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Soy Expansion and Socioeconomic Development in Municipalities of Brazil

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Abstract: Soy occupies the largest area of agricultural land in Brazil, spreading from southern states to the Amazon region. Soy is also the most important agricultural commodity among Brazilian exports affecting food security and land use nationally and internationally. Here we pose the question of whether soy expansion affects only economic growth or whether it also boosts socioeconomic development, fostering education and health improvements in Brazilian municipalities where it is planted. To achieve this objective, we divided more than 5000 municipalities into two groups: those with >300 ha of soy (soy municipalities) and those with <300 ha of soy (non-soy municipalities). We compared the Human Development Index (HDI) and the Gini coefficient for income for these two groups of municipalities in 1991, 2000, and 2010. We made such comparison at the municipality level for the whole country, but we also grouped the municipalities by major geographical regions and states. We found that the HDI was higher in soy municipalities, especially in the agricultural frontier. That effect was not so clear in more consolidated agricultural regions of the country. Soy municipalities also had a higher Gini coefficient for income than non-soy municipalities. We concluded that soy could be considered a precursor of socioeconomic development under certain conditions; however, it also tends to be associated with an increase in income inequality, especially in the agricultural frontier.

Keywords: soy; development; Brazil; HDI; Gini coefficient

1. Introduction

In the 53 years from 1961 to 2014, the harvested area of soy in South America increased two orders of magnitude, from 0.25 to 55 million ha. During the same period, the productivity increased from approximately 1 to 3 tons ha^{-1}, and production jumped from 0.30 to 156 million tons [1]. More than half of the soy harvested area in South America is cultivated in Brazil (~33 million ha), followed by Argentina, Paraguay, Uruguay, and Bolivia. In Brazil, the 2014 exports of soy chain products, which include beans, animal feed and oil, generated a revenue of approximately 30 billion dollars, which was equivalent to 13% of the total annual exports revenue [2]. There are almost 250,000 soy producers in the country [3], distributed in more than 1500 municipalities, spreading from approximately 30° S to 3° N. Therefore, soy has an important role in the country's economy.

Federal, state and municipal governments benefit from soy chain revenues through different taxes [4]. However, it is unclear if such gains are reaching society as a whole. It is also fair to ask, if not only economic gains, but also social development has been affected by soy expansion.

One of the first attempts to investigate socioeconomic development in the Amazon region concluded that agriculture expansion brought some positive outcomes in the first years of occupation, but that was soon lost in a typical boom-and-bust development [5]. Lately, several authors have reached different results at the state level. For instance, agriculture intensification in the State of Mato Grosso, with soy and double-cropping (e.g., soy followed by maize or cotton) has been a true engine of lasting socioeconomic development [6,7]. Weinhold et al. [8] and Tristich and Arvor [9] broaden this type of analysis from the state level to the Brazilian Amazon region, concluding that socioeconomic indicators have improved with agriculture intensification, without a direct relationship with deforestation, refuting the hypothesis of boom-and-bust development. Garret and Rausch [4] included all municipalities of Brazil in their analysis, grouping them according to prevalent land cover: soy, sugarcane, cattle and nonagricultural municipalities. These authors found that socioeconomic indicators were better or equal in soy municipalities when compared to sugarcane dominated municipalities, and both were better than cattle and nonagricultural municipalities. In contrast with these findings, Choi and Kim [10] found that soy expansion increased poverty, especially in the northern part of the country.

Although it seems that soy is a real engine of social development, soy expansion in Brazil is associated with several negative environmental and social effects. Perhaps one of the most important issues is the direct and indirect deforestation in two of the most important biomes of the country—the Cerrado and the Atlantic Forest [11–14]. Also, landscape transformation of the magnitude seen in areas of soy expansion lead to natural vegetation fragmentation and loss of habitat with an important role on local biodiversity [14,15]. In addition, monocultures like soy require the heavy use of agrochemicals that have not been properly evaluated so far [16]. Soy is associated with large-scale agriculture [17], leading to an increase in land concentration and income inequality [4,7,8,10].

We advance this research area by investigating if soy brought social development by comparing the Human Development Index (HDI), created by the United Nations, and the Gini coefficient for income among Brazilian municipalities with different amounts of land dedicated to soy.

2. Soy Distribution and Expansion in Brazil

Soy was introduced in Brazil in 1882, but remained as a minor crop associated with Japanese immigrants for the production of tofu and soy sauce. In the 1920s and the 1930s, soy was mainly used as feed for pigs. In 1938, Brazil exported soy to Germany for the first time. By the end of the 1940s, it started to be used as a feedstock and for cooking oil [18]. Ironically, one of the major supporters of soy in the country was the agronomist José Gomes da Silva, who believed that soy was ideal for small properties as a cheap source of protein to domestic animals and to the low-income population of Northeastern Brazil [18]. However, soy eventually became the main agricultural commodity exported by the country.

In the early 1950s, soy occupied an area of approximately 0.06 million ha in the country, with a mean production of 1500 kg ha^{-1} [19]. At the beginning of the 1960s, soy was cultivated in two states (Rio Grande do Sul and Paraná), and the harvested area was approximately 0.3 million ha. The early 1970s were a decisive time of soy expansion in Brazil. Soy international prices were very high, the US had reduced production that resulted in a soy export embargo in the US, and international buyers turned to Brazil as an alternate supplier [19]. At the same time, soy started to be cultivated in lower latitudes, such as in the states of Mato Grosso and Góias. By the end of the 1970s, the harvested soy area in the country had expanded to 8.5 million ha. In the 1980s, soy started to be cultivated in the northeastern region, particularly in western Bahia [18,20]. Such expansion to lower latitudes was only possible due to the work of several research organizations that adapted this temperate crop to sub-tropical and tropical conditions [21]. Therefore, the soy area progressively increased, reaching 12 million ha by the end of the 1990s. More recently, soy expanded to the common border of four states (Maranhão, Tocantins, Piauí and Bahia). This region named "Matopiba" produces more soy today than the Southeastern region of the country (Figure 1). The last region to become a soy producer area was the Northern region, where besides Tocantins, soy is also cultivated in the states of Pará, Rondônia, and Roraima. In 2004, the country reached an area of 20 million ha of soy, and in 2015/16, approximately 33 million ha (Figure 2).

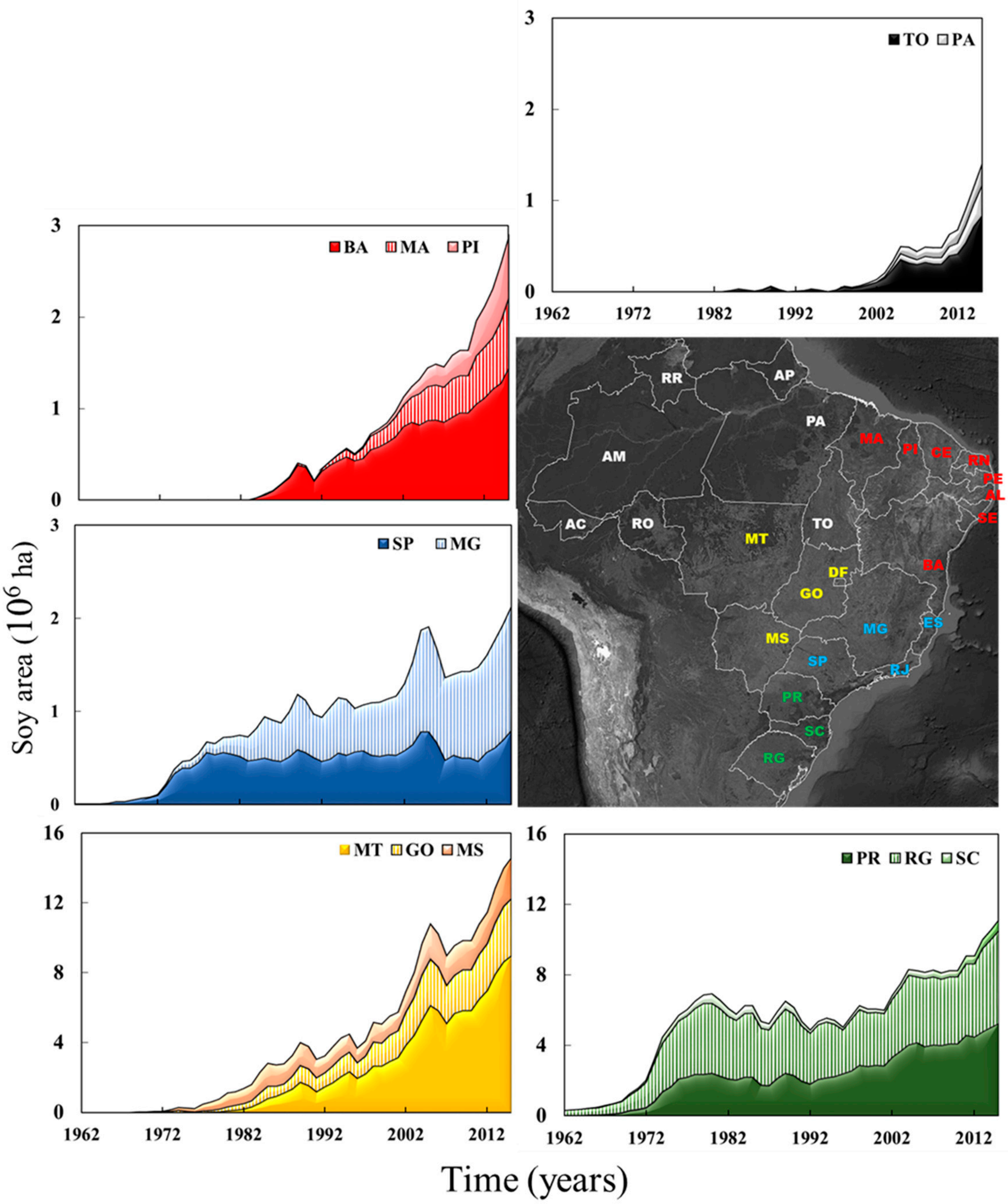

Figure 1. On the right, map of Brazil with state borders in white and abbreviations of states in colors illustrating major geographic regions: North—white, Northeast—red, Center-West—yellow, Southeast—blue, South—green. Graphs around the map show annual variability of soy-harvested areas (ha) in selected states.

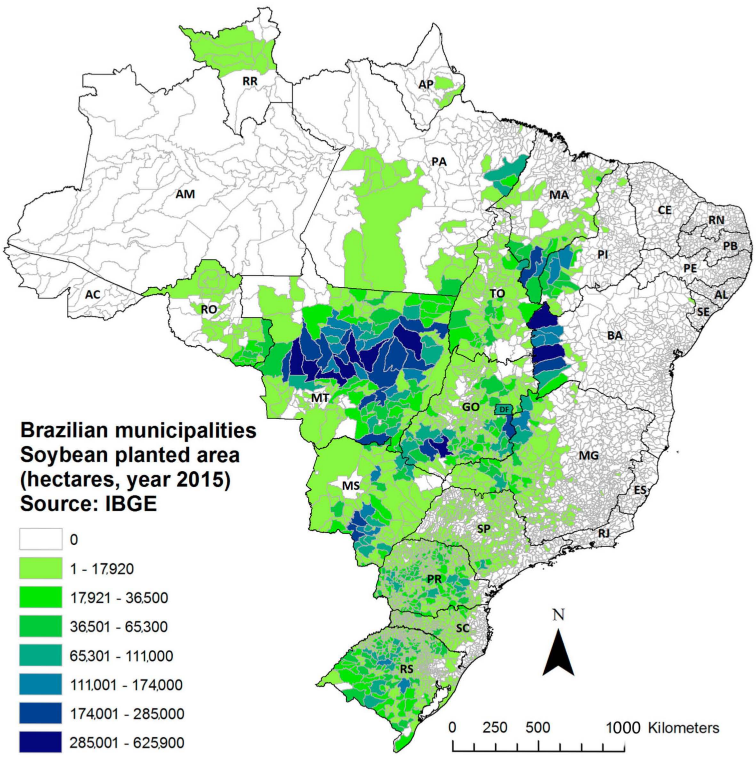

Figure 2. Brazilian municipalities and soybean planted area in 2015. Letters indicate abbreviations of Brazilian states.

This unprecedented increase in the soy area was due to a combination of factors. For example, a series of policies took place in the early 1990s that favored the expansion of agriculture, which was historically the sector that the country relied on for its economic development [22–24]. In addition, there were massive investments in research. For instance, the Brazilian Agricultural Research Corporation (Embrapa) created a center exclusively dedicated to soy-related research in Londrina, Paraná. A series of new soy varieties were adapted to grow in central and northern regions of the country and the ability of soy plants to fix nitrogen from the atmosphere was progressively increased. Consequently, the mean productivity in the country increased from 1 ton ha^{-1} to more than 3 tons ha^{-1}. With the combination of area increase and productivity increases, the soy production went from 0.27 million tons in the earlier 1960s to approximately 100 million tons in 2016—an increase of two orders of magnitude in these decades (Figure 3, [25–27]).

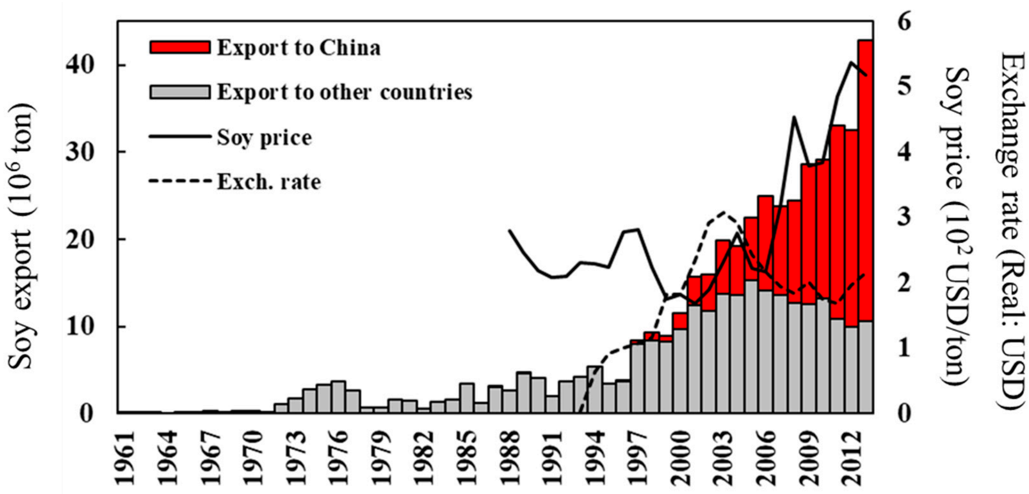

Figure 3. Historical variability of Brazilian soy exports (left axis), and share of China in relation to world export (left axis) [25]. On the right axis, the international market soy price [26] is shown in continuous black line and the exchange rate Brazilian Real/US Dollar is shown in dashed line [27].

Another important factor that contributed to the increase of soy area in the country was the demand by the external market [28], which started to increase in the mid 1990s, when approximately 25% of the soybean was exported, reaching approximately 60% (Figure 3). Until 2000, the major buyer was the European Union; however, China has progressively increased soy imports from Brazil, reaching approximately 75% of the Brazilian soy exports in 2016.

3. Materials and Methods

We worked with the entire set of municipalities in Brazil, except the state capitals, in three different periods according to HDI data availability: 1991, 2000, and 2010 [29]. We grouped municipalities with >300 ha of soy harvested area (soy) and compared socioeconomic indexes with municipalities where the soy-harvested area was <300 ha (non-soy) [30]. Besides the HDI itself, we tested the three main components of such index: income (HDIi), health (HDIh) and education (HDIe), and Gini coefficient for the income between the two groups of municipalities [29]. One advantage of breaking-down the HDI in its major components is to overcome the sensitivity attributed to weights for income and education components as noted by Aguña and Kovacevic [31].

The HDI was created in 1990 by the United Nations as a response to persistent critics through the 1980s that economic development alone could not capture human development. However, it is clear that to capture human development in a mathematical formula considering only three dimensions would be rather simplistic [32]. On the other hand, there is also consensus that including a much larger number of dimensions would add complexities impairing any meaningful comparison between countries. Inequality in the three dimensions of the HDI is recognized to be critical. As a response, the UNDP launched the inequality-adjusted Human Development Index (IHDI) [33]. As we could not use the IHDI because it is not available at the municipality level, we added the income and land-distribution Gini coefficient in our analysis.

In order to group municipalities in soy and non-soy categories, we estimated the average soy harvested area for five years before the tested year. Therefore, the average soy areas from 1986 to 1990 (1980s), 1995 to 1999 (1990s), and 2005 to 2009 (2000s) were estimated for each municipality. The minimum area of 300 ha was chosen because it represented the 25th quartile of the median soy area in 1991 among all municipalities.

In 1991, there were 4382 municipalities excluding State capitals; in 2000, the number of municipalities increased to 5462; and, in 2010 the number of municipalities was 5573. The five major geographical regions of Brazil are: North, Northeast, Center-West, Southeast and South. The North region is composed by the following states: Amazon (AM), Acre (AC), Pará (PA), Rondônia (RO), Roraima (RR) and Tocantins (TO); the Northeast region is composed by: Alagoas (AL), Bahia (BA), Ceará (CE), Maranhão (MA), Paraíba (PB), Pernambuco (PE), Piauí (PI), Sergipe (SE), and Rio Grande do Norte (RN); the Center-West region is composed by: Goiás (GO), Mato Grosso do Sul (MS), and Mato Grosso (MT); the Southeast region is composed by: Espírito Santo (ES), Minas Gerais (MG), São Paulo (SP), and Rio de Janeiro (RJ). Finally, the South region is composed by: Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS) (Figure 1). The only states that do not have a significant soy area are: Acre, Alagoas, Amazonas, Espírito Santo, Pernambuco, Rio Grande do Norte, Rio de Janeiro e Sergipe.

The Gini coefficients for land, which is a proxy for land distribution inequality, is only available for 2006. We included this index in our analysis considering major crops (soy, maize, and beans) and livestock. We estimated this coefficient based on the number of properties and the harvested area in these properties according to IBGE [34]. The group of properties included the following areas: 1 to <2 ha, 2 to <5 ha, 5 to <10 ha, 10 to <20 ha, 20 to <50 ha, 50 to <100 ha, 100 to <200 ha, 200 <500 ha, 500 to <1000 ha, 1000 to <2500 ha, and >2500 ha. We first derived a "Lorenz curve" and then we estimated the Gini coefficient. In this case, we compared the Gini for land use between Brazilian political regions and among states.

We used ANCOVA (Co-variance analysis) to minimize the amount of influence we erroneously attributed to our grouping variable—soy and non-soy municipalities. As co-variables, we used the municipality area and population, as well as harvested area of corn and number of cattle heads in each municipality. To use ANCOVA, we first tested the normality distribution for each variable. For those that did not follow a normal distribution (area, population, maize area, and cattle heads), we used the Box Cox transformation. To assure independence among data, we did not test changes between the three periods (1991, 2000, and 2010), but instead we only tested differences between soy and non-soy municipalities in each period. Differences at 0.05 probability level were considered significant. All statistical analyses were done using STATISTICA13.

4. Results

4.1. Human Development Index and Gini Coefficient for Income

Considering the country as a whole, in the three periods of study, the bulk HDI of municipalities with soy was significantly higher than that of non-soy municipalities. The same was true for HDIi, HDIh, HDIe. In the 1980s, the Gini coefficient for income was significantly higher in soy municipalities. However, this trend changed in the 1990s and 2000s (Table 1).

Table 1. The Human Development Index (HDI), its three components: income (HDIi), health (HDIh), education (HDIe), and the Gini coefficient for income for Brazil in the 80s, 90s and 00s. Statistical differences at 5% probability level are indicated by *.

Period	Municipalities	*n*	HDI	HDIi	HDIh	HDIe	Gini
80's	Non-soy	3244	0.373	0.501	0.630	0.174	0.529
	Soy	1138	0.455 *	0.584 *	0.699 *	0.240 *	0.545 *
90's	Non-soy	4181	0.501	0.555	0.709	0.328	0.548 *
	Soy	1281	0.593 *	0.636 *	0.766 *	0.435 *	0.544
00's	Non-soy	3576	0.639	0.615	0.789	0.533	0.500 *
	Soy	1672	0.701 *	0.693 *	0.826 *	0.604 *	0.480

Considering the five major geographical regions in Brazil, the North region is one of the poorest in the country, and soy is cultivated in large scale only in portions of the states of Pará and Rondônia. In this region, the HDI of soy municipalities was higher in the three periods investigated; the same was true for HDIi and HDIe. The exception was the HDIh that was lower in soy municipalities in the 1980s, but became higher in the 1990s and 2000s (Table 2). There was no significant difference between municipalities in terms of the Gini coefficient in the 1980s and 1990s; it became lower in soy municipalities only in the 2000s (Table 2).

Table 2. The Human Development Index (HDI), its three components: income (HDIi), health (HDIh), education (HDIe), and the Gini coefficient for income for the five geographical regions of Brazil in the 1980s, 1990s and 2000s. Statistical differences at 5% probability level are indicated by *.

Period	Region	Municipalities	*n*	HDI	HDIi	HDIh	HDIe	Gini
80′s	North	Non-soy	260	0.323	0.489	0.615 *	0.119	0.556
		Soy	28	0.361 *	0.525 *	0.604	0.154 *	0.569
90′s	North	Non-soy	415	0.438	0.527	0.688	0.240	0.599
		Soy	16	0.496 *	0.584 *	0.705 *	0.306 *	0.604
00′s	North	Non-soy	328	0.594	0.581	0.774	0.472	0.575 *
		Soy	108	0.640 *	0.621 *	0.796 *	0.533 *	0.547
80′s	Northeast	Non-soy	1419	0.306	0.428	0.562	0.126	0.526
		Soy	34	0.296	0.430 *	0.579	0.107	0.549
90′s	Northeast	Non-soy	1741	0.421	0.479	0.652	0.245 *	0.560
		Soy	33	0.433 *	0.488 *	0.658 *	0.239	0.603 *
00′s	Northeast	Non-soy	1641	0.588	0.560	0.753	0.486	0.523
		Soy	60	0.589 *	0.553 *	0.762 *	0.487 *	0.574 *
80′s	Center-West	Non-soy	145	0.401	0.560	0.659	0.194	0.532
		Soy	230	0.419 *	0.580	0.673 *	0.194	0.554
90′s	Center-West	Non-soy	213	0.541	0.606	0.743	0.357	0.546
		Soy	229	0.563 *	0.641 *	0.757 *	0.372 *	0.575 *
00′s	Center-West	Non-soy	119	0.670	0.665	0.820	0.578	0.487
		Soy	341	0.691 *	0.690 *	0.823	0.584	0.497
80′s	Southeast	Non-soy	1129	0.438	0.566	0.692	0.223	0.532 *
		Soy	271	0.488 *	0.621 *	0.712 *	0.266 *	0.514
90′s	Southeast	Non-soy	1374	0.580	0.620	0.759	0.421	0.529 *
		Soy	279	0.626 *	0.662 *	0.782 *	0.485 *	0.527
00′s	Southeast	Non-soy	1171	0.685	0.667	0.824	0.588	0.467 *
		Soy	401	0.727 *	0.710 *	0.838 *	0.648 *	0.456
80′s	South	Non-soy	291	0.471	0.592	0.721	0.251	0.502
		Soy	574	0.469	0.580	0.713	0.254	0.557 *
90′s	South	Non-soy	438	0.607	0.657 *	0.785 *	0.439	0.505
		Soy	714	0.600	0.633	0.777	0.448 *	0.536 *
00′s	South	Non-soy	317	0.726 *	0.730 *	0.848 *	0.620	0.430
		Soy	852	0.708	0.706	0.830	0.609 *	0.469 *

The northeast region is also one of the poorest regions in Brazil, and soy is only cultivated in Bahia, Maranhão, and Piauí. In the 1980s, only HDIi was significantly higher in municipalities with soy (Table 2). In the 1990s and 2000s, the bulk HDI and its three components became higher in soy municipalities. The only exception was HDIi that was not statistically different between the two groups in the 2000s. The Gini coefficient also became higher in the 1990s and 2000s in municipalities with soy (Table 2).

The Center-West is the main soy producer region in Brazil. In the 1980s, the total HDI and HDIh were higher in soy municipalities, and no difference was observed in the HDIi and HDIe, nor in the Gini coefficient. In the 1990s, all indexes, including Gini, became higher in soy municipalities. In the 2000s, only total HDI and HDIi were still higher in soy municipalities, with no difference between the two groups of municipalities for HDIh, HDIe, and Gini (Table 2).

The southeast region is considered the most developed region of the country, where only two states do not cultivate soy (i.e., Rio de Janeiro and Espiríto Santo). In this region, in all periods, HDI and its components were significantly higher in the soy municipalities, and the Gini coefficient was significantly lower (Table 2).

The south region is the second most developed region and the oldest soy producer region in the country. In the 1980s, there were no differences between HDI and its components; only the Gini coefficient was higher in the soy municipalities group (Table 2). Interestingly enough, in the 1990s, the total HDI was not different between the two groups. However, the HDIi and HDIh were significantly lower, and only the HDIe was higher in the soy municipality group. The ni index was also higher in this period (Table 2). Finally, in the 2000s, the total HDI and its components were lower in the soy municipalities group; again, the Gini coefficient was higher in the soy municipality group (Table 2).

We further analyzed major regions by states in order to investigate differences among soy-producer states belonging to a same region (Figure 4). At this level, we only investigated the 2000s because before that period many municipalities did not have a large area of soy, which is especially true in the north and northeast region.

In the North region, we investigated Pará, Rondônia, and Tocantins states. In Pará, there were only 17 municipalities producing soy among 135 municipalities. With the exception of HDIh, all other indexes were significantly higher in the soy municipalities. The Gini coefficient was not different between the two groups (Figure 4). Among 51 municipalities, Rondônia had only nine producing soy. Total HDI and its other indexes were all higher, and Gini was lower in soy municipalities (Figure 4). In Tocantins, there were 75 municipalities producing soy among 138 municipalities. With the exception of HDIe, all other HDI indexes were higher, and Gini was lower in soy municipalities (Figure 4).

Piauí, Bahia, Maranhão, and Tocantins states belong to a newer soy frontier denominated MATOPIBA. In the Piauí state, there were only 15 municipalities producing soy in the 2000s, out of 222. The HDI and HDIe were significantly higher in the soy-producing group, while there were no differences between the HDIi, HDIh, and the Gini coefficient (Figure 4). In Bahia state, the number of municipalities cultivating soy is also low (i.e., 12) when compared with 381 non-soy municipalities. In this state, the HDI, its components, and the Gini coefficient were always higher in the soy municipalities (Figure 4). Maranhão is the state of the MATOPIBA region with the second highest number of municipalities producing soy. In this state, all HDI indexes and the Gini coefficient were higher in the soy municipalities (Figure 4).

The states of the Center-West region are among the highest soy-producer states in the country. The State of Mato Grosso is the largest, with 106 out of 140 municipalities producing soy in the 2000s. The total HDI, HDIi, and HDIe were higher in the soy municipalities while there was no difference between HDIe and Gini (Figure 4). The State of Goiás had 140 out of 213 municipalities producing soy in the 2000s. Surprisingly for this region, only the total HDI was higher in the soy municipalities, with no significant differences among the other indexes (Figure 4). In the State of Mato Grosso do Sul, there were 65 municipalities producing soy. It was also surprising that there was no difference among all indexes between soy and non-soy municipalities (Figure 4).

The São Paulo State was not a traditional producer of soy, but currently, more than half of its municipalities produces soy (Figure 4). As in Mato Grosso do Sul, there were no significant difference. On the contrary, in the State of Minas Gerais, all indexes, including Gini were higher in soy than in non-soy municipalities (Figure 4).

Finally, in the South region, the Paraná State is the second larger producer state in Brazil, where more than 350 municipalities produce soy. In this state, only the HDI and HDIe were significantly higher in the soy municipalities group. Rio Grande do Sul, the oldest producer in Brazil, also had more than 350 municipalities producing soy in 2000s (Figure 4). Interesting enough, in the oldest producer state, the HDI and HDIh were lower in the soy municipality group, and the Gini coefficient was higher, while there was no statistical difference between HDIi, and HDIh (Figure 4). The State of Santa Catarina followed a similar trend. The total HDI and its components were lower, and the Gini was higher in soy municipalities (Figure 4).

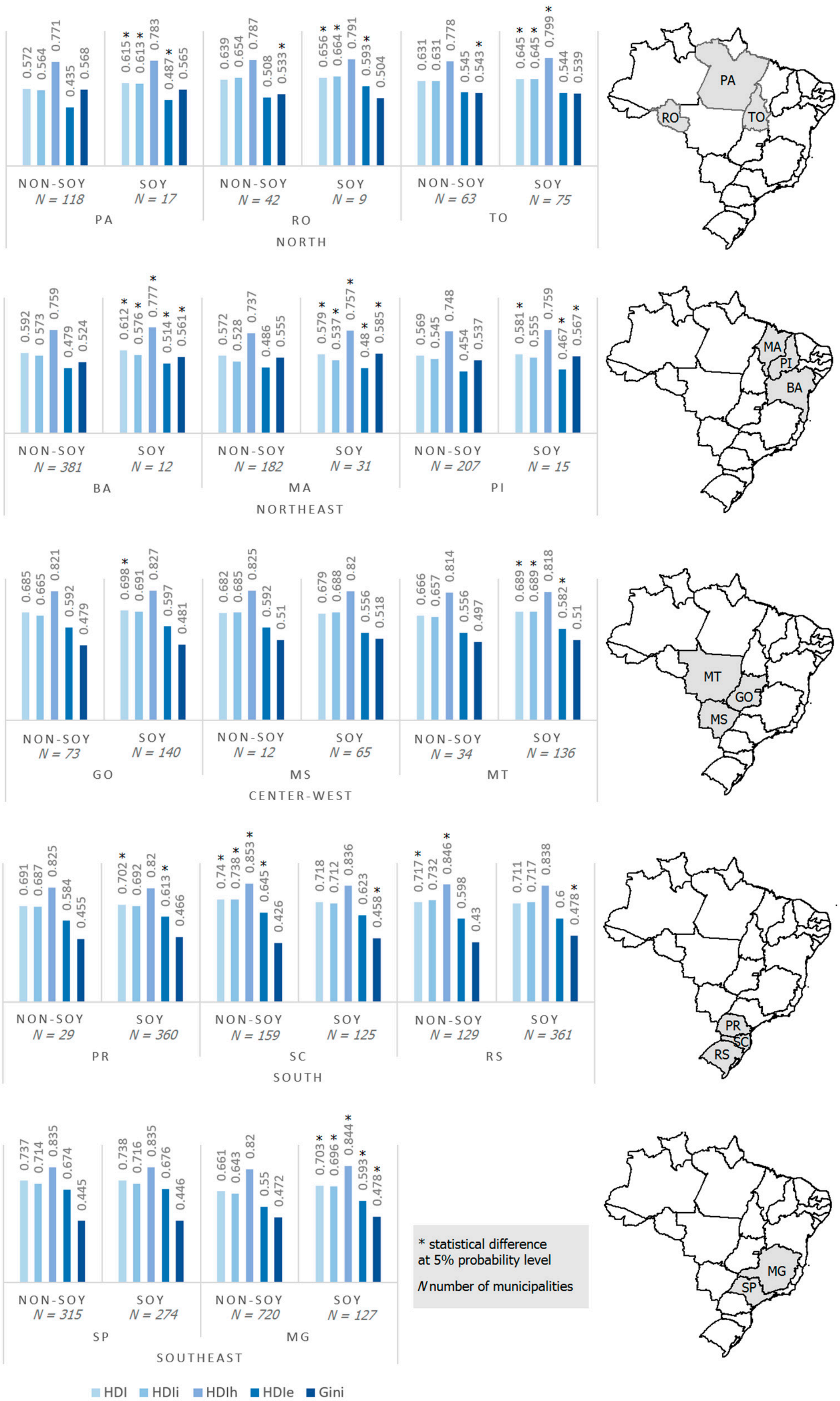

Figure 4. Human Development Index (HDI), its three components, and the income Gini coefficient for income in Brazilian states grouped by the national geographic regions: North, Northeast, Center-West, Southeast and South (* denotes statistical difference at 5% of probability level).

4.2. Gini Coefficient for Land Use

The Gini coefficient for land use, based on the cultivated area of each crop, is a proxy for land-distribution inequality. We estimated this coefficient in 2006 for beans, which is one of the Brazilian staple crops; for maize and livestock, which are consumed in the internal market and also exported; and soy, which is mostly exported. Considering the whole country, soy had a larger coefficient than livestock, larger yet than maize, and much higher than beans (Table 3). The North and Northeast region follow the same trend for beans, maize, and soy; however, the livestock coefficient is higher than soy (Table 3). Interestingly, the coefficient for beans in the Southeast region is much higher than in the north and northeast regions, approaching soy and maize coefficients (Table 3). The soy coefficient was also higher than maize and beans in the south region, and again similar to livestock (Table 3). Finally, in the Center-West region, the Gini coefficient followed a different trend than in the rest of the country. The soy coefficient is still high, but lower than maize, beans, and livestock that have the highest coefficient in the country (Table 3).

Table 3. Land Gini coefficient for beans, maize, soy, and livestock in 2006 for Brazil (BR) and its major geographical regions: N—North, NE—Northeast, SE—Southeast, S—South, CW—Center-West.

Crop	BR	N	NE	SE	S	CW
Beans	0.15	0.14	0.14	0.49	0.45	0.79
Corn	0.51	0.28	0.26	0.56	0.42	0.79
Soy	0.78	0.52	0.47	0.62	0.63	0.62
Livestock	0.70	0.57	0.59	0.60	0.62	0.73

5. Discussion

The main question addressed by this investigation is if agricultural expansion brings socioeconomic development, meaning not only growth in the Gross Domestic Product (GDP), but also better income, health and education (HDI) to municipalities where it takes place [8]. This question relates to the general perception that, by supporting commodity crops such as soy, local inequality and poverty are accentuated, since such crops require large areas and less labor per hectare [35,36]. The opposite view is that the wealth generated by the commodity crop will positively affect other private and governmental sectors that will absorb those rural workers not directly employed by the soy production [37]. Weinhold et al. [8] emphasize that although this question has raised intense debate, there have been few studies addressing it quantitatively.

Our work contributes to the debate by showing that socioeconomic development measured by human development indices considering the whole country was larger in soy than in non-soy municipalities for the three periods investigated (Table 1). At the country level, the income inequality in the 1980s was higher in soy municipalities, but in the 1990s and 2000s the trend was reversed, with lower inequality in soy municipalities. Garret and Raush [4] also found that soy municipalities had a better socio-economic performance than municipalities with large areas of sugar, cattle or another major crop in a study for the year 2000. However, these authors found higher income inequality in soy municipalities, which we show was the case only in the 1980s (Table 1).

Our finding is also in line with studies focused on soy frontier producer regions of the Amazon region [8] or well-established production areas such as the State of Mato Grosso [6,7]. Richards et al. [7] call attention to state level institutional arrangements as an essential condition for socioeconomic development promoted by soy expansion. Therefore, a key question is if the experience of Mato Grosso can be generalized to other regions and states of the country. This paper advances this discussion by analyzing major Brazilian regions and main soy producer states and concludes that generalizations are not possible regarding soy expansion and socioeconomic development.

Our results indicate that soy expansion is more beneficial in new agricultural frontiers, especially those located in the north and northeast regions. In these regions, our results unequivocally show that soy municipalities reach a higher level of socioeconomic development (Table 2). Even when the analysis is done for the states, the tendency persists. For instance, in the north region, HDI in soy municipalities of Pará, Rondônia and Tocantins are higher than in non-soy municipalities, without necessarily increasing income inequality. Inequality is high in the North region, but it is not particularly higher in soy municipalities (Figure 4). In the northeast region, the same tendency was observed in soy producer states (Bahia, Maranhão, and Piauí). However, income inequality was accentuated in soy municipalities within these states, a trend not observed in the north region (Figure 4).

In the south region, the oldest soy producer region in the country, and where the economy is much more diversified than the north and northeast region, soy seems not to be the development engine it is in the two other regions (Table 2). In states such as Santa Catarina and Rio Grande do Sul, some socioeconomic indices were better in non-soy municipalities than in soy municipalities. Additionally, in these two states, income inequality was higher in soy municipalities (Figure 4). The southeast region obviously is not an agriculture frontier, but soy is a relatively new crop, and as a whole the region seems to have benefited from the soy expansion (Table 2). However, when the two producing states of this region (São Paulo and Minas Gerais) are investigated separately, it is clear that soy municipalities of Minas Gerais benefited from soy expansion, but not São Paulo municipalities. This trend contrasts with Martinelli et al. [38] who showed that São Paulo municipalities with a relatively large sugarcane industry had a higher socioeconomic development than municipalities where sugarcane was present without a sugar mill in the municipality, which in turn was more developed than municipalities where cattle was dominant. Perhaps the most intriguing region is the Center-West because only soy municipalities of Mato Grosso had higher development indexes than non-soy municipalities. Soy does not seem to have a similar growth effect in the two other states of the region—Goiás and Mato Grosso do Sul (Figure 4).

Therefore, based on results found here and elsewhere [4,6–8], we propose that soy may work as an engine for development, especially in agricultural frontiers that have minimum logistical capability to host an export oriented crop like soy. The North and Northeast regions especially benefited by the soy expansion (Table 2). In the Center-West region, Mato Grosso also experienced such soy related development; however, more consolidated frontiers did not experience such impact. A notable exception was Minas Gerais, which is one of the oldest agricultural areas of the country and has a large industrial and manufacturing sector, but even under these conditions, soy expansion in this state seems to foster socioeconomic development (Figure 4).

A downside of this development model is that there is always a strong dependence on the international demand for soy and on the exchange rate between the Brazilian and other currencies. This makes the economy of soy municipalities vary dependent on market forces that are beyond their control [7,39]. Figure 2 captures such dependence by showing the share of China soy exports in relation to total soy exports by the country. Any change in China policies related to its exports would reverberate in Brazil, especially in soy dependent states and municipalities. In the same figure, soy price in the international market has increased in recent years, after a small decrease related to the 2008 crisis. The Brazilian real to dollar exchange rate is also represented (Figure 2). Note that in the last three years, which is not shown in the figure, the exchange rate is increasing, favoring even more the export of primary commodities like soy (Figure 2). While prices are high and China continues to import, soy will probably remain as an engine of development in soy municipalities. However, if these trends change, uncertainty will prevail in such soy-dependent municipalities. Overall, it is important to mention that such telecoupled mechanisms between sending and receiving systems are still lacking investigation [40].

Although we show that soy expansion was responsible for promoting development in some regions of the country, we also found that in the northeast and south regions (Table 2), and in Minas Gerais (Figure 4), income inequality was exacerbated due to soy expansion [36]. Weinhold et al. [8] and Garret and Rausch [4] also detected this trend. This is especially worrisome, since Brazil has one of the highest inequalities in Latin America, although the Gini coefficient for income has declined since

1998 [41,42]. Garret and Rausch [4] argue that soy farming is not labor intensive, as other crops, and at the same time soy municipalities attract migrants that are not able to find high wage jobs. These authors also discuss the fact that, as we showed here, land distribution inequality is very high in soy expansion areas. Consequently, if non-agricultural jobs were not enough to absorb workers, this would lead to further income inequality. Although Laurenti et al. [43] agreed that export-oriented agriculture generated less jobs, these authors argue that non-agricultural jobs are increasing in rural areas of Brazil, decreasing the income gap between rural and urban workers, and rural income inequality. Lustig et al. [42] also note a decreasing difference between urban and rural wages. These authors claim that an unidentified productive sector in the Brazilian hinterland is increasing wages in smaller and medium-sized municipalities. Although the authors did not identify such sector, this could be due to the non-agricultural jobs of the "new rural" sector of the country as proposed by Laurenti et al. [43]. In this respect, at least in Mato Grosso, the local supply chain and the presence of processing facilities allows the state to generate off-farm wealth, although the ultimate source of this wealth is in the soy expansion [7]. As our income Gini coefficient was not separated in urban and rural segments and due to the complexity of this debate, further research on this topic is needed.

Finally, findings of this paper relies entirely on the HDI. As mentioned before, it is rather simplistic to capture development in a single mathematical equation, considering only three dimensions of development [32]. Silva and Ferreira-Lopes [44] advocate that two important dimensions still missing in the HDI are governance and environmental sustainability. Governance is a key aspect in our study that we could not incorporate into our analysis. Although Brazil is a federative republic, a series of policies are specific for each state. Law enforcement also varies among the states. These facts reinforce the importance of governance, but also pose a challenge because it is difficult to capture these nuances in our proposed analysis. Environmental sustainability is also a key issue because agriculture inherently causes several environmental impacts, such as deforestation or contamination by pesticides. Therefore, the findings of this paper are limited to the dimensions captured by the HDI, and clearly miss the analysis of some important dimensions of development.

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