Climate Change, Agricultural Productivity and Economic Performance: an exercise using a Dynamic CGE Model

M. Nazareth[1]; D. Cunha[1]; A. Gurgel[2]

1: Universidade Federal de Viçosa, Departamento de Economia Rural, Brazil, 2: Fundação Getúlio Vargas, Escola de Economia de São Paulo, Brazil

Corresponding author email: marcos.nazareth@ufv.br

Abstract:

Agriculture is highly dependent on environment conditions, mainly temperature, precipitation and soil quality, thus it becomes the most vulnerable economic sector to the new climate conditions projected for the next decades. Therefore, knowing these impacts and the consequences for the rest of the economy is essential to map the effects and to elaborate, if necessary, mitigating environmental and economic policies. However, studies focusing on Brazil based on more regionalized data but linked to the rest of the world using dynamic computable general equilibrium (CGE) models are still very incipient. So this is precisely the gap that this article intends to fill, offering a modest contribution to the debate. Then, the objective of this paper is to determine the economic impact of the estimated changes in average agricultural productivity for the coming decades using a dynamic CGE model, the PAEGDyn linked to GTAP. Basically, the results found confirm trends in other works: the tropical regions in the world will be the most affected by the probable increase in the planet temperature, decreases in agricultural productivity and, thus, a reduction in economic performance.

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JEL Codes: Q54, Q01

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CLIMATE CHANGE, AGRICULTURAL PRODUCTIVITY AND ECONOMIC PERFORMANCE: AN EXERCISE USING A DYNAMIC CGE MODEL

ABSTRACT

Agriculture is highly dependent on environment conditions, mainly temperature, precipitation and soil quality, thus it becomes the most vulnerable economic sector to the new climate conditions projected for the next decades. Therefore, knowing these impacts and the consequences for the rest of the economy is essential to map the effects and to elaborate, if necessary, mitigating environmental and economic policies. However, studies focusing on Brazil based on more regionalized data but linked to the rest of the world using dynamic computable general equilibrium (CGE) models are still very incipient. So this is precisely the gap that this article intends to fill, offering a modest contribution to the debate. Then, the objective of this paper is to determine the economic impact of the estimated changes in average agricultural productivity for the coming decades using a dynamic CGE model, the PAEGDyn linked to GTAP. Basically, the results found confirm trends in other works: the tropical regions in the world will be the most affected by the probable increase in the planet temperature, decreases in agricultural productivity and, thus, a reduction in economic performance.

Keywords: Brazilian Regions, Simulations, CGE models.

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1 INTRODUCTION

The exponential increase in the demand for goods and services due to the strong economic development in the last decades around the globe has caused, as one of its effects, deforestation, depletion of fossil fuels, emission of pollutants and greenhouse gases, among other consequences in the stock of natural resources of the planet, leading to a situation where human demands may be overloading the resilience capacity of the biosphere (Intergovernmental Panel on Climate Change – IPCC, 2014).

This situation has resulted in the process known as global environmental change, whose main manifestation is climate change. In addition, it is widely recognized that, because agriculture is highly dependent on conditions, mainly temperature, precipitation and soil quality, it becomes the most vulnerable economic sector to the new climate conditions projected for the next decades. Therefore, knowing these impacts and the consequences for the rest of the economy is essential to map the effects and to elaborate, if necessary, mitigating environmental and economic policies.

In this sense, the long-term impacts of climate change on agricultural productivity, in Brazil as well as around the world using typically agronomic models are well documented in the literature (Zhao et al., 2017; Rosenzweig et al., 2014). However, sophistication in modeling, agricultural crops and selected regions and, of course, estimated magnitudes are still widely debated. Anyway the existing estimates subsidize the complementary investigations, especially those of economic nature.

Thus, the number of researches that seek to extend productivity impacts to economic variables (GDP, income, commodities market, etc) has increased worldwide recently, given the relevance of this sector to the world economy and, especially due to food security issues involved for the next decades (Andrade, 2016; Domingues et al. 2016).

To that end, empirical strategies use econometric models with basically two currents of research: the estimation of a typical production function and the Ricardian approach. Several studies have been carried out with several important results, for example, in the repercussions on regional and class income inequalities (Feres et al., 2009; de Moraes, 2010). In any case, the theoretical and empirical debate in literature is in progress all over the world.

However, studies focusing on Brazil based on more regionalized data but linked to the rest of the world using dynamic models of computable general equilibrium are still very incipient (Ferreira Filho e de Moraes, 2014). Therefore, this is precisely the gap that this article intends to fill, offering a modest contribution to the debate.

Thus, the objective of this paper is to determine the economic impact of the estimated changes in average agricultural productivity for the coming decades using a dynamic computable general equilibrium economic model, the PAEGDyn linked to GTAP, for the five major Brazilian regions and more three regions selected, including the others countries in the world.

The paper is structured as follows: after this introductory section, section 2 presents a brief literature review on the topic. Section 3 presents the economic model, the database and the scenarios used. The fourth section discusses the simulations results. Finally, section 5 summarizes the main conclusions of the article and presents some policy recommendations.

2 LITERATURE REVIEW

The agronomic and economic literature about the effects of global climate change on global agriculture is extensive and has many ramifications, mainly in terms of models and databases used, climate scenarios for the coming decades, types of factors considered (CO2 level, pluviometric change, etc.), the adoption of adaptation and mitigation policies, the degree of technological advance, the time horizon, the regions of the world considered, the types of crops evaluated, the prediction indicators (such as income groups most affected, for example) and so on.

In Rosenzweig et al. (2014), for example, a typically agronomic approach is used by Global Gridded Crop Models (GGCMs) in order to measure impacts of climate change on the production and productivity of soy, rice, wheat and maize globally. By comparing results, the authors highlight how sensitive are the structural and parameterization differences of the models.

Zhao et al. (2017) report results from various publications using different analytical models and show that independent methods consistently estimate the negative impacts of temperature increases on agricultural yields at the global and regional levels[1]. Finally, they suggest the expansion of research and extension programs at the regional level aiming to elaborate an effective adaptation strategy to the expected impacts of climate change.

Nelson et al. (2014) shows results of climate impacts change on agriculture in a series of economic models, especially of computable general equilibrium (CGE). Although there are differences in the choice of parameters and specification of these models, there is a certain convergence of results. The endogenous responses of economic models distribute the effects of climate change on the selected economic variables, moreover, there is more heterogeneity in the responses from the production side than from the consumption side.

According to the same authors, the negative effects on productivity increase prices, as expected. It activates more effective practices of production management, area expansion, reallocation of

[1] In the four main agricultural crops again: rice, corn, soy and wheat.

resources through international trade and consumption reduction, especially in poorer areas. Therefore, knowing the differences and magnitudes of these effects is crucially important because of the consequences in human well-being.

In the case of Brazil, there are typically regional issues to be considered due to the territorial extension and the radical differences in climate, soil, type of predominant crop, use of technology and other differences in characteristics (including or especially economic) among large Brazilian regions. In fact, it makes Brazil a kind of small-scale sample of what happens around the world. Oliveira *et al.* (2013), for instance, explores particular characteristics of the Brazilian Legal Amazon and the negative consequences of the agricultural expansion coming from increases in the planet temperature.

Pires et al. (2016) use a technical model to measure impacts of climate change on soy production and productivity in regions of Brazil, as well as in Argentina and Paraguay. The results suggest a worsening in indicators in the central-north regions of Brazil until 2050 (regions of tropical climate) and improvement in the south region of the country and Argentina (temperate regions).

According to Feres et al. (2009), in general, studies about Brazilian agriculture suggest that the effects of climate on the agricultural sector will be very different among regions. The studies identify the North, Northeast and part of the Midwest as the most vulnerable to the effects of climate change. Municipalities located in the southern regions could benefit from the higher temperatures projected by climatological models. In Assunção and Stein (2016) the same trend is observed.

In Ferreira Filho and de Moraes (2014) a static computable general equilibrium (CGE) model was used to evaluate impacts of climate change on the Brazilian economy. Different types of income, capital mobility and endogenous investment were considered in the model, which gave it a long-term (though static) character. The criteria used to simulate the impacts of climate change on agriculture are based on the concepts of viable agricultural areas or the loss of viability of areas due to changes in climate. The most interesting result is the confirmation that the currently hottest and poorest regions will be the most affected, with a reduction in work force via migration. Therefore, the inevitable prediction is that, *ceteris paribus*, there will be a worsening effect of regional inequalities in Brazil.

Finally, de Moraes (2010) also using EGC to evaluate economic impacts of climate change scenarios for Brazilian agriculture. In the milder scenario, the northeast and center-west regions show the greatest economic losses (in the central west, especially because of soy), benefiting the Southeast. There is a rise in food prices and regional labor displacements. For the most severe scenario, the northeast and center-west remain the most affected, but gains for Southeast economic activity are lower causing a larger national decline from the milder scenario, with migration trends remaining the same. These results corroborate once again that, in the absence of more intense adaptation and mitigation measures, climate change may pose a greater risk to historically underdeveloped or newly developed regions.

3 ANALYTICAL FRAMEWORK

In order to determine the economic impact of the estimated productivity changes in agriculture due to climate change, a multi-regional dynamic recursive version of the static PAEG model built on the GTAPinGAMS programming was used in this paper, the PAEGDyn[2].

The General Economic Analysis of the Brazilian Economy Project (PAEG) is a static[3], global, multiregional and multi-sector computable general equilibrium model, constructed for analyzing the

[2] In the recursive dynamic model basically the results of one period operate as initial values of the subsequent period.
[3] In original version.

Brazilian economy in a regional way, each of the five major regions being represented by an intermediary and final demand structure composed of selected sectors and public and private expenditure on goods and services (Teixeira *et al.*, 2013). It is fully integrated with the Global Trade Analysis Project (GTAP) model and database, version 9.

In GTAP, the world is divided into regions, typically representing individual countries, and the final demand of each region is made up of private and public expenditures. Therefore, the database encompasses a complete set of bilateral trade flows, including transport costs, export taxes and rates, and matched national input-output tables[4].

The PAEG has the basic structure of the GTAPinGAMS model, originally created by Rutherford (2010). GTAPinGAMS was elaborated as a non-linear complementarity problem in the GAMS (General Algebraic Modeling System) programming language.

PAEG is based on neoclassical microeconomic assumptions for agent behavior: the representative consumer seeks to optimize his or her welfare subject to a budget constraint, and the productive sector combines intermediate inputs and primary factors, with a view for minimizing costs, given the technology[5].

On the assumption, preferences are continuous and convex, resulting in continuous and homogeneous demand functions of degree zero in relation to prices, that is, only relative prices can be determined. On the firm side, technology is represented by a production function with constant returns to scale, meaning that firms' economic profit is zero in equilibrium, acting in markets perfectly competitive.

In this way, three essential conditions of database consistency can be enumerated: market equilibrium (supply equal to demand for all goods and factors); income balance, that is, net income equal to the net expense for each economic agent; and, finally, income is exhausted by productive units, given a set of identities that apply to each productive sectors: economic profit equal zero.

Regarding the macroeconomic closure rules, the distinction between the static and dynamic mode is imposed, characterizing the use of PAEGDyn in this paper. Thus, it was necessary to specify the parameters that controlled capital accumulation and depreciation in the model.

As it is a recursive dynamic model, these parameters gave the greater or lesser intensity of the changes from year to year. The initial specification was a depreciation rate of 5% for all regions annually. The annual rate of return on investment was 5% for the rich regions (Nafta, euro countries and southeast of Brazil) and 10% for other regions

The initial capital was defined as the income of primary factors for the capital factor in all regions. That is, the initial capital base according to GTAP database 9. The initial PIB is the sum of the values of the private consumption with the government consumption with the production value of capital goods, plus the sum of the values of the net exports. The initial values will be calculated and adopted as a static version balance benchmark.

With respect to investment, this is inserted in the model to compose the regional production. Its price is specific to each region and is determined in the savings/investment market. Private demand is separate for non-Brazilian regions and Brazilian ones. The regional representative agent consumes the commodity denoted by the price *pw* (welfare level) and receives as income the allocation of factors. The investment was considered exogenous in the static PAEG. In PAEGDyn it is endogenous

[4] For a full description of the GTAP, see Hertel (1997).
[5] The microeconomic closure rules of PAEG are well documented in Teixeira et al. (2013).

and varies in the same proportion of consumption, that is, it is considered that there is a marginal propensity to save constant in the economy, and savings equal investment (neoclassical hypothesis).

Parameters were also created to express the increase in labor supply, labor productivity, land productivity, capital productivity and factor productivity. The increase in labor supply is specified with different growth rates for the subsets of rich, European, middle-income and poor countries. From year 2, the growth rate per year of the rich is 0.5% (Nafta and Southeast); of the countries of the European Union is 0.2%; of middle-income countries is 1% (Midwest and South); and poor countries is 1.5% (North, Northeast and rest of the World). For labor productivity, a growth rate per year of 1% was adopted. For the productivity of capital, there is a growth per year to 0.75% for rich countries and 1% for others. For land productivity, the rate per year is 0.5% for the rich and 1% for others. For PIB growth relative to 2016, the annual growth rates per years are: 3% for the Brazilian regions; 2.5% for the Nafta countries; 2% for the European Union; and 3.5% for the others[6].

Finally, factor productivity is compounded by the variation in the productivity of each factor. For the case of labor factor, productivity varies by product between supply and labor productivity. The price elasticity of land supply is assumed and the increase of the crops total area is based on the total price of land. The price elasticities of land supply will be: 0.5 for the North region; 0.3 for the northeast and midwest; 0.15 for the Southeast and 0.1 for the south.

The works of Teixeira et al. (2006), Pereira (2011), Gurgel (2002), Rutherford (1999) and Hertel (1997) present a complete exposition of the behavioral and equilibrium equations of PAEG base model and its original sources: GTAP and GTAPinGAMS.

The equations guarantee the presence of market equilibrium for all goods and factors, balance of income of economic agents and the existence of zero profit conditions, according to the presuppositions that define the model.

In this sense, it is worth mentioning that the construction of a computable general equilibrium model also includes the attribution of functional forms to the economic agents, so that, presumably, they represent their behavior in the generation of revenue and expenditure flows of the data matrix. The purpose is that the values expressed in these flows result from optimal behavioral actions.

Thus, the structure of the optimization problems of each economic agent, the respective technological decision trees and the equations derived from the equilibrium conditions of this study are exactly the same as the standard PAEG model. All parameters of substitution elasticities at each level choice of the technology trees are taken from the GTAP version 9 database[7]. The interested reader can check the reference literature of the base model cited above.

3.1 Database and simulations

Table 1 shows the aggregation of PAEGDyn used in this work composed of 3 sectors, 8 regions and three factors of production: labor, capital and land. The three aggregate sectors are agricultural, manufacture and services. And still the five major regions of Brazil; the United States, Canada and Mexico added as Nafta (NAF); European Union, with 25 Member States (EUR), therefore, without considering the entry of the last three[8], as well as without excluding the United Kingdom; the other countries contained in the GTAP database are assembled in the rest of the World (ROW).

[6] These rates were taken from the World Bank Global Economic Prospects document by the year 2021 and extrapolated to the others.
[7] See Aguiar et al. (2016).
[8] Bulgaria, Romania and Croatia.

In this sense, it is emphasized that this is an initial investigative exercise within a long-term research agenda that intends to estimate in greater detail the economic impacts of agricultural productivity changes due to climate change using a dynamic computable general equilibrium model. In order to do so, it is intended in the future to disaggregate the agricultural sector in at least the four main crops (rice, maize, soybeans and wheat) to the most important producing regions/countries in the world, as well as detailing land use in Brazil.

The regionalized database for the Brazilian economy compatible with GTAP 9.0 for the year of 2011 was used by PAEGDyn model as reference for calibration of the model. The standard code of the PAEG model, written in MPSGE, has also undergone modifications in order to be adapted to the dynamic model and required shocks[9]. The Mathematical Programming System for General Equilibrium (MPSGE), developed by Thomas Rutherford (Rutherford, 1999), is a programming language developed to solve economic equilibrium models of the Arrow-Debreu type. The MPSGE, using the GAMS programming language as an interface, also allows access and modification of both the database and the basic GTAP model, according to the research purposes[10].

Table 1 – Aggregations and notations of sectors, regions and production factors

Sectors		**Regions**	
Agriculture	agr	Brazil	BRA
Manufacture	man	North	NOR
Services	ser	Northeast	NDE
		Midwest	COE
Production Factors		Southeast	SDE
Labor	lab	South	SUL
Capital	cap	Nafta	NAF
Land	lnd	European Union	EUR
		Rest of the world	ROW

Source: Adapted from Teixeira et al. (2013).

This study intended to construct scenarios that could predict in an aggregate and preliminary way the impact of the estimated changes in average agricultural productivity due to climate changes in macroeconomic indicators of selected regions over 30-years, from 2017 to 1946. This forecast period was chosen because most estimates consider 2050, the turn of the century, as a measurement framework and by the level of reasonableness possible of long-term projection of parameters used in the dynamic model[11].

Table 2 presents the three scenarios with the respective mean values implemented in the average agricultural productivity (AAP) shocks[12].

As can be seen, two scenarios of the IPCC were chosen: the most optimistic (RCP 2.6) and the most pessimistic (RCP 8.5) in relation to the reference scenario (with no average change in agricultural productivity). In a way, they represent a linear combination of two extreme measures of climate change effects. It is likely that the true economic impacts are within the range created by the results found in both scenarios.

[9] The complete data matrix and the GAMS code of the PAEGDyn model are available for reference.

[10] In order to facilitate the formulation and solution of computable general equilibrium models, the MPSGE elaborates them as a mixed complementarity problem (MCP).

[11] 30 years is also the period used by the World Meteorological Organization to define climatic conditions.

[12] In the course of this research it is also intended to increase the time horizon with estimates of more precise parameters and average changes in agricultural productivity in shorter periods, such as decades, for example.

Finally, it should be noted that only the southern regions of Brazil and European countries have projections of average productivity increase for scenario 1 because they have temperate climates, therefore, they are favored by the increase in the moderate temperature and consequent viability of previously uncultured crops.

Table 2 – Scenarios implemented with productivity shocks in agriculture in each region

Regions	**Scenarios**		
	Reference **– RS**	**S1** (RCP 2.6)	**S2** (RCP 8.5)
NOR	0	-5	-13
NDE	0	-16	-30
COE	0	-8	-16
SDE	0	-3	-9
SUL	0	3	-5
BRA (mean)	0	-6	-15
NAF	0	-5	-14
EUR	0	3	-3
ROW	0	-4	-11

Source: Zhao et al. (2017); Assunção and Stein (2016); Pires et al. (2016); Nelson et al. (2014).

4 RESULTS

The tables below show impacts indicators of average agricultural productivity (AAP) shocks on six macroeconomic variables using PAEGDyn for two climate change scenarios in 8 selected regions, as described in the previous section.

Table 3 shows the findings for GDP. As expected, in all regions and scenarios where agricultural productivity reductions are projected, decreases in projected GDP growth over the next 30 years is noted. The losses of GDP are not greater because the reductions in the product supply of the agricultural sector and the consequent increase of its prices causes that migration of production primary factors to the other two great sectors of the economy in order to face the increase of the their demands. Even so, the relative annual losses in PIB growth are significant in both scenarios.

Table 3 – GDP Results

Regions	**growth over 30 years (bi US$)**			**relative variation (bi US$)**		**relative variation (%)**		**relative variation annual mean - RVAM (%)**		**RVAM/produtivity variation mean estimation**	
	RS	**S1**	**S2**	**S1/RS**	**S2/RS**	**S1/RS**	**S2/RS**	**S1/RS**	**S2/RS**	**S1**	**S2**
NOR	241.20	238.81	234.61	-2.39	-6.59	-0.99	-2.73	-0.76	-2.11	0.15	0.16
NDE	590.99	567.61	540.72	-23.38	-50.27	-3.96	-8.51	-2.66	-5.60	0.17	0.19
COE	409.24	392.51	371.83	-16.73	-37.41	-4.09	-9.14	-2.78	-6.04	0.35	0.38
SDE	2,217.66	2,208.45	2,188.05	-9.21	-29.60	-0.42	-1.33	-0.17	-0.60	0.06	0.07
SUL	655.73	665.66	649.83	9.93	-5.90	1.51	-0.90	0.90	-0.64	0.30	0.13
NAF	21,173.23	21,123.47	21,021.32	-49.77	-151.92	-0.24	-0.72	-0.18	-0.55	0.04	0.04
EUR	14,335.81	14,374.67	14,304.07	38.86	-31.75	0.27	-0.22	0.14	-0.23	0.05	0.08
ROW	44,274.38	43,762.51	42,779.83	-511.87	-1,494.55	-1.16	-3.38	-0.80	-2.34	0.20	0.21

Source: by the authors.

However, there are two exceptions in scenario 1 (milder): the southern Brazilian regions and the European Union, both with autistic expectations of productivity with temperature increases, causing distancing of wealth level between rich and poor regions. Then, at regional level, in addition to the food price increases mentioned above, the effects of climate tend to affect the lower income classes.

In fact, these two tendencies have been reported recurrently in the most recent literature, particularly those using computable general equilibrium models (Nelson *et al.* 2014) , and can be considered as very likely to occur: (*i*) up to a certain limit, temperature elevation will favor temperate countries or, in more extreme cases, less harmed cases, and countries with a tropical climate will be more adversely affected. In other words, the warmer the region, *ceteris paribus*, the more impaired by the increase in temperature; and (*ii*) because of the expected increases in prices of basic necessities, and because the great majority of tropical countries concentrate the most of the low-income population, these are probably the most affected classes, leading to an increase in global inequality.

Finally, in this table, in the last two columns an interesting relative data is shown: an indicator that relates the average annual percentage variation in the GDP growth in relation to the expected variations of the agricultural productivity for each scenario in relation to the reference scenario. It shows that losses (gains) in GDP growth for every 1 percent reduction in agricultural productivity tend to increase (decrease) in scenario 2, except for the remaining NAFTA countries, showing that the countries making up this region are able to maintain the same conditions of resource allocation in extreme scenarios of climate change.

This is not the case for the other regions, that is, for the latter, the greater the loss in AAP, the greater the reduction in GDP growth by a 1% change in productivity. It also shows that regions, such as northern and northeastern Brazil, with distinct average agricultural productivity declines (-5 and -15, -13 and -30, respectively) obtain close relative losses (0.15, 0.17 and 0.16, 0.19, respectively). On the contrary, regions with close estimates (-5 and -4, -14 and -11), such as Nafta and rest of the World, present distant relative results (0.04, 0.20 and 0.04, 0.21). This proves that the regional economic structure matters to explain the "marginal" impacts on economic growth of changes in agricultural productivity and need to be taken into account in the design and implementation of adaptation and mitigation policies.

Table 4 below shows the results for variation in family welfare. In general terms, the pattern response is the same as that of GDP: the shocks implemented in the model and the results in the new equilibrium are in the same direction, that is, fall in GDP implies a reduction of well-being.

Table 4 – Welfare results

Regions	growth over 30 years (bi US$)			relative variation (bi US$)		relative variation (%)		relative variation annual mean - RVAM (%)		RVAM/produtivity variation mean estimation	
	RS	S1	S2	S1/RS	S2/RS	S1/RS	S2/RS	S1/RS	S2/RS	S1	S2
NOR	104.27	102.92	100.42	-1.36	-3.86	-1.30	-3.70	-0.78	-2.16	0.16	0.17
NDE	339.49	325.17	307.93	-14.32	-31.57	-4.22	-9.30	-2.56	-5.49	0.16	0.18
COE	185.44	176.95	166.69	-8.48	-18.75	-4.57	-10.11	-3.09	-6.62	0.39	0.41
SDE	1,344.73	1,335.32	1,314.14	-9.41	-30.59	-0.70	-2.27	-0.45	-1.45	0.15	0.16
SUL	383.07	387.78	377.38	4.71	-5.69	1.23	-1.49	0.83	-0.75	0.28	0.15
NAF	13,107.06	13,073.32	13,003.89	-33.74	-103.17	-0.26	-0.79	-0.18	-0.55	0.04	0.04
EUR	8,407.07	8,423.24	8,377.30	16.17	-29.78	0.19	-0.35	0.13	-0.19	0.04	0.06
ROW	24,776.60	24,509.32	23,998.19	-267.28	-778.41	-1.08	-3.14	-0.75	-2.18	0.19	0.20

Source: by the authors.

However, it is worth noting that, even though the Midwest has an estimated reduction in AAP that is considerably lower than the northeast (the region with the highest estimate), for example, its percentage loss of well-being growth in 30 years, the average rate of this loss and that rate for each

1% decrease in AAP are higher than for all other regions considered. This is due to the fact that the midwest earns a large part of its family income from the agricultural sector and is therefore, the most disadvantaged in terms of consumption capacity with reduced agricultural gains.

Another two points to highlight are: (*i*) the annual average falls in welfare growth over the 30 years by the average reduction of 1% in AAP are equal or very close in the two scenarios to the north, northeast and southeast (last two columns of table 2), regions that have different AAP fall projections. This shows that families in the north and southeast also suffer considerable losses in relative terms even if they do not have a productivity decrease as high as the northeast, which suffers more because of the magnitude of the expected reduction in AAP; (*ii*) the same can be said for the "rest of the world" region. This includes a large number of food importing countries that experience welfare declines with the considerable increase in prices due to a reduction in the supply of agricultural products.

Table 5 lists the results for government expenditures. The importance of the midwest in terms of tax collection from the agricultural sector is evident: it is the region with the highest percentage rate of reduction in government expenditure growth in the two scenarios (in relation to the baseline scenario). The reduction of the growth rate from 1% in the estimated AAP is only the fourth largest of the eight regions considered. In this respect, the rest of the world, Europe and Southeast gets the biggest falls, in addition to the very high rate of the south in scenario 2 (last column).

Table 5 – Governments results

Regions	growth over 30 years (bi US$)			relative variation (bi US$)		relative variation (%)		relative variation annual mean - RVAM (%)		RVAM/produtivity variation mean estimation	
	RS	S1	S2	S1/RS	S2/RS	S1/RS	S2/RS	S1/RS	S2/RS	S1	S2
NOR	42.87	42.39	41.43	-0.48	-1.44	-1.12	-3.36	-0.54	-1.77	0.11	0.14
NDE	120.29	117.32	113.40	-2.97	-6.89	-2.47	-5.73	-0.88	-2.28	0.06	0.08
COE	76.03	73.53	69.87	-2.50	-6.16	-3.29	-8.11	-0.83	-2.22	0.10	0.14
SDE	538.50	535.35	527.84	-3.15	-10.66	-0.59	-1.98	-0.48	-1.61	0.16	0.18
SUL	149.05	149.15	144.93	0.09	-4.12	0.06	-2.76	-0.32	-2.48	-0.11	0.50
NAF	3,310.59	3,302.18	3,284.14	-8.41	-26.45	-0.25	-0.80	-0.15	-0.49	0.03	0.04
EUR	4,318.82	4,324.13	4,299.31	5.31	-19.51	0.12	-0.45	0.10	-0.38	0.03	0.13
ROW	5,877.09	5,812.81	5,686.92	-64.28	-190.17	-1.09	-3.24	-0.72	-2.17	0.18	0.20

Source: by the authors.

In the case of Brazil, the lowest variations of this indicator are in the north and northeast. Hence, the main conclusion of the results of this table is inferred: "marginally" the regions most affected by climate changes lose less in government expenditures, more likely as an "anti-cyclical" response the greater economic losses predicted for these regions.

Regarding the investments shown in table 6 above, three results are highlighted: (*i*) the midwest and ortheast regions experienced significant declines in investment growth. The first one is due to the importance of the agricultural sector in its economy and the second one is due to the size of the reduction of AAP; (*ii*) the southeast gains an increase in both scenarios and the south in scenario 2, rather than the expected decline, in the growth rate of investments. This is due to the size of the industrial and services sectors in these regions, those most benefited by the increase in supply owing to the migration of capital and labor to these sectors due to shocks; (*iii*) the countries of the European Union, contra-intuitively, observe a decrease in the investments in scenario 1 (estimated increase of AAP). This can be explained by the fact that the greater allocation of primary factors to agriculture due to increased productivity in these countries reduces the supply in the industrial and service sectors and consequently the investments since they are the main driver of the economies of these countries.

Table 6 – Investment results

Regions	growth over 30 years (bi US$)			relative variation (bi US$)		relative variation (%)		relative variation annual mean - RVAM (%)		RVAM/produtivity variation mean estimation	
	RS	S1	S2	S1/RS	S2/RS	S1/RS	S2/RS	S1/RS	S2/RS	S1	S2
NOR	104.61	103.98	102.99	-0.63	-1.61	-0.60	-1.54	-0.38	-0.96	0.08	0.07
NDE	237.34	233.70	229.69	-3.64	-7.65	-1.53	-3.22	-1.34	-2.63	0.08	0.09
COE	173.93	170.60	166.59	-3.33	-7.34	-1.92	-4.22	-1.34	-2.58	0.17	0.16
SDE	522.64	522.76	524.42	0.11	1.77	0.02	0.34	0.10	0.56	-0.03	-0.06
SUL	272.40	274.49	273.99	2.09	1.59	0.77	0.58	0.32	0.46	0.11	-0.09
NAF	1,647.85	1,645.52	1,640.82	-2.33	-7.03	-0.14	-0.43	-0.01	-0.04	0.00	0.00
EUR	905.61	903.09	898.01	-2.51	-7.60	-0.28	-0.84	-0.17	-0.28	-0.06	0.09
ROW	3,254.33	3,230.95	3,182.05	-23.38	-72.29	-0.72	-2.22	-0.25	-0.83	0.06	0.08

Source: by the authors.

Regarding the results for export and import shown in Tables 7 and 8 below, the most relevant results, which confirm the previous analyzes, are: (*i*) the increase in exports from the Southeast region in both scenarios and the South in scenario 2, even with the productivity fall. These regions started exporting additional domestic production because of the factor migration and taking into account the new demand arising from the depression of the agricultural sector in several parts of the world; (*ii*) declining exports and imports in the European Union, even with an increase in AAP in scenario 1, which seems to indicate that in this scenario a movement in Europe to reduce its external international trade and increase domestic trade; (*iii*) the southern starts to import less in scenario 1 with the increase of productivity, becoming more self-sufficient; and (*iv*) the imports from the central-west region increase considerably, worsening their terms of trade, substituting what was domestically produced.

Table 7 – Exports results

Regions	growth over 30 years (bi US$)			relative variation (bi US$)		relative variation (%)		relative variation annual mean - RVAM (%)		RVAM/produtivity variation mean estimation	
	RS	S1	S2	S1/RS	S2/RS	S1/RS	S2/RS	S1/RS	S2/RS	S1	S2
NOR	104.61	103.98	102.99	-0.63	-1.61	-0.60	-1.54	-0.38	-0.96	0.08	0.07
NDE	237.34	233.70	229.69	-3.64	-7.65	-1.53	-3.22	-1.34	-2.63	0.08	0.09
COE	173.93	170.60	166.59	-3.33	-7.34	-1.92	-4.22	-1.34	-2.58	0.17	0.16
SDE	522.64	522.76	524.42	0.11	1.77	0.02	0.34	0.10	0.56	-0.03	-0.06
SUL	272.40	274.49	273.99	2.09	1.59	0.77	0.58	0.32	0.46	0.11	-0.09
NAF	1,647.85	1,645.52	1,640.82	-2.33	-7.03	-0.14	-0.43	-0.01	-0.04	0.00	0.00
EUR	905.61	903.09	898.01	-2.51	-7.60	-0.28	-0.84	-0.17	-0.28	-0.06	0.09
ROW	3,254.33	3,230.95	3,182.05	-23.38	-72.29	-0.72	-2.22	-0.25	-0.83	0.06	0.08

Source: by the authors.

Therefore, the preliminary results of the research program current stage that this papers inserts, in general, confirm the predictions of other studies that find negative economic impacts of climate change on the Brazilian economy (Domingues et al., 2016; Ferreira Filho and de Moraes, 2014). It is worth mentioning the constant prominence of the midwest region in the results always with significant impacts. As already mentioned, due to the importance of the agricultural sector in this region. The work of Haddad et al. (2010) also points in this direction.

Table 8 – Imports results

Regions	growth over 30 years (bi US$)			relative variation (bi US$)		relative variation (%)		relative variation annual mean - RVAM (%)		RVAM/produtivity variation mean estimation	
	RS	**S1**	**S2**	**S1/RS**	**S2/RS**	**S1/RS**	**S2/RS**	**S1/RS**	**S2/RS**	**S1**	**S2**
NOR	44.50	44.20	43.67	-0.30	-0.84	-0.67	-1.88	-0.11	-0.29	0.02	0.02
NDE	204.46	203.72	202.26	-0.75	-2.20	-0.37	-1.08	0.05	-0.05	0.00	0.00
COE	98.40	99.31	101.48	0.91	3.08	0.93	3.13	0.98	2.60	-0.12	-0.16
SDE	622.31	617.87	609.01	-4.44	-13.31	-0.71	-2.14	-0.80	-2.12	0.27	0.24
SUL	261.44	260.64	261.45	-0.80	0.01	-0.31	0.00	-0.27	0.32	-0.09	-0.06
NAF	1,298.06	1,291.98	1,278.93	-6.08	-19.13	-0.47	-1.47	-0.01	-0.09	0.00	0.01
EUR	2,428.79	2,415.98	2,390.48	-12.80	-38.30	-0.53	-1.58	-0.14	-0.38	-0.05	0.13
ROW	2,080.98	2,072.61	2,056.88	-8.37	-24.10	-0.40	-1.16	-0.27	-0.69	0.07	0.06

Source: by the authors.

5 CONCLUSION

The objective of this paper was to determine in a preliminary and aggregate way the economic impact of the estimated changes in average agricultural productivity for the coming decades using a dynamic computable general equilibrium model, the PAEDyn linked to GTAP, to the five major Brazilian regions and more three selected regions, which includes all the other countries in the world.

Basically, the results found confirm trends in other works: (i) the tropical regions in the world will be the most affected by the probable increase in the planet temperature, decreases in agricultural productivity and, thus, a reduction in economic performance; and (ii) particularly, in the case of Brazil, the midwest region obtains prominence in the unfolding effects of the climate.

Thus, a more detailed examination in the midwest region of Brazil, as well as in the impacts on investments and international trade that are shown to be more susceptible to counter-intuitive effects is suggested for future works. It is also recommended further disaggregation in the agricultural sector and in regions, as well scenarios refinement, estimates and parameters of the economic model used.

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