companies invest only 36% of total R&D expenditures, a percentage equivalent to approximately half of the average investment in the OCDE. Erber (2004) also states that the governments of Brazil and South Korea invest in R&D a portion of GDP (Brazil 0.57% and South Korea 0.7%) and the private sector invest the difference in total investments in R&D. and corresponding to a percentage of GDP, in Brazil 0.9% and in South Korea 2.5%.

To learn about how other countries are managed in terms of innovations, Salami and Soltanzadeh (2012) analyzed the policies and experiences with ST&I of the countries: Brazil; India; China; South Africa; and South Korea, considered successful in managing their technological change. They noted that each country's government played its role in designing and formulating science, technology and innovation policies in their countries. In each of these countries an adequate infrastructure has been created to implement STI policies to enable them to achieve success in their nation's overall national technological development. They concluded that with the analysis of the countries studied, policymakers from least developed countries should adopt ST&I policies that integrate with their national development.

Oliveira *et al*. (2015) analyzed the impact of R&D expenditures in Brazil on national patent applications and the country's Gross Domestic Product (GDP), and the results of econometric models confirm that public and private expenditures are important for GDP growth, and that patent registration is a way of securing intellectual property.

According to the context presented, it is observed that in Brazil there is a slow evolution of the policies of Science, Technology and Innovation (CT&I), even so, there has been progress in the performance of innovations and consequent economic growth. These factors could be better to allow the reduction of the external technological dependence that still prevails in the country.

2.3 Economy and CO_2e emissions

The growth of nations must ensure, over time, a development process in accordance with the objectives and standards of economic, social and environmental sustainability. Researchers conduct daily studies to determine under what conditions and which factors contribute to the increase or decrease in greenhouse gas emissions. These two factors: economic, social and environmental sustainability and increase or reduction of greenhouse gas effect studies (GHG) are facts that are being studied by several researchers and are the constant concern of the governments of each country.

In this sense, Boopen and Vinesh (2010) analyzed the relationship between GDP and carbon dioxide emissions for Mauritius and reciprocally for the year 1975-2009. They used the properties of time series and econometric analysis, and the results suggested that carbon dioxide emission is closely related to GDP over time.

The close relationship between CO_2 emissions and economic growth (GDP) is a consequence of increased productivity and consumption. To have productivity, as a result there is energy consumption. The energy to be produced emits CO_2.

In this reasoning, Soares and Lima (2013) analyzed the relationship between energy production, income and carbon dioxide (CO_2) emissions in Brazil, from 1962 to 2007, and found that in Brazil, even with a relatively clean energy matrix is not managing to reduce CO_2 emissions.

In the same theme as Soares and Lima (2013), researchers Zhang and Cheng (2009) investigated the existence of Granger causality between economic growth, energy consumption and carbon dioxide (CO_2) emissions in China since 1960 to 2007, they applied a multivariate model of economic growth and found evidence that neither carbon emissions nor energy consumption promote economic growth in China.

Therefore, according to Zhang and Cheng (2009), CO_2 emissions and energy consumption do not promote economic growth in China. In this same follow-up Wang et al. (2011) conducted a study with another objective, examining the causal relationships between carbon dioxide emissions, energy consumption and actual economic output in 28 provinces in China during the period 1995 to 2007. Results showed that CO_2 emissions, energy consumption and economic growth appear to be cointegrated. They found that energy consumption and economic growth cause CO_2 emissions. Therefore, they concluded that CO_2 emissions in China will not reduce and could undermine the country's economic growth.

Thus, increased productivity, energy production, energy consumption, increased consumption of goods and consequent economic growth are CO_2 emissions. Thus, many researchers have conducted studies to verify if technological evolution can be the solution to prevent or reduce GHG emissions, as well as to remove them. In this sense, Shaari et al. (2016) analyzed the positive and negative effects of technology in developed countries (Germany, the United Kingdom, France, the United States, and Canada) from 1996 to 2011. Cointegration results showed that there is a long-term relationship between the variables (R&D, GDP, Energy Use and Carbon Dioxide Emissions).

Therefore, in the study by Shaari et al. (2016) showed that energy use and economic growth emit GHG and, as a result, R&D positively and negatively influences CO_2 emissions. Already in a new study by Shaari at al. (2014), the authors investigated the effects of economic growth and foreign direct investment-FDI on CO_2 emissions from 15 developing countries from 1992 to 2012. The results showed a cointegrated relationship. Among the variables (FDI, CO_2 and GDP), they analyzed FMOLS and found that, in the long run, direct FDI has no effect on CO_2 emissions. Therefore, Shaari et al. (2016) stated that increases in economic growth may intensify CO_2 emissions.

3 MATERIALS AND METHOD

3.1 Data

The econometric analysis used secondary data in time series collected from the Ministry of Science, Technology and Innovation - MCTI & C which adopts the methodology according to OECD (2002) "Frascati Manual" of the Organization for Economic Cooperation and Development, for the values of expenditures in Research and Development (R&D). The National Bank for Economic and Social Development (BNDES) is responsible for credit disbursement data.

The Brazilian Institute of Geography and Statistics (IBGE) calculates GDP and discloses in the first half of each year the annual GDP for the previous period. The Greenhouse Gas Emissions Estimating System (SEEG) calculates the estimated values of Brazil's Greenhouse Gas (GHG) emissions using the emission factors from the Intergovernmental Panel's Fifth Assessment Report (AR5) 2013- IPCC. The IPCC adopts the acronym CO_2e for carbon dioxide equivalent to refer to the total GHG Greenhouse Gases (SEEG, 2017).

Table 1 - Time series for econometric analysis of models 1 and 2

	Ano	CO2e[1]	CO2Agro[2]	PDpub[3]	PDpriv[4]	BNDES[5]	PIBpc[6]
1	2000	2.246.338.610,49	384.605.797,46	6.493,84	6.066,81	23.046,00	6.913,25
2	2001	2.231.782.360,62	398.106.835,13	7.447,79	6.525,23	25.216,52	7.480,35
3	2002	2.490.316.648,38	412.154.021,62	7.760,89	7.271,02	37.419,27	8.350,46
4	2003	3.703.761.245,57	435.326.856,74	8.825,99	8.343,02	33.533,59	9.511,04
5	2004	3.929.252.165,35	453.609.253,20	9.335,28	9.526,30	39.833,90	10.703,18
6	2005	3.261.774.332,79	459.307.531,49	10.371,21	11.388,10	46.980,24	11.723,76
7	2006	2.875.364.993,65	458.547.385,27	11.911,11	11.895,90	51.318,02	12.862,61
8	2007	2.681.721.585,19	445.269.796,82	15.184,84	14.231,55	64.891,80	14.359,12
9	2008	2.806.913.074,72	453.033.595,63	17.680,75	17.430,08	90.877,91	16.237,99
10	2009	2.003.105.249,55	460.430.021,97	19.498,13	17.787,17	136.356,36	17.222,52
11	2010	1.924.983.500,34	472.207.175,68	23.039,23	22.033,63	168.422,75	19.877,68
12	2011	1.926.895.069,33	483.930.348,29	26.382,62	23.493,24	138.873,44	22.170,80
13	2012	1.947.464.822,56	478.163.670,37	29.802,88	24.451,71	155.992,27	24.165,02
14	2013	2.106.776.356,05	483.146.335,18	36.783,75	26.964,85	190.419,04	26.520,06
15	2014	2.022.249.199,96	487.909.422,84	38.742,60	34.645,00	187.836,87	28.498,21
16	2015	2.091.294.970,58	490.923.397,59	38.394,40	38.137,40	135.942,05	29.117,47

Source: BNDES (2017); IBGE (2017a); MCTI&C (2017); SEEG (2018)

CO2e = Equivalent greenhouse gases - total gross amount in Brazil (Tons)
CO2Agro = Greenhouse gases equivalent - total gross amount in agriculture (Tons)
PDpub = R&D expenditure by public institutions (Millions of Reais)
PDpriv = R&D expenditure by private institutions (Millions of Reais)
BNDES = BNDES disbursements for companies
PIBpc = Gross domestic product per capita (Thousand reais)

The values of the variables Pdpub, Pdpriv, BNDES are expressed in millions of Reais and in current values. The GDP per capita variable (Pibpc) is expressed in one thousand Reais and the CO_2Agro variable is expressed in tons between 2000-2015. The data for analysis were organized in Table 1 to provide a better view of the evolutions they had during the study period.

3.2 Theoretical Model

Model (1) estimates the linear and nonlinear impact of spending on public R&D (PDpub), private R&D (PDpriv); CO_2e emissions from the agricultural sector (CO_2Agro_2) in Brazil.

$$CO_2Agro_2 = \beta_o + \beta_1 PDpub_t + \beta_2 PDpriv_t + \beta_3 PDpub_t^2 + \beta_4 PDpriv_t^2 + \varepsilon_t \quad (1)$$

Model (2) analyzed the impact of: R&D expenditures for the public (Pdpub) and private (Pdpriv) sectors, BNDES credit disbursements (BNDES); and GDP per capita (BIPpc) on CO_2e Emissions from the agricultural sector (CO_2Agro) in Brazil.

$$CO_2Agro_2 = \beta_o + \beta_1 PDpub_t + \beta_2 PDpriv_t + \beta_3 BNDES_t + \beta_4 BIPpc_t + \varepsilon_t \quad (2)$$

3.3 Estimation Method

For the empirical analysis, econometric modeling was defined as a methodological procedure and the estimation method applied was the Ordinary Least Squares (OLS). For the analysis procedure, two different models were elaborated, the first one using public and private sector research and development (R&D) expenditures in linear and quadratic form, to investigate the impact on CO_2e emissions of the agricultural sector (CO_2Agro2) in Brazil. And, in the second model, besides the expenditures on research and development (R&D) of the public and private sectors, the credit disbursements of the National Bank of Social Economic Development - BNDES and the per capita gross domestic product (GDP) to investigate the impact on CO_2e emissions from the agricultural sector (CO_2Agro) in Brazil. The estimation method uses an econometric approach to time series data from 2000-2015. The dependent variable of both models is the CO_2 emissions from the agricultural sector (CO_2Agro) in Brazil.

All variables were converted to natural logarithms in the econometric analysis to avoid the effects of variables that could affect the data. The use of logarithms improves the interpretation of the coefficients allowing the evaluation to be on a percentage basis.

For the analysis of model fit, R^2 was used. The coefficient of determination, called R^2, which is a measure of fit of a generalized linear statistical model, such as linear regression, in relation to observed values R^2 ranges from 0 to 1, indicating, in percentage, how much the model can explain the observed values. The larger the R^2, the more explanatory the model, ie, the better the model fits the sample (GUJARATI and PORTER, 2011).

4 RESULTS AND DISCUSSION

4.1 Descriptive Data Analysis

CO_2e emissions over the period 2000-2015 grew by an average of 0.74% with an average of 2,515,624,636.6 tons of CO_2e (Table 2), while CO_2Agro emissions grew by an average of 1.66%. (Table 3) and an average of 453,541,965.3 tons of CO_2e (Table 2). Per capita GDP in the same period had an average increase of 10.11% and an average of R $ 16,607.10 (Table 2), suggesting that the growth of GHG emissions did not evolve proportionally to GDP-per capita. However, from 2004 to 2010 there was a reduction in total estimated emissions in Brazil from 3,929,252,165.35 tons to 1,924,983,500.34 tons. In the same period, total estimated emissions from the agricultural sector increased from 453,609,253.20 tons to 472,207,175.68 tons, while GDP-per capita went from R $ 10,703.18 in 2004 to R $ 19,877.68 in 2010.

Table 2 - Descriptive statistics of variables: CO_2et; CO_2Agro; PDpub; PDpriv; BNDES; PIBpc in the periods from 2000 to 2015

	CO_2et[1]	CO_2Agro[2]	Pdpub[3]	Pdpriv[4]	BNDES[5]	PIBpc[6]
Average	2515624636,6	453541965,3	19228,5	17511,9	95435,0	16607,1
Median	2239060485,6	458927458,4	16432,8	15830,8	77884,9	15298,6
Standard deviation	644665080,3	32018139,2	11613,8	9990,0	61894,8	7611,6
Variancy	4,15593E+17	1,02516E+15	134880348	99799360,2	3830964320	57935705,7
Minimum	1924983500	384605797,5	6493,8	6066,8	23046,0	6913,3
Maximum	3929252165	490923397,6	38742,6	38137,4	190419,0	29117,5
Score	16	16	16	16	16	16

Source: the author based on BNDES (2017); IBGE (2017); e MCTI&C (2017)

CO2et = Equivalent greenhouse gases - total gross amount in Brazil (Tons)
CO2Agro = Greenhouse gases equivalent - total gross amount in agriculture (Tons)
PDpub = R&D expenditure by public institutions (Millions of Reais)
PDpriv = R&D expenditure by private institutions (Millions of Reais)
BNDES = BNDES disbursements for companies
PIBpc = Gross domestic product per capita (Thousand reais)

In the inference of these data, it appears that the agricultural sector is emitting greenhouse gases, proportionally much higher than the total CO_2e emissions of Brazil.

R&D expenditures for public and private institutions increased from 12.80% to 13.30% from 2000 to 2015 (Table 3) and averages of 19,228.5 and 17,511.9 (millions of Reais) respectively (Table 2), which shows a balance between expenditure for both sectors.

The loans made by BNDES in the period under study resulted in an average percentage of 14.75% (Table 3) and an average of 95.435.0 (millions of Reais) (Table 2), while the per capita BIP had 10.11%. average increase over the same period (Table 3).

The three variables PDpub, PDpriv, BNDES, and PIBpc had average increases of 12.80%, 13.30%, 14.75%, 10.11% (Table 3) respectively, while the variables CO_2Agro and CO_2e had an average increase of 1.66% and 0.74%. Given these data it can be inferred that the variables under study may influence the stabilization of greenhouse gas emissions.

Table 3 - Percentages of annual changes in variables

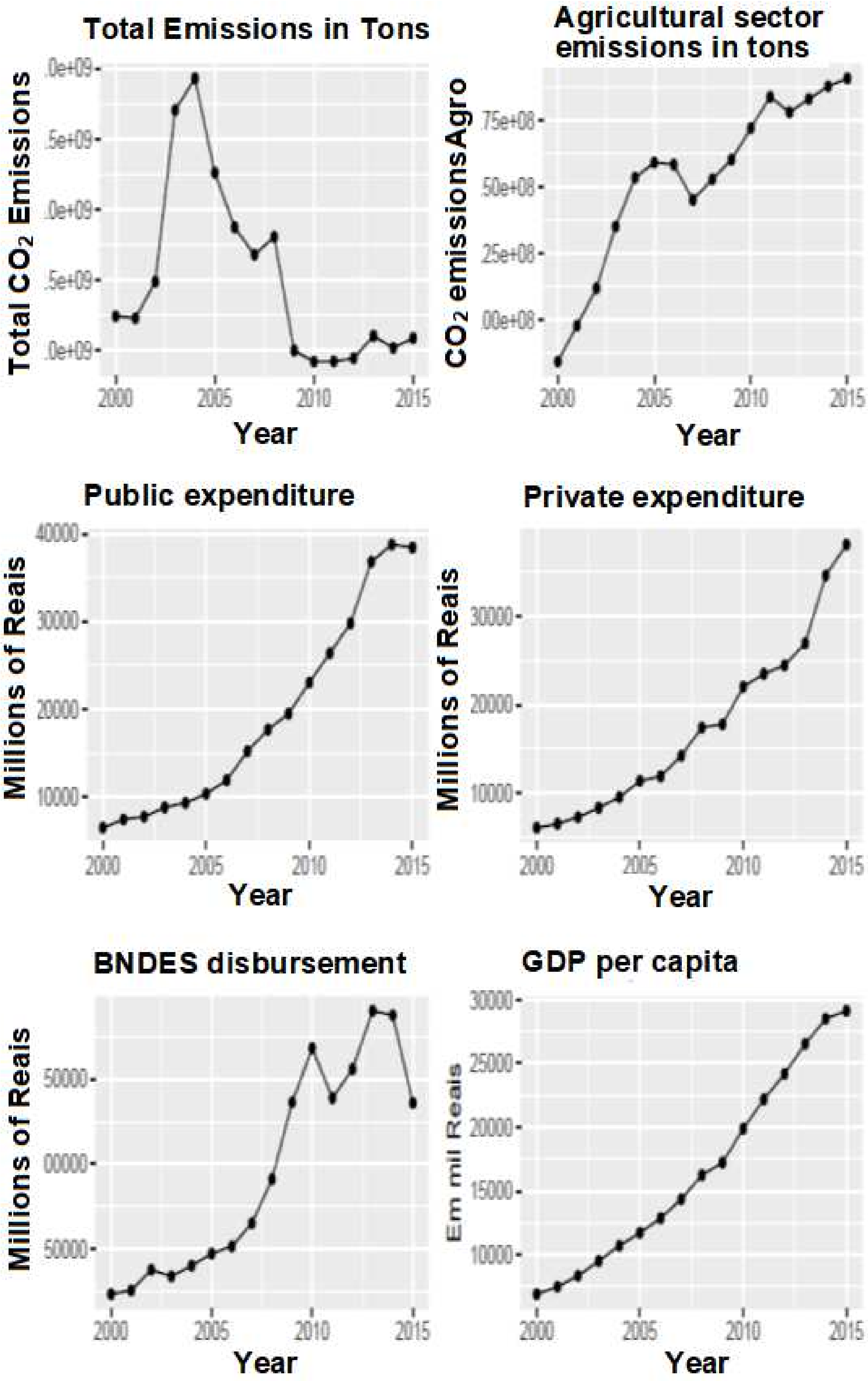
Year	CO2e[1]	CO2Agro[2]	Pdpub [3]	Pdpriv [4]	BNDES [5]	PIBpc[6]
2000	0,00	0,00	0,00	0,00	0,00	0,00
2001	-0,65	3,51	14,69	7,56	9,42	8,20
2002	11,58	3,53	4,20	11,43	48,39	11,63
2003	48,73	5,62	13,72	14,74	-10,38	13,90
2004	6,09	4,20	5,77	14,18	18,79	12,53
2005	-16,99	1,26	11,10	19,54	17,94	9,54
2006	-11,85	-0,17	14,85	4,46	9,23	9,71
2007	-6,73	-2,90	27,48	19,63	26,45	11,63
2008	4,67	1,74	16,44	22,47	40,05	13,08
2009	-28,64	1,63	10,28	2,05	50,04	6,06
2010	-3,90	2,56	18,16	23,87	23,52	15,42
2011	0,10	2,48	14,51	6,62	-17,54	11,54
2012	1,07	-1,19	12,96	4,08	12,33	8,99
2013	8,18	1,04	23,42	10,28	22,07	9,75
2014	-4,01	0,99	5,33	28,48	-1,36	7,46
2015	3,41	0,62	-0,90	10,08	-27,63	2,17
Average	0,74	1,66	12,80	13,30	14,75	10,11

Source: the authors based on data from: BNDES (2017); IBGE (2017); MCTI & C (2017)

CO2et = Equivalent greenhouse gases - total gross amount in Brazil (Tons)
CO2Agro = Greenhouse gases equivalent - total gross amount in agriculture (Tons)
PDpub = R&D expenditure by public institutions (Millions of Reais)
PDpriv = R&D expenditure by private institutions (Millions of Reais)
BNDES = BNDES disbursements for companies
PIBpc = Gross domestic product per capita (Thousand reais)

The evolution of the variables of this study is shown in Figure 1.

Figure 1 - Annual evolution of variables



Source: the author in the data base: BNDES (2017); IBGE (2017a); MCTI&C (2017); SEEG (2018**).**

4.2 Analysis and discussion of econometric results

The proposed models were estimated in order to analyze the impact of R&D expenditures for the public and private sectors and the economy (BNDES credit disbursements and GDP per capita) on agricultural sector CO_2 emissions (CO_2Agro) in Brazil between the period 2000 and 2015.

Table 4 presents the econometric results.

Table 4- Econometric results of models 1 and 2

	Dependent variable:	
	log(CO2Agro)[1]	
Variável	Modelo 1	Modelo 2
[2]log(PDpub)	-0.373**	-353***
	(0.137)	(0.049)
[3]log(PDpriv)	0.522***	-0.078
	(0.134)	(0,058)
[4]PDpub2	-0.000*	
	(0.000)	
[5]PDpriv2	-0.000**	
	(0.000)	
[6]log(BNDES)		-0.003
		(0,018)
[7]log(Pibpc)		0.697***
		(0,093)
Constant	18.546***	17.445***
	(0.230)	(0.189)
Observations	16	16
R^2	0.922	0.977
Adjusted R^2	0.893	0.969
Residual Std. Error (df = 11)	0.024	0.013
F Statistic (df = 4; 11)	32.367***	118.533***
Note:	*p<0.1; **p<0.05; ***p<0.01	

Log(COAgro) = Carbon dioxide equivalent logarithm - total gross amount in agriculture
Log(PDpub) = R&D expenditure log by public institutions (millions of Reais)
Log (PDpriv) = R&D expenditure log by private institutions (millions of Reais)
PDpub² = R&D expenditure by public institutions
PDpriv² = R&D expenditure by private institutions
Log (BNDES) = BNDES Disbursement Logarithm for Companies (millions of Reais)
Log (PIBpc) = Logarithm of gross domestic product per capita (thousand Reais)

4.2.1 Analysis and discussion of the results of Models 1 and 2

Table 4 presents the econometric results of the two models. Model 1 analyzes the linear and nonlinear impact of public and private R&D expenditures on CO_2Agro emissions. Model 2 analyzes the linear impact of: public and private R&D expenditures; credit disbursements made by BNDES; and Gross Domestic Product Per capita on CO_2Agro emissions. The fit of the models presented a great level, in Model 1 R^2 was 0.922 and in Model 2 R^2 was 0.977

In Model 1, the logarithm of R&D expenditure for the Public-log sector (Pdpub) resulted in -0.373 (negative) and significant with p-value <0.05. This result suggests that increases in R&D expenditure in the public sector promote the reduction of CO_2e emissions in the agricultural sector in a linear manner. In the nonlinear form the coefficient was -0,000 and p-value <0.10 significant.

In Model 2, the R&D expenditure coefficient for the Public-log sector (Pdpub) resulted in -353 (negative) and significant with p-value <0.01. This result suggests that the greater the investments in R&D in the public sector, the lower the CO_2e emissions in the agricultural sector.

Therefore, both models presented similar results, but model 2 presents a more significant result because it presents higher coefficient and statistical significance. So, these results suggest that R&D expenditures for the public sector contribute to the reduction of CO_2e and agricultural emissions. Consequently, there is evidence that public R&D expenditures positively impact CO_2e and livestock emissions.

The study by Raulino (2018) corroborates the results of this analysis. The author states that the greater the investments in technologies, especially in technologies that enable the mitigation of GHG emissions and the reduction of environmental impacts, the better the conditions of social welfare.

Moreover, this result is in agreement with the studies by Yii and Geetha (2017) that examined the causal relationship between technological innovation and CO_2e emissions with economic growth, electricity consumption and energy price in Malaysia. Data over the period from 1971 to 2013 were analyzed using the VECM and TYDL granger causality tests. The results indicated that technological innovation is negatively related to short-term CO_2e emissions, while no long-term relationship was found, ie, the study suggests that technology innovation promotes, in the short term, the reduction of CO_2e emissions.

The result still goes against Fernández et al. (2018) who in their study empirically verified whether innovation efforts have a positive effect on reducing CO_2e emissions in the European Union, the United States and China from 1990 to 2013. The estimate was made using an ordinary least squares linear regression, using R&D expenditures and energy consumption as independent variables. The results support the hypothesis that the reduction of CO_2 emissions in developed countries may be a consequence of the contribution of R&D expenditures.

As an example that R&D corroborates the reduction of CO_2 emissions is suggested in the study by Burchart-Korol et al. (2016) aimed to disseminate the technological innovations that most participate in reducing greenhouse gas emissions during the production of steel. The result featured innovative steelmaking technologies that reduce greenhouse gas (GHG) emissions by 25-35%.

Model 1 the logarithm of R&D expenditures for the private sector resulted in a coefficient of 0.522 (positive), with p-value <0.01 with high significance. That is, in the linear impact analysis, increases in R&D expenditure in the private sector corroborate with the increase in agricultural CO_2 emissions, but at the first moment, in the nonlinear impact analysis, the coefficient resulted in -0,000 (negative) and with significance p-value <0.05, data that suggest the existence of a maximum point, and from this point, the CO_2 emissions from Farming begin to decrease with each unit invested in private sector R&D. This result suggests that spending on private R&D may contribute to the reduction of CO_2e and agricultural emissions over time. Similar result, which suggests that private sector R&D expenditures contribute to increased agricultural CO_2 emissions, no other study was found.

In model 2, in contrast to the result of model 1, expenditures on research and development (R&D) for the private sector, when analyzed together with the logarithm of BNDES credit disbursements and per capita gross domestic product, presented a coefficient -0.078 (negative) and with p-value> 0.10 without statistical significance. But because the coefficient is negative, it shows that increases in R&D spending in the private sector promote a reduction in CO_2e in the agricultural sector, but with little intensity. This result is in agreement with the studies by Fernández *et al*. (2018) and Burchart-Korol *et al*. (2016), who stated that investments in R&D contribute to the reduction of CO_2e emissions.

Therefore, the result of the impact of private R&D expenditures on Model 1 was in contrast to the impact of public sector R&D expenditures, that is, public sector R&D promotes reduction of agricultural CO_2 emissions and private sector R&D increases greenhouse gas emissions. Agricultural CO_2, but until a certain time, and after that, also reduces emissions.

Thus, it can be recommended that private sector R&D expenditures could be favorable for reducing CO_2e emissions if they were to be realized in larger amounts so as to enable the same effects as R&D expenditures on the public sector.

In this context, Zuniga et al. (2016) ensure that the Brazilian private sector invests little in science, technology and innovation (CT&I) in various critical areas of research, development and innovation (RD&I), or other intangible assets when compared to its peers and OECD countries. Erber (2004) in his study stated that the Brazilian government makes most of the investments in R&D, while the public sector invests only 36%.

According to the above considerations, any R&D expenditure can corroborate the reduction of CO_2e emissions, a fact that is in agreement with the authors Solow (1956) and Gonda (2005) who defended the technology with the argument that the ecological problems caused by the economic growth will be overcome with technological progress that creates new resources to meet new or old needs, or replaces scarce resources and / or saves existing resources.

In Model 2, the log(BNDES) variable had the same behavior as R&D expenditure for the private sector, with the coefficient -0.003 (negative) and not statistically significant with p-value> 0.10. This result has low relevance to corroborate the increases or reductions in CO_2e emissions from the agricultural sector. But according to Muhammad *et al*. (2013) who examined the links between economic growth, energy consumption, financial development, trade openness and CO_2e emissions during the period from 1975 to 2011 in Indonesia. Empirical results have suggested that economic growth and energy consumption increase CO_2e emissions, but financial development and trade openness compress it and may play a role in improving environmental quality. Thus, according to the results of the study by Muhammad et al. (2013), we can consider that BNDES plays a significant role in financial development, which in turn corroborates the compression of CO_2e emissions.

According to the studies listed in this item, it can be inferred that with the financial development and consequent increase in the supply of resources in the market, as performed by BNDES, it is possible to reduce or intensify emissions.

In Model 2, the GDP per capita presented the coefficient 0.697 (positive) and with statistical significance p-value <0.01. This result demonstrates that per capita GDP impacts emissions with increases in agricultural CO_2. This result shows high relevance of this variable, but it is opposite to the results of the other variables of this model, because the per capita GDP corroborates the increase of CO_2Agro emissions.

This result confirms the studies by Shaari et al. (2014) when they stated that increases in economic growth may intensify CO_2 emissions. It also corroborates the studies by Cederborg and Snöbohm (2016) that examined the relationship between GDP per capita and per capita emissions of CO_2e.

The study was conducted in 69 industrialized countries and 45 poor countries using cross-sectional data. The empirical result of the cross-sectional study indicated that there is a relationship between GDP per capita and CO_2e emissions per capita. The correlation was positive, suggesting that GDP growth per capita leads to increased CO_2e emissions

Therefore, the analysis of the impact of GDP per capita on agricultural CO_2 emissions suggests that this variable promotes increases in agricultural CO_2 emissions.

5 CONCLUSIONS

In the context of the study, it was found that increases in public and private research and development (R&D) expenditures lead to a reduction in CO_2e emissions. Therefore, R&D expenditures generate positive externalities for the environment and, in this study, specifically, are the reductions of impacts on CO_2e emissions in the agricultural sector. But it should be noted that in the linear analysis of the impact of increases in R&D expenditures in the private sector, it was found that they corroborate the increase in CO_2 and agricultural emissions, but in the first instance, in the analysis of nonlinear impact there is a suggestion of the existence of a maximum point, and from this point, Agricultural CO_2 emissions begin to decrease with each unit invested in R&D in the private sector.

The behavior of economic variables (disbursements with BNDES credit and Gross Domestic Product per capita) are not similar, disbursements from BNDES promote a reduction in agricultural CO_2 emissions with low statistical significance, GDP per capita presented high statistical significance in the impact of emissions, that is, strongly corroborates the increase in emissions in CO_2e and agriculture. Therefore, the results suggest that with the development of the country, and from the increase in R&D expenditures for both public and private sectors, clean technologies will be generated over time, aiming at reducing CO_2e emissions in the agricultural sector. This sector is very important for the Brazilian and world economy.

Therefore, it is suggested, as a possible discussion for future works, to analyze the impact of expenditures on Research and Development in the Public and Private Sector on CO_2e emissions by other productive sectors in South America.

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Como Referenciar este Artigo, conforme ABNT:

G. J. VALERETTO, M. A. C. OLIVEIRA, G. E. O. PORFIRIO, R. B. COSTAM C. L. CHIARIELLO. Do Expenditures on Research and Development (R&D) Cause Externalities in the Environment? Empirical Evidence for Brazil. **Rev. FSA**, Teresina, v.19, n. 1, art. 6, p. 104-129, jan. 2022.

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