The human capital effect on productivity and the agricultural frontier expansion: evidence from Brazil

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Abstract

The agricultural production expansion is an important strategy to encourage structural changes and lead to economic development. However, the increase in the agricultural goods supply can occur in two different ways: through productivity - intensive margin - and the area expansion - extensive margin. In this context, the human capital can enhance production in both ways, but its effects are still little explored in the literature. Therefore, this paper aims to investigate the human capital effect on the agricultural productivity increase and on the agricultural frontier expansion. The results indicate the human capital has a positive effect on agricultural productivity and in the frontier expansion. In addition, the empirical evidences suggests significant heterogeneities with human capital affecting more the productivity in frontier regions, which is characterized by a shortage of skilled labor. However, it does not affect the agricultural area expansion in consolidated agriculture regions.

Keywords: Agricultural Productivity, Frontier Expansion, Human Capital, Education.

Resumo

A expansão da produção agrícola é vista como uma importante estratégia para incentivar mudanças estruturais e levar ao desenvolvimento econômico. No entanto, a elevação da oferta de bens agropecuários pode ocorrer de duas formas distintas: por meio do aumento na produtividade - margem intensiva - ou com a expansão da área cultivada - margem extensiva. Nesse ínterim, o capital humano pode potencializar a produção por meio de ambas as margens, mas seus efeitos ainda são pouco explorados pela literatura. Logo, o objetivo desta pesquisa é investigar o impacto do capital humano na expansão da produtividade agropecuária e da fronteira agrícola. Os resultados indicam que o capital humano impacta positivamente na produtividade e no avanço da fronteira agrícola. Entretanto, as evidências apontam para heterogeneidades significativas, com o capital humano impactando a produtividade em regiões de fronteira, caraterizadas pela escassez de mão de obra qualificada. Entretanto, o avanço da área agrícola não é incentivado em regiões com a agricultura consolidada.

Palavras-Chave: Produtividade Agrícola, Fronteira Agrícola, Capital humano, Educação.

JEL: O13, O15, Q1, Q12, E24

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1 Introduction

A significant part of the world's poor population lives and works in rural areas. Thus, the agricultural production growth is one of the most efficient ways to promote poverty allivation. However, one of the main issues in underdeveloped countries is related to the human capital (i.e. skilled labor). The human capital is usually low and misallocated in underdeveloped countries, especially in the agriculture sector. Thus, the knowledge and skills accumulation increase productivity and agricultural income. Therefore, the human capital is an important propeller for economic development (Schultz 1956, 1960, 1980; Banerjee e Duflo 2007; Duflo, Kremer e Robinson 2008, 2011).

The agricultural sector has a fundamental role in economic development. The agricultural production expansion is seen as an important strategy that leads to structural changes and increased welfare (Byerlee, Janvry e Sadoulet 2009; Bustos, Caprettini e Ponticelli 2016). In particular, this sector is strategic for food security (Hubbard e Hubbard 2013; Capone et al. 2014. It also reduces rural exodus and provides resources for low-income families, especially in family farming (Berchin et al. 2019). In addition, agricultural modernization generates technical progress and benefits, such as reduced costs and increased productivity (Foster e Rosenzweig 2004; Vieira Filho e Silveira 2016). In fact, the Brazilian regions with the greatest growth in agricultural production and modernization have obtained greater economic and social gains in the recent decades (Weinhold e Reis 2008; Tritsch e Le Tourneau 2016; Bragança 2018).

The increase in agricultural production can occur in two different ways: (i) through increases in productivity - intensive margin - or (ii) with the agricultural area expansion - extensive margin. The Increases in productivity are related, to a large extent, to the technology's adoption and the skilled labor (i.e. human capital) employed in agriculture production. On the other hand, in most cases the agricultural area expansion occurs with the insertion of new deforested areas (Foster e Rosenzweig 2004; Babcock 2015). The agricultural production expansion has occurred largely through deforestation. This fact is increasing pressure on forest areas. Therefore, understanding the agricultural productivity dynamics and the agricultural frontier advance helps to understand agricultural production and also, it's environmental impacts (Bento de Souza Ferreira Filho, Ribera e Horridge 2015; Assunção, Gandour e Rocha 2015).

In this context, the human capital has direct impact on productivity and is indirect in facilitating technology adoption and in the institutional improvement (Hanushek e Woessmann 2008). The human capital helps in the learning, application and technical knowledge dissemination. It's also affect the farmer's ability to adjust new technologies to particular conditions, such as changes in demand, area restrictions and in the environmental issues (Djomo e Sikod 2012; Gollin, Lagakos e Waugh 2013). The complementarity between education and technology makes the expected return on adoption higher for more educated economic agents (Foster e Rosenzweig 2004). The human capital improvement, by encouraging the agricultural sector modernization, can also reduce the agricultural frontier expansion (Bhattarai e Hammig 2004).

Thus, the paper main goal is to investigate the human capital effect on agricultural productivity increase and on the agricultural frontier expansion in Brazil. Such an objective is due to the importance of agricultural production in social and economic development, as it ensures the food and nutritional security in developing countries (Capone et al. 2014). In addition, agricultural production impacts the environmental, social and structural changes in the economy (Bustos, Caprettini e Ponticelli 2016). In this sense, the concern arises to assess the possible implications of human capital on the agricultural sector in Brazil.

In order to obtain the proposed aims, the article is structured in four sections, including this introduction. In the second section, there is the theoretical and empirical framework, while in the third, the empirical strategy and the database are detailed. The results and their analysis are in the fourth section, followed by the final remarks.

2 Theoretical Framework

The presence of market and government failures are common in developing countries, such as: informational asymmetries, restrictions on access to credit and with ill-defined property rights. In addition, the mean population has a low level of human capital, which makes it difficult to obtain and process information. The skills low level resulting in not optimal decisions (Greenstone e Jack 2015). The institutional improvement can positively impact productivity, mainly in the agricultural property rights definitions. The institutional advance increases the incentives to invest in physical, human capital and reducing uncertainties and transaction costs. This scenario creates incentives for the efficient use of productive resources impacting agricultural production and productivity. In the final analysis, the institutional improvement defines whether the agricultural expansion occurs by intensive or extensive margin (Barbier e Burgess 2001; Otsuki, Hardie e Reis 2002; Faria e Almeida 2016). The human skills investments, which also reflects the quality of institutions, can act to reduce environmental degradation and in the improving the agricultural production sustainability (Salahodjaev 2016). However, resource-rich countries typically lack incentives to build strong institutions. Therefore, the lack institutions create conditions for corrupt behavior and reducing the expected return on investment in human capital (Gylfason 2001).

In fact, Igliori (2006) found evidence that the human capital level is negatively correlated with the agricultural area expansion and positively with productivity. According to Barbier e Burgess (2001), the agricultural frontier advance in developing countries reflects the structural features of the agricultural sector, such as by low technological adoption, low human and physical capital and weak institutions. Another point that affects agricultural production is foreign trade. The access to the international market impacts relative prices, which may create incentives for the area expansion and / or agricultural productivity. These results depend on the characteristics of the sector and institutions in the country (Assunção, Gandour e Rocha 2015; Faria e Almeida 2016). Since the 2000s, the Brazilian agricultural sector has significantly increased its international insertion. The results reflected in the expansion of its productivity, through investment in technology and capital, and in the planted area (Faria e Almeida 2016). The size of the population and the economic scale are also important to explain agricultural production as they increase the demand for agricultural products and forest resources (Cropper e Griffiths 1994; Igliori 2006).

In this context, the human capital is important to the agriculture production, especially because it increases its productivity. The human capital in general allows the individual to increase the capacity to receive, decode and understand information (Nelson e Phelps 1966). The education increases the ability to perceive new types of problems and, consequently, how to solve them (Schultz 1975). However, there are two possible distinct effects of human capital on agricultural production: i) worker effect; ii) allocative effect. According to Welch (1970), the first effect proves to schooled workers are better able to use resources more efficiently. The second effect, it refers to their ability to acquire and decode information about the input's costs and characteristics. Although the human capital positive impact on agricultural production is often evidenced in the literature, the topic is still the subject of extensive research that tries to clarify the transmission channels through which human capital can improve agricultural productivity (Headey, Alauddin e Rao 2010; Peterman et al. 2011; Gollin, Lagakos e Waugh 2013; Cao e Birchenall 2013; Menon, van der Meulen Rodgers e Nguyen 2014; Reimers e Klasen 2013; Abro, Alemu e Hanjra 2014; Bustos, Caprettini e Ponticelli 2016; Rocha, Ferraz e Soares 2017; Sabasi e Shumway 2018; Valencia Caicedo 2018; O'Gorman e Pandey 2010).

For example, according to Asadullah e Rahman (2009), the education allows the economic agent to make better use of the information available and, consequently, allocate his resources more efficiently, becoming better managers. On the other hand, Asfaw e Admassie (2004) claim that more educated farmers are not only able to use the information available more efficiently, but also have better access to the required information. Lockheed, Jamison e Lau (1980) argue that educated farmers pay and receive better prices for their inputs and outputs. These results indicating that education can be a public policy for the information asymmetries prevalent in the agricultural market in general.Reimers e Klasen 2013 describe that farmers with higher levels of human capital are more likely to adopt new technologies or products. Thus, these farmers have better access to information related to their work environment and the ability to distinguish between promising and non-promising innovations.

According to Foster e Rosenzweig (2004), the technological adoption and diffusion has complementarities with the human capital, mainly in the agricultural sector. Agents with higher education are more likely to adopt new technologies, especially if they are complex and with uncertain returns. In general, there are three important links that more educated farmers usually have:(i) a higher level of income and wealth and a budget constraint low to the acquisition of new technologies; (ii) greater access to information and; (iii) high capacity to process and decode new information, making learning more efficient and faster.

3 Empirical Design

3.1 Identification Strategy

We estimate by ordinary least squares (OLS) the following basic model in order to capture the human capital effect on the agricultural productivity increase and on the agricultural frontier expansion in Brazilian municipalities:

$$Y_i = \beta HumanCapital_i + \varepsilon_i \tag{1}$$

where Y_i represent the maize productivity, soybean and livestock, as well as the agricultural area expansion. Therefore, we estimate one regression for each dependent variable. $HumanCapital_i$ is the human capital proxy and is the error term. The choice of these crops to represent agricultural productivity is due to the fact that soybeans and maize are the ones that have the highest Gross Production Value (GPV) in the country. For livestock, we use cattle ranching that occupies the first position of the GPV of livestock.

However, due to the recurring endogeneity problem in papers that measure the human capital impact, $(E(\varepsilon \mid x) \neq 0 \rightarrow Cov(\varepsilon \mid x) \neq 0$ –explanatory variable correlated with the regression error term), we need a method that overcome this problem. The basic hypothesis for the consistency of OLS estimators is that the error term cannot be correlated with the explanatory variables, otherwise, they will be biased and inconsistent. To overcome this issue, we used the instrumental variables (VI) approach to treat endogeneity (Greene 2008). In other words, we explored an exogenous source of variation to instrumentalize human capital. Technically, it is necessary to have valid and relevant instruments, that is, not correlated with the endogenous regressors and at the same time orthogonal to the error term (Greene 2008).Therefore, we used the number of schools that existed in the year of birth of the representative (average) rural producer in the municipality. The schools supply in the period is correlated with the average schooling and it is exogenous to the other components of the regression. Thus, the first stage, estimated in a reduced form is:

$$HumanCapital_i = \gamma Schools_i + u_i \tag{2}$$

where $HumanCapital_i$ " is the human capital for which we used the average schooling as a proxy, commonly adopted by the economic literature, as in Hanushek e Woessmann (2008); $Schools_i$ is the number of primary state schools that existed in the year of birth of the representative (average) rural producer. This variable aims to capture the fact that the offer of schools has an effect on the student's subsequent schooling, an identification strategy similar to that used by Teixeira e Menezes-Filho (2012) e Binelli e Menezes-Filho (2019); u_i is the error term.

We need to consider the possibility of weak instruments to use the instrumental variables method. Otherwise, two major problems in two-stage estimation (2SLS) may occur: selection bias and minimum standard error. We used the Wooldridge test to test the validity of the instrument. We estimate the second stage to capture the human capital impact on productivity (intensive margin) and the agricultural area expansion (extensive margin), considering the following specification:

$$Y_i = \beta HumanCapital_i + \delta Tec_i + \alpha Controls_i + \varepsilon_i \quad (3)$$

where Y_i is the soybean, maize, livestock and the agricultural frontier expansion; $HumanCapital_i$ is the exogenous human capital variable; Tec_i is a agricultural technology index; $Controls_i$ are control variables that capture state, institutional, socioeconomic and geographic features that may be correlated with instrument and the error term, which would invalidate identification strategy.

In particular, we construct the agricultural technology index with Principal Component Analysis (PCA), which summarized twelve technology variables pointed as important by the literature (Souza et al. 2019). TThe index seeks to represent the multidimensional character of the technological modernization of Brazilian agriculture, especially with regard to the use of inputs, machinery and modern practices, extracted from the 2017 agricultural census, which are: (1) tractors; (2) Seed drill; (3) fertilizers; (4) harvesters; (5) technical assistance; (6) irrigation; (7) fertilizing; (8) soil preparation; (9) electrical energy; (10) limestone; (11) pesticides; (12) food supplementation.

We consider per capita income, population density, proportion of individuals living in rural areas and inequality to control structural characteristics. These variables seek to capture the local demand for agricultural goods, agglomeration effects, size of the labor market and social inequality. We use variations in rainfall, temperature, altitude, soil quality and forest remnants as geographic controls, since the crops and the agricultural frontier are sensitive to these features, encouraging or curbing it. We consider "proxies"for property rights, trade opening, access to rural credit and land tenure as institutional controls. We used the agricultural settlements controlled by squatters as property right. We constructed the trade opening variable considering the sum between exports and imports as a proportion of GDP in the municipality, $(X + M)/GDP$, The access to rural credit variable consists in the proportion of agricultural establishments that have obtained some type of credit from financial institutions. The land structure variable is represented by the average area of agricultural establishments in the municipality.

In order to check the results robustness, we estimated the model using the generalized moments method (GMM)[1] and using an equation systems method (3SLS), which controls possible correlations between equation errors. In general, the agricultural productivity and frontier expansion have important interconnections. Such as technology, labor market, inputs and land use that must be considered to ensure that results are consistent and accurate.

As heterogeneity test, we re-estimate our main results for two distinct groups: (i) agricultural frontier; (ii) and non-agricultural frontier. We considering the years 2006 and 2016, decade prior to year used in this paper. This procedure seeks to verify whether the dynamics vary depending on the local characteristics in land use changes. Agricultural frontier regions are expected to show important institutional and structural differences in their economic scales, labor market and infrastructure, which can heterogeneously impact the trends of the variables. It is worth

1. To verify the model's endogeneity, we used Sargan's C statistic.

mentioning that we estimate all models using standard errors clustered at the municipal level. Therefore, minimizing potential autocorrelation in the database.

3.2 Database

The main data sources are they are the 2017 agricultural and 2010 demographic census, both carried out by *Instituto Brasileiro de Geografia e Estatística* (IBGE). The first is conducted through direct interviews with the owners of agricultural farms while the second considers the entire population of the country, both are available at the municipal level. For the instrument, we used the IBGE 20th century statistics that include data on the number of primary schools per state from 1908 to 2000. Table 1 shows the description, source and expected results for the database.

Tabela 1: Description, source and expected results for the database.

Type	**Variable**	**Description**	**Source**
Dependent	Corn (ton/hec)	Production in tons (1st and 2nd harvest) per hectare.	IBGE
	Soybean (ton/hec.)	Production in tons (1st and 2nd harvest) per hectare.	IBGE
	Cattle (head/hec)	Number of heads per hectare of pasture.	IBGE
	Agriculture Frontier (hec)	Agriculture Frontier Expansion in hectares (hec).	Mapbiomas
Explanatory	Human Capital	Years of education of farmers.	IBGE
	Technology Index*	Technological level of agricultural establishments.	IBGE
Instrument	Schools	Primary schools in the state when the individual was born.	IBGE
Institutional Controls	Trade Opening	Trade opening index.	IPEA
	Property Right	Squatter-controlled settlements.	IBGE
	Insecurity in Property Right	Number of landless workers.	IBGE
	Land Structure	Average area of agricultural establishments	IBGE
	Rural Credit	Proportion with access to the credit market.	IBGE
	States	Dummy variables representing states	-
Socioeconomic Controls	Demographic density	Total inhabitants per km^2	IBGE
	Rural Population	Proportion of the population living in rural areas.	IBGE
	per capita GDP	Economic scale.	IBGE
	Inequality	Gini Index	
Geographic Controls	Pluviometric Index	Average Pluviometric Index	IPEA
	Temperature	Average Temperature	IPEA
	Altitude	Average Altitude	IPEA
	Forest	Proportion of forest area	Mapbiomas
	Soil	Soil quality	Embrapa

Source: Prepared by the authors.

The proxy used for the agricultural frontier expansion is the municipal area increase destined to agricultural production. The information was obtained through the Annual Coverage and Land Use Mapping Project (Mapbiomas). The number of municipalities included in the sample is 5,080 (we excluded those without data for agriculture).

3.3 Descriptive Statistics

In our identification strategy the variations in the farmer's human capital and availability of schools in their years of birth perform an important role. Therefore, their descriptive statistics are shown in Table 2.

The average education of farmers, the human capital proxy, is 8.04 years of study, corresponding to complete primary education. In addition, 16% of municipalities have the lowest education level of the sample, 4% have the EJA (Youth and Adult Education), 62% have primary education, 15% have high school and 6% have higher education. In summary, it is worth noting that the majority of workers hired in the Brazilian agricultural sector do not have formal education or have incomplete elementary education. This fact reinforces the low level of education in the Brazilian rural area (Bernardelli et al. 2020).

Tabela 2: Descriptive Statistics ($n = 5080$).

Variables	Mean	Standard Dev.	Min.	Max.
Corn (ton/hec.)	3810.77	2832.66	7.00	12400.00
Soybean (ton/hec.)	1441.80	1657.51	0.00	4800.00
Cattle (cbç/hec)	2.33	23.25	0.00	1628.93
Agricultural Frontier (hec)	-0.01	0.05	-0.68	0.21
Human Capital	8.05	1.39	2.59	12.43
Technology Index	0.08	0.07	0.00	1.00
Schools	7146.69	4561.86	45.00	21798.00
Trade Opening	0.04	0.15	0.00	3.36
Property Right	18.38	55.92	0.00	797.00
Insecurity in Property Right	14.19	63.44	0.00	1073.00
Land Structure	98.51	203.06	0.68	5949.06
Rural Credit	17.76	12.32	0.00	75.45
Demographic Density	58.77	171.74	0.15	4386.67
Rural Population	0.37	0.22	0.00	0.94
Inequality	0.49	0.07	0.28	0.80
Per capita GDP	21850.74	20538.16	3285.03	344847.20
Pluviometric Index	1640.00	782.06	0.00	4357.11
Temperature	22.78	3.05	14.38	28.04
Altitude	421.82	292.32	0.00	1505.00
Forest	0.43	0.28	0.01	1.00
Soil	0.37	0.24	0.00	1.00

Source: Prepared by the authors.

On the other hand, the average number of primary schools per state in the period from 1935 to 1975 is 7146 schools, with the state of São Paulo having the largest number (21,798 units in 1975) and the Roraima state the smallest (45 units in 1963). According to Binelli e Menezes-Filho (2019), the Brazilian educational expansion in recent decades reflects the increase in primary schools, mainly between 1936 and 1980, which increased the availability and quality of education, positively impacting the educational choices of individuals. Finally, it is worth noting that we did not and extreme correlation values that could compromise the model estimates and / or inferences.

4 Results and Discussion

The results causal relationship of human capital on agricultural productivity and on the agricultural frontier expansion are in the Tables 3, 4, 5 and 6. The results tables presentation productivities of corn, soybean and cattle and, finally agricultural area expansion. First, we estimate the regressions with ordinary least squares (OLS), which we compare with the estimates that consider the endogeneity between human capital and the various agricultural production dimensions. We estimate columns from (1) to (6) in two stages with the number of state primary schools in the year of birth as an instrument for the current schooling of farmers. In addition, institutional, socioeconomic and geographical controls were gradually included to check the robustness of the results. The column (7) aims to test the robustness of the coefficients for human capital, adopting an alternative method estimated by GMM. Finally, column (8) considers the possible endogeneity between the dependent variables, estimating the equations in a system of equations (3SLS).

In the OLS estimates, a positive and statistically positive correlation was found between human capital and all dependent variables. However, the Wooldridge endogeneity test for robust standard errors confirmed the endogeneity of human capital, a fact that makes the coefficients biased. Therefore, we consider the IV results. Specifically, Table 3 presents the results for corn productivity. It is important noting that, after estimating by two stages using an instrumental variable, the estimation is no longer endogenous. In addition, human capital has only a small change after the introduction of additional controls (State, Institutional, Socioeconomic and Geographic) and remain statistically significant, reinforcing the robustness of the results. Finally, due to the log-log specification of the model, we can interpret the coefficient as elasticity, that is, an increase of 1% in human capital (measured by average farmers schooling) causes an increase of 2.59% in the corn productivity (ton/hec).

Tabela 3: Results for corn productivity.

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	4.46***	4.92***	4.58***	4.63***	4.27***	2.59***	2.58***	2.58***	2.47***
	(0.07)	(0.22)	(0.18)	(0.25)	(0.40)	(0.52)	(0.51)	(0.51)	(0.36)
Technology							0.57***	0.57***	0.56***
							(0.2)	(0.2)	(0.17)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.42								
Endog. test	5.35*								
F test		444.13	563.89	497.68	275.09	197.38	198.68	198.67	
Chi2 test									11132

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

It is worth noting that in column (6), which introduces the technology variable in order to measure how much corn productivity is correlated with the technological level of farmers the magnitude of the human capital parameter has not changed significantly. Despite this, the technological variable has a positive relationship with corn productivity, with an increase of 1% in technology index being correlated to an increase of 0.57% in corn productivity. Finally, to check the robustness of our results, we re-estimated the model IV (6) by GMM and 3SLS to further eliminate any endogeneity and autocorrelation between the equations that could bias the estimates. The results for the GMM did not change while for the 3SLS there was a reduction in the magnitude of the coefficients, however the variables remained statistically significant at 1%, not changing the relationship between human capital and corn productivity.

We use the same identification strategy for soybean productivity (Table 4), which considered the endogeneity of human capital. Among the results, we highlight that human capital is no longer endogenous and the coefficient has remained statistically significant despite the reduction in magnitude. In addition, the magnitude of the coefficient is relevant from an economic point of view, with an increase of 1% in human capital (measured by average farmers schooling) causing an increase of 7.97% in soybean productivity (ton / hec.). The technological index (IV (6)), on the other hand, does not change the impact of human capital. It is worth noting that soybean productivity has a significant correlation with the adoption of modern technologies, with an increase of 1% at the technological level being related to a growth of 4.70% in productivity. To check the robustness of the estimates, we re-estimated the model IV (6) using GMM and 3SLS. In short, the impact of human capital was reduced to 4.98%, indicating that to access the role of education in soybean productivity is necessary to consider its relationship with the agricultural sector.

Tabela 4: Results for soybean productivity.

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	10.72***	7.24***	14.24	12.97***	13.66***	8.10***	7.97***	7.97***	4.98***
	(0.26)	(0.89)	(0.68)	(0.88)	(1.39)	(1.74)	(1.73)	(1.73)	(1.34)
Technology							4.70***	4.70***	4.47***
							(0.61)	(0.61)	(0.64)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.24								
Endog. test	17.71**								
F Statistic		444.13	563.89	497.68	275.09	197.38	198.68	198.67	
Chi2 Test									6483.20

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

The fact that soybean productivity is more sensitive to human capital, compared to corn, may be related to its greater use of technology, which reflected in the reduction of the coefficient after considering the technological level. However, it is worth noting that corn is less sensitive to edaphoclimatic conditions such as precipitation and temperature, thus allowing its agricultural area to be larger even with a lower expected return. Another point is that the technological advancement of soy allowed the expansion of a second crop (usually rotation of soy and corn), which, in some cases, uses the investments made in the first crop, such as fertilizing and preparing the soil, which may have resulted in the minor impact of the technology for corn (Bustos, Caprettini e Ponticelli 2016). The results for cattle productivity are presented in Table 5.

Tabela 5: Results for cattle productivity.

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	0.99***	2.17***	1.95	2.35***	2.10***	2.85***	2.67***	2.67***	2.16***
	(0.04)	(0.15)	(0.14)	(0.16)	(0.25)	(0.39)	(0.39)	(0.39)	(0.24)
Technology							-0.66***	-0.66***	-0.56***
							(0.13)	(0.13)	(0.11)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.07								
Endog. Test	4.10**								
F Statistics		444.13	563.89	497.68	275.09	197.38	198.68	198.67	
Chi2 Test									4973.54

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Although the impact of human capital on cattle productivity reduced with the inclusion of control variables, the coefficients remain statistically significant at 1%, indicating that an increase of 1% in human capital causes an increase of 2.85% in the productivity (head per hectare of pasture). It is worth noting that although the result hardly changes with the inclusion of the technology index, the technological level is negatively correlated with cattle productivity, with an increase of 1% being related to a fall of 0.66% in productivity. Finally, the results estimated with 3SLS showed only a slight reduction in the impact of human capital, confirming the robustness of results. In fact, a positive effect of human capital on livestock productivity is expected, since more educated individuals are able to adopt better practices due to their greater management skills which, in the end, translates into larger herds and productivity.

Finally, Table 6 presents the results for the agricultural area expansion - extensive margin. We confirm that human capital is no longer endogenous and that its coefficient has changed as additional controls have been included. Despite this, it is important to note that the coefficients remained significant and increased their relative size. On the other hand, the technological index is not correlated with the agricultural frontier expansion or with human capital. We also confirmed the robustness of the results with the system of equations estimated by 3SLS, despite the reduction in the impact of human capital. In short, the increase of 1% in human capital leads to an increase of 0.06% in the expansion of the agricultural area.

Tabela 6: Results for Agricultural Frontier Expansion.

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	0.04***	-0.37***	0.03***	0.02*	0.04*	0.08***	0.08***	0.08***	0.06***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)
Technology							0.00	0.00	0.00
							(0.01)	(0.01)	(0.01)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.02								
Endog. Test	71.87*								
F Statistic		444.13	563.89	497.68	275.09	197.38	198.68	198.67	
Chi2 Test									1476.83

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

To better exploit this opportunity cost, we replicated the identification strategy for two distinct groups, dividing the sample into municipalities with agricultural frontiers and municipalities with consolidated agricultural areas . The results are described in Appendices 2 to 9. In general, we confirm that productivity and the advance of the agricultural frontier have significant heterogeneities after considering local changes in land use. In particular, the impact of human capital is greater for corn in frontier regions, with an increase of 1% in schooling, causing a growth of 3.10% in its productivity, against 1.64% in other regions.

The impact on soybean productivity, in turn, presents an even more heterogeneous relationship, with frontier regions showing an increase of 21.48% for each 1% increase in schooling against a non-statistically significant result for non-frontier regions. Finally, the impact of human capital on cattle productivity is 3.93% in frontier regions versus 1.17% for other regions, similar to corn.

Thus, the results confirm the importance of human capital for agricultural productivity, especially in border regions where its impact is greatest. In addition, the impact is greater for complex and capital-intensive agricultural activities, which employ a higher level of machinery and technology, such as soybeans and, to a lesser extent, corn. Finally, human capital presented a causal relationship with the advance of the agricultural area in frontier regions, but not in consolidated ones. An increase of 1% in the average schooling of farmers in frontier regions leads to an expansion of approximately 0.26% in the agricultural area, which, in most cases, is equivalent to deforestation.

Thus, the results confirm the importance of human capital for agricultural productivity, especially in agriculture frontier regions where its impact is greatest. In addition, the impact is greater for complex and capital-intensive agricultural activities, which employ a higher level of machinery and technology, such as soybeans and, to a lowest level, such as corn. Finally, human capital presented a causal relationship with the advance of the agricultural area in frontier regions, but not in consolidated ones. An increase of 1% in the average schooling of farmers in frontier regions leads to an expansion of approximately 0.26% in the agricultural area, which, in most cases, is equivalent to deforestation. Therefore, we can conclude that in non-frontier regions, human capital positively impacts production via productivity - intensive margin, but not through the expansion of the area - extensive margin. On the other hand, human capital had a significant impact both in the expansion of the area and in productivity in the agricultural frontier regions. The scarcity of qualified labor in agricultural frontier regions, associated with a greater demand for skilled labor in capital and technology intensive activities, may have created the conditions that explain the results.

5 Final Remarks

Understanding the causes of the advance of agricultural production is important due to the growing world demand for food and raw materials. This is even more relevant in the Brazilian case, which is a major world producer and has a wide margin for productive expansion. In this context, the quality of the labor input has become increasingly important in the agricultural production function, especially due to the capital-biased technological advancement. For this reason, this article sought to investigate the human capital effect on the soybeans, corn and cattle productivity, and on the agricultural area expansion.

To achieve the proposed objectives, we use an identification strategy based on an instrumental variable, aiming to correct the presence of endogeneity, in a two-stage estimation since human capital has an endogenous relationship with agricultural production. As an instrument, we used the number of state primary schools existing in the year of birth of the representative farmer in all Brazilian municipalities. In general, it is expected that a greater supply of schools in the past impacts the level of average schooling at the same time that it does not affect the current expansion in the agricultural production except through the human capital channel. Then, to check the robustness of the results, we estimate the models with the GMM and 3SLS methods.

The results present that human capital has a positive impact on the productivity of soybeans, corn and livestock, although with different intensities, and in the agricultural area expansion. The technology index, in turn, has a positive correlation with the productivity of soybeans and corn, however, with a negative relationship with livestock. We also confirmed the robustness of the results using the GMM and 3SLS methods. Despite this, it is important to note that the variables are determined endogenously in a system of equations, with important interconnections between them, which was captured by the 3SLS method. Then, by considering the endogenous relationship between the variables, we have improved empirical inference and also confirmed the robustness of results. In summary, the empirical evidence is in line with the literature that claims that human capital is a relevant input in the agricultural production function.

Therefore, we can conclude based on the empirical evidence that human capital has a positive impact on agricultural production. However, it is possible that there are relevant negative externalities in this relationship due to important interconnections with Brazilian deforestation.

If, on the one hand, the increase in agricultural productivity can encourage investments and the production intensification, discouraging an increase in the area expansion, on the other hand, it can create incentives for deforestation due to the growth in the expected return from agricultural. In addition, agricultural frontier expansion itself is ultimately conditioned by forest clearings, especially in Brazil. In this context, we highlight the central role that the strengthening of environmental institutions can play, since it minimizes the potential negative impacts of improving human capital by creating the right incentives for farmers, especially in agricultural frontier regions.

The results, in general, intensify for agricultural frontier regions and decrease for municipalities with consolidated agricultural area. Therefore, empirical evidence points to the importance of education in increasing agricultural production on the extensive and intensive margin while. However, the negative environmental externalities generated by expanding the agricultural area, such as deforestation, must be considered and minimized.

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A Appendix

Tabela A1: Definition used to construct the human capital variable.

Education	Years of education
Never attended school	0
Literacy of youth and adults (AJA)	4
Youth and adult education and supplementary elementary or primary education (EJA)	4
Youth and adult education and supplementary secondary or high school education (EJA)	4
Literacy class (CA)	8
Former primary (elementary)	8
Former junior high school (middle 1st cycle)	8
Regular elementary school or 1st grade	8
Ancient scientific, classic, etc. (medium 2nd cycle)	11
Regular high school or 2nd grade	11
High school or high school technician	11
Higher education	14
Master's or doctorate degree	14

Source: Prepared by the authors.

Tabela A2: Results for corn productivity (agricultural frontier).

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	4.21***	2.87***	4.12***	4.66***	4.60***	4.30***	3.03**	3.03**	3.10***
	(0.12)	(0.72)	(0.48)	(0.54)	(0.91)	(0.52)	(1.29)	(1.29)	(1.00)
Technology							-0.56***	-0.56*	-0.55***
							(0.34)	(0.34)	(0.17)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.25								
Endog. Test	3.64*								
F Statistic		50.25	65.24	96.94	57.46	38.19	28.47	28.47	
Chi2 Test									3325.55

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A3: Results for soybean productivity (agricultural frontier).

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	10.73***	-0.37***	16.03***	16.73***	20.53***	23.62***	23.30***	23.30***	21.48***
	(0.37)	(3.87)	(1.80)	(1.87)	(3.29)	(4.81)	(5.27)	(5.27)	(4.07)
Technology							4.70***	4.70***	4.11***
							(0.61)	(0.61)	(1.22)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.24								
Endog. Test	14.74***								
F Statistic		50.25	65.24	96.94	57.46	38.19	28.47	27.46	
Chi2 Test									1655.02

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A4: Results for cattle productivity (agricultural frontier).

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	0.67***	3.03***	3.40***	2.88***	2.90***	5.10***	5.04***	5.04***	3.93***
	(0.07)	(0.60)	(0.56)	(0.41)	(0.67)	(1.19)	(0.397)	(1.30)	(0.76)
Technology							-0.54***	-0.54***	-0.63***
							(0.26)	(0.26)	(0.23)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.03								
Endog. Test	19.31***								
F Statistic		50.25	65.24	96.94	57.46	38.19	28.47	28.46	
Chi2 Test									1127.89

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A5: Results for agriculture frontier expansion (agricultural frontier).

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	0.04***	-0.11***	0.58***	0.86***	0.15***	0.33***	0.33***	0.33***	0.26***
	(0.00)	(0.03)	(0.02)	(0.03)	(0.05)	(0.08)	(0.09)	(0.03)	(0.66)
Technology							0.01	0.01	0.01
							(0.01)	(0.01)	(0.01)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.02								
Endog. Test	32.17***								
F Statistic		50.25	65.24	96.94	57.46	38.19	28.47	28.46	
Chi2 Test									476.75

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A6: Results for corn productivity (non-agricultural frontier).

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	4.50***	5.42***	3.85***	3.77***	3.31***	1.64***	1.45***	1.45***	1.64***
	(0.09)	(0.27)	(0.24)	(0.35)	(0.44)	(0.51)	(0.48)	(0.48)	(1.12)
Technology							0.57***	0.57***	0.56***
							(0.16)	(0.16)	(0.21)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.45								
Endog. Test	16.84***								
F Statistic		320.58	474.14	293.90	211.06	174.56	153.40	153.40	
Chi2 Test									6284.81

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A7: Results for soybean productivity (non-agricultural frontier)

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	11.18***	10.27***	13.27***	10.80***	9.94***	1.32	0.83	0.83	-0.98
	(0.39)	(0.96)	(0.92)	(1.32)	(1.68)	(1.81)	(1.84)	(1.73)	(1.34)
Technology							4.36***	4.36***	4.15***
							(0.77)	(0.77)	(0.91)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.14								
Endog. Test	26.82***								
F Statistic		320.58	474.14	293.90	211.06	174.56	153.40	153.40	
Chi2 Test									3540.81

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A8: Results for cattle productivity (non-agricultural frontier

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	0.97***	1.40***	1.42***	2.17***	1.76***	1.78	1.73	1.73	1.17
	(0.04)	(0.15)	(0.13)	(0.20)	(0.26)	(0.30)	(0.31)	(0.31)	(0.24)
Technology							-0.63***	-0.63***	-0.70***
							(0.14)	(0.14)	(0.13)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.07								
Endog. Test	9.41***								
F Statistic		320.58	474.14	293.90	211.06	174.56	153.40	153.40	
Chi2 Test									3325.54

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.

Tabela A9: Results for the agricultural frontier expansion (non-agricultural frontier).

Variables	OLS	IV (1)	IV (2)	IV (3)	IV (4)	IV (5)	IV (6)	GMM	3SLS
Human Capital	0.05***	0.01***	0.07***	0.03	0.02	-0.00	-0.01	-0.01	0.00
	(0.00)	(0.01)	(0.01)	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
Technology							-0.02	-0.02	-0.01
							(0.01)	(0.01)	(0.01)
State	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Institutions	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Geographic	No	No	No	No	No	Yes	Yes	Yes	Yes
Observations	5080	5080	5080	5080	5080	5080	5080	5080	5080
R^2	0.05								
Endog. Test	17.17***								
F Statistic		320.58	474.14	293.90	211.06	174.56	153.40	153.40	
Chi2 Test									713.87

Source: Prepared by the authors.
Note: * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$. Standard errors clustered at municipality level.