Opportunity cost of environmental preservation: the case of the Brazilian Legal Amazon

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Currently, the Brazilian Legal Amazon (BLA) represents the agricultural frontier of Brazil and concentrates the deforestation processes. A recurrent discussion involves what to do to reduce the deforestation process. A compensation to no-deforestation is a way to this, but involves an opportunity cost for agents in BLA, represented by the expected cash flow that these agents are expected to lose by not using the land for agricultural production in the future. The expectation formation process is uncertain, but the occupation in Brazil's Midwest, a region near the BLA, in the 1970s can provide a proxy value. We use the stochastic frontiers method to compare both regions and conclude that the actual production mode in the BLA is very similar to that in the Midwest in the past. Thus, we take the production function estimate to project the future income flow for this region. The results show that producers in the BLA region can expect a 9% to 13% increase in average annual income over the next forty years, depending on the discount rate of the cash flow.

Keywords: Environmental preservation; climate change; land use; Brazilian Legal Amazon; deforestation.

JEL Codes: Q51; Q56; R14.

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1. Introduction

Since the 1970s, the Brazilian agricultural frontier has expanded to the North and Midwest regions of the country. In the 1980s and 1990s, this expansion was marked by the occupation of the states of Mato Grosso and Mato Grosso do Sul (two states in the Brazilian Midwest) by various crops, such as corn, rice, and soybean, as well as livestock. Currently, the Brazilian agricultural frontier area is the Amazon region, especially the so-called "arc of deforestation," which covers the states of Mato Grosso, Pará, Rondônia, and Acre.

This paper presents an estimation of the opportunity cost that private economic agents located in agricultural frontier areas would incur by stopping the clearing of new forest areas for the purpose of economic exploitation, i.e., the cost that the preservation of the forest would mean to them. This cost may be indicative of the maximum amount required to encourage such officers to stop deforestation.

The main hypothesis is that the Amazon region is currently at a production stage similar to that in midwest Brazil in the 1970s, the period in which the productive utilization of the Midwest states began to intensify. Given this assumption, the producers in the Amazon may form their expectations about the future profitability of their production on the basis of the recorded rates in the Midwest in the last forty years.

The present value of the expected income from the productive use of the land is assessed through the construction of a stochastic production frontier, assuming that the land has maximum profitability given its efficient use. Therefore, we estimated a land rent function for the control region (Midwest) based on data from the agricultural censuses of 1970, 1975, 1980, 1985, and 2006. Using the actual census data to Amazon region, we found the exact point where this region is in the estimated curve. The opportunity cost of the non-expansion of the converted area was calculated as the difference between the current income and the present value of the expected income, according to the estimated function.

The empirical work is divided into four methodological steps. The first consists in determining the production frontier of Midwest municipalities by using data from the

Agricultural Censuses. In the second step, we estimated the income producer based on the results of the stochastic frontier. Therefore, the producer is assumed to be a typical capitalist owner or the owner of the land and capital used in production. In the third step, the expected income of the producer in the Amazon is projected based on the period of development of agricultural production corresponding to the current state of the Amazon. The present value, in the fourth step, is obtained by applying the most appropriate discount rate to the expected income of municipalities as determined by the estimated stochastic frontier.

The results show that producers in the Amazon region expect a significant increase in income. Some institutional factors, however, can affect the rate at which the decision makers discount the time. The literature suggests that the uncertainty of land tenure in the region can cause such rate to be higher than expected. Moreover, empirical studies point to the fact that producers are risk-averse, citing their willingness to accept compensation below the expected value of future production. In any case, the results obtained in this study can be considered as a proxy for the maximum value to be transferred to land owners in order to discourage the expansion of agricultural activities in forest areas, assuming the efficient use of resources, maximum profitability production, and the existence of official support, as occurred in the Midwest.

The paper is organized as follows. In Section 2 we provide a review of the literature on the environmental services and the economic returns of deforestation. The methods and data used are described in Sections 3 and 4, respectively. Section 5 presents the results obtained, and Section 6 develops some final considerations and possible prospects for future work.

2. Literature review

This work fits into the discussion of the environmental services that nature provides to individuals. The Amazon region, specifically, is important in regulating rainfall in the South American subcontinent, besides the fact that it is home to ecosystems that are among the richest in the world and has a high potential to conserve and sequester carbon in soil (IPCC, 1996).

Igliori (2006) opposed these concepts of services to the value represented by goods and services that are no longer produced under alternative land uses, determining the existence of a trade-off between development and environmental conservation. This trade-off becomes particularly critical due to the poverty in the Amazon region. The author added that, in the decision-making regarding land use, there is conflict between horizons, as well as between private and global views on the cost of activities that degrade the environment.

Young (1996) addressed the issue of land conversion, through the composition of a portfolio of assets, to generate income flow. Like other portfolio problems, two parameters are fundamental: the discounted future flow of revenue associated with each land use option and the degree of risk or uncertainty involved in each option. The uncertainty about future prices and the specific definition of property rights differently affect the process of decision-making regarding land use. Basically, the possibility of replacement land at a relatively low cost and the uncertainty of tenure induce a reduction of the time relevant to decision making.

The profitability achieved by the conversion of forests should be contrasted against the environmental benefits offered by their preservation. To emphasize the importance of the economic valuation of natural resources, Young and Faust (1997) assigned economic values to the benefits derived from goods and services that are not captured by the market. The estimation of such values entails serious difficulties, due mainly to the absence of markets for most of the natural resources and the occurrence of market failures. Additional difficulties may arise from the fact that the property rights on environmental assets are often not well defined and the preferences of future generations are not taken into account when prices are assessed.

The methods used for the valuation of environmental resources try to calculate the total economic value of these resources through the willingness of officers to pay, assigning monetary value to the desire to preserve the environment (Faust and Young, 1997; Tietenberg and Lewis, 2009; Field, 2001). The total economic value of an environmental good is given by the sum of direct (consumption, nonconsumption, and production) or indirect (derived from ecosystem functions) use, the option value (that is, the possibility of future use), and the value of existence or non-use, regardless of current or future use[3]. As explained by Andersen (1997), in the case of tropical forests, the direct use value relates to cutting wood, non-timber extraction activities, tourism, and genetic material available for them, and the indirect use value relates to protect soil and water systems.

Since environmental goods can be priced in accordance with the flow of income or the benefits they may generate in the future, the discount rate used to estimate the present value of this flow is also a crucial factor in the valuation of such assets (Field, 2001; Andersen, 1997). Two factors stand out in the discussion of the discount rate. The first is the definition of property rights, since uncertainty about the possibility of holding assets in the future increases the discount rate, which can lead to overexploitation of resources. The second concerns the preferences of future generations. Given that the discount reflects the perspective of the current generation, the tendency is to attach lesser value to future benefits relative to current ones.

The price of environmental resources, obtained from valuation, is compared the costs involved in its preservation. Field (2001) indicated four main costs that must be considered: the opportunity costs (social and private), notably the production sacrificed; the costs linked to changes in prices, since the internalization of externalities should generate an adaptation to the new market situation; the cost of the physical facilities necessary to protect the resources in question; and the cost of public regulation, which involves knowledge of the cost structure of firms, information on the conditions of market demands, etc.

This work focuses on the first of these costs, specifically with the opportunity costs for agents in the Amazon region. Some studies that have sought to further this work are briefly reviewed below.

Andersen (1997) compared the costs and benefits of environmental conservation in the Amazon region from the point of view of private agents, the federal government, and a global social planner. The costs were measured based on the net present value of agricultural land use,

[3] Pearce (1993) pointed out that the existence value reflects moral, cultural, ethical, or altruistic values. He used the term "environmental charity" to refer to the fact that some people are willing to pay simply for the existence of environmental resources.

and the benefits according to the total economic value of the standing forest. The values used to calculate the net present value were obtained from studies conducted by IMAZON (Instituto do Homem e Meio Ambiente da Amazônia) in the first half of the 1990s, which analyzed the farming methods used in state of Pará and reported initial costs and annual profits for different types of land use. Paragominas municipality was used as reference due to its early occupation.

Andersen called attention to the importance of the indirect positive effects of deforestation on the urban economy of the region, which enhanced the overall benefits generated by deforestation, and the fact that the price of land is the main determining factor for the intensity of land use. The author considered a land use sequence that begins with logging, followed by extensive cattle farming and, finally, the raising of crops, the intensity of which increases over time. Andersen concluded that in the actual stage of deforestation, the expansion of the deforested area was more advantageous than the preservation of the forest under any of the optical analyzed. From the perspective of the first occupants of the land, the establishment of agriculture based on the burning of the forest would be economically advantageous, despite the decrease in profits and in proportion to the nutrient reduction, due to the prospect of land sale to occupants from the second generation, who have greater access to capital. From the point of view of a social planner, however, this would be justified only if the land was used more efficiently. Nevertheless, as emphasized in this work, the cost and benefit estimates presented relate to a specific point in each curve, associated with a deforestation level of 10%. As deforestation increases, so do the costs, which at some point will exceed the value of the agricultural land.

Dias and Schwartzman (2005) examined the possible effects of a policy of compensated reduction in Amazon region deforestation through carbon credits. They pointed out that monitoring by the government would not be enough to stop the expansion of deforested areas unless environmental conservation can generate a stream of income in the long term. It is necessary to find the break-even point, that is, the carbon price that would make the preservation as profitable as the main alternative land use (livestock, soybean cultivation, and forest management). The authors cited that soy crops, despite yielding higher returns, tend to have limited growth due to geographical factors. Livestock, on the other hand, is seen as a guarantee of tenure, making it the primary use of converted land despite yielding not-so-high returns at present.

This work is based on the hypothesis that changes in land use occur in the following cycle: forestry, livestock farming for about five years, and finally, soy cultivation. The authors used as reference the NPV (Net Present Value) rates of return calculated by Seroa da Motta (2002) and Margulis (2003) for forestry and livestock, respectively, and the economic returns of soy in the state of Mato Grosso. The total horizon considered was 30 years. The results showed that carbon credits priced between $14/tC and $ 22/tC would be enough to make conservation attractive in the eyes of private producers. However, the current prices of carbon credit, although competitive with those of forestry and livestock, would not be enough to make soybean cultivation less attractive. The authors noted that the implementation of a policy of compensated reduction would be extremely difficult, as would also be extended to other agents as well as to private producers, and would require more advanced governance tools than those currently existing.

Pinedo-Vasquez et al. (1992) also came very close to the objective of this work: they were interested in estimating the economic returns obtained from the conversion of forest areas in the Peruvian Amazon. To do this, they used an inventory of plant species present in the area in 1985-86 and data on production costs and prices of timber resources and agricultural crops raised by farmers' unions in the region[4]. According to the authors, the regional agents adopted a very short-term horizon of decision-making due to uncertainty regarding the ownership of land. Their results indicate that in the

[4] Taking the more commonly used techniques and the average production per hectare, the present value of agricultural activity based on continuous cultures of rotations is given by$R_{NPV} = \frac{R_1}{1-(e^{-ht_3})}$, where h is the continuous interest rate, t_3 is the rotation time, and R_1 is the liquid income adjusted to culture 1. R_1 is defined by $R_1 = (-C_1)(e^{-kt_1}) + (pV - C_2)(e^{-kt_2})$, where C_1 is the initial cost, t_1 is the plantation time, C_2 is the harvest transport cost, and t_2 is the harvest time. The liquid revenue adjusted to culture 2 is defined by $R_2 = R_1 (e^{-kt_3})$. These values are calculated with discount taxes of 5%, 10%, and 15%. To this NPV it is possible to add the revenue from timber extraction.

present context, the local population should continue converting forest areas to agriculture land through burning, unless alternative land uses become more attractive economically.

According to Margulis (2001), from the point of view of private agents, deforestation provides clear economic gains that stem primarily from productive, rather than speculative, activities. The agents who appropriate these gains are loggers and intermediaries who transform native forests to pastures (small agents with the lowest opportunity costs), particularly ranchers and farmers. On the other hand, the author cited the approach of the agricultural frontier into the densest area of the forest, where heavy rainfall prevents the realization of any economic activity.

Margulis (2003) estimated the income potential of private ranching in the Eastern Amazon region. Thus, we conducted surveys and panel interviews with 43 producers in 8 municipalities. From the results of the surveys, the income potential and Internal Rate of Return (IRR) of private activity were estimated. Research showed that livestock farming in the region has high productivity, with an IRR of more than 10% and a private income potential of R$75/ha/year (about US$ 35/ha/year). The results also indicated that producers have high risk aversion, accepting a compensation of R$ 45/ha/year (US$ 20/ha/year) for not expanding the area under cultivation in forest areas (the values may increase to R$ 200/ha/year, not less than US$ 100/ha/year, if there is lower risk aversion). When the effects of a tax on deforestation were simulated, the results showed only a change in the mix of cultures, not a decrease in the deforested area.

Souza-Rodrigues (2011) sought to determine the demand for deforestation in the Brazilian Amazon private property, defined as the area of forest felled due to differences in the amount of private agricultural land and forest. The authors estimated the effect of transport costs on deforestation and then resized these costs using the income to determine the difference in price per hectare between agricultural land and forest. The sample of farms was divided according to size to take into account the existence of diminishing returns in agricultural land use. The estimated demand function was used to evaluate the costs and effectiveness of different policies for preventing deforestation. The results indicated that a Pigouvian tax of US$ 100/ha/year would have achieved 70% coverage retention in private areas (in contrast to the observed 40%) and would have yielded an annual revenue of US$ 2.5 billion. A program of payment for environmental services, also worth US$100/ha/year, would have had the same effect on vegetation cover and would have cost US$ 2.1 billion to US$ 5.33 billion per year, depending on the ability of the Program to identify farmers that in fact intend to deforest. A REDD+ program with a fixed carbon price of US$ 1 per ton per year would increase the carbon stock in private forests from 4 to 7 billion tons, amounting to about US$ 7 billion per year or US$ 2.33/tC/year. Finally, the imposition of quantitative restrictions on land use that specify 80% participation for forests on private land, such as those that exist today, would entail so much costs for farmers that they would be willing to pay up to US$ 8.43 billion per year to prevent such law from being implemented. The author also pointed out that medium- and large-scale farmers were more responsive to such policies due to the diminishing returns from land use.

Regarding the studies reviewed, the main contribution of this paper is to incorporate the expectations of economic agents about the future profitability of converted land into the calculation of the net present value. Given that the Amazon region is one of recent economic occupation, and considering that production methods are being adapted to the local climate and soil and that the regional infrastructure is being developed, it is reasonable for producers based in the region to expect an increase in the income generated by land use. Thus, the currently observed levels of returns cannot represent the best reference values for estimating the economic value of the land in the Amazon region; rather, they reflect the present value of the expected future income stream. The comparison of the current stage of production in the Amazon region with that achieved in the Midwest is due precisely to the fact that the latter has already gone through the same process of economic occupation and maturation of farming activities.

3. Methods

The producer/owner who maximizes the expected income is given by

$$E(\pi_{it}) = E[f(A_{it}, T_{it}, K_{it}, L_{it}, I_{it}) - c(T_{it}, K_{it}, L_{it}, I_{it})], \quad (1)$$

where $E(.)$ is the expected operator, and $f(.)$and $c(.)$ are the functions of, respectively, the revenues and costs expected for each time t. The production function is given as

$$f(A_{it}, T_{it}, K_{it}, L_{it}, I_{it}) = Y_{it} = A_{it}G(T_{it}, K_{it}, L_{it}, I_{it}),$$

where Y_{it} is the total production of firm *i* at instance *t*; A_{it} is a Hicks-neutral technical index; T_{it}, K_{it},, and L_{it} are the production factors land, capital, and labor, respectively, that are used as inputs by the firm*;* I_{it} are other production inputs; and *G*(·) is a function of the C^2 class. Differentiating this function totally and dividing it by Y_{it}, results in

$$\frac{dY_{it}}{Y_{it}} = \frac{dA_{it}}{A_{it}} + \frac{\partial Y}{\partial T}\frac{dT_{it}}{Y_{it}} + \frac{\partial Y}{\partial K}\frac{dK_{it}}{Y_{it}} + \frac{\partial Y}{\partial L}\frac{dL_{it}}{Y_{it}} + \frac{\partial Y}{\partial I}\frac{dI_{it}}{Y_{it}} \quad (2)$$

Representing by α_J the participation of factor J in the sector income and μ the *markup* in the sector (defined by the proportion between the price and the marginal costs), the profit maximization conditions of a firm in Cournot's imperfect market implies

$$j = \frac{\square Y}{\square J}\frac{P}{\mu} \; e \; \sum \alpha_J = \frac{\beta}{\mu}. \tag{3}$$

where *j* is a remuneration of factor J, J_{it} is the quantity used for this factor, *P* is the price of *Y*, and β is the parameter indicator for the scale returns. If $\beta < 1$, the technology presents decreasing scale returns. If $\beta = 1$, the technology has constant scale returns. And if $\beta > 1$, the technology presents increasing scale returns.

Substituting this result in (2) yields

$$d\,ln\left(\frac{Y_{it}}{K_{it}}\right) = \mu\left[\alpha_L d\,ln\left(\frac{L_{it}}{K_{it}}\right) + \alpha_T d\,ln\left(\frac{T_{it}}{K_{it}}\right) + \alpha_I d\,ln\left(\frac{I_{it}}{K_{it}}\right)\right] + (\beta - 1)d\,ln(K_{it}) + d\,ln(A_{it}) \tag{4}$$

A simple version of this model is obtained if the constant returns scale is imposed to technology. In this case, the expected return by the producer is:

$$E(\pi_{it}) = E\left[f(A_{it}, T_{it}, K_{it}, L_{it}, I_{it}) - \sum_j \frac{df(A_{it}, T_{it}, K_{it}, L_{it}, I_{it})}{d\,j_{it}} j_{it}\right].$$

where, as before, $j = T, K, L$ or I represents the input variables.

Defining $\sum_j \frac{df(A_{it}, T_{it}, K_{it}, L_{it}, I_{it})}{d\,j_{it}} \frac{j_{it}}{f(A_{it}, T_{it}, K_{it}, L_{it}, I_{it})} = \gamma$ as the share of production factors external to the farmer, it is concluded that the expected income of producers in each time t equals the share of production factors owned by producers in the total production, that is

$$E(\pi_{it}) = E[f(x_{it})(1 - \gamma)]. \tag{5}$$

where $x_{it} = (A_{it}, T_{it}, K_{it}, L_{it}, I_{it})$.

3.1. Stochastic frontier production

For each instant t, the function $f(x_{it})$ throughout the production possibilities frontiers for the Midwest in the years 1970, 1975, 1980, 1985, and 2006 and for the Legal Amazon in 2006 was estimated by using the stochastic frontier method. This method, developed by Meeusen and Van Den Boeck (1977), and Aignel, Lovell, and

Schmidt (1977), consists of maximum likelihood estimation of a production function in the form

$$y_i = \epsilon_i f(x_i, \beta) e^{v_i},$$

where y_i is the production, f(x_i, β) is the deterministic frontier common to all producers, x_i are the inputs, β is the parameter vector, ε_i is a term indicative of inefficiency, and v_i is the random component. Linearizing the equation and setting u_i = - ln ε_i, it follows that

$$\ln y_i = \ln f(x_i, \beta) + v_i - u_i$$

Thus, the deviation from the deterministic part of the production frontier is given by u_i and v_i, which determine the characteristics of the composite error model. The term u_i captures inefficiency. If $u_i > 0$, there is inefficiency; that is, the producer operates under the production line; if $u_i = 0$, the producer is efficient, operating on the border. The term v_i follows a normal distribution and captures random shocks beyond the control of the firm, specifically those affecting the ith producer, as well as observation and measurement errors in y. Thus, v_i expresses the fact that the boundary may vary randomly from one company to another or over time for the same firm (Aignel, Lovell, & Schmidt, 1977).

Given

$$\varepsilon_i = v_i - u_i,$$

and $u_i \geq 0$, we can say that the composite error is asymmetric, adding to the hypothesis that it is non-zero.

3.2. Factor analysis

We used the method of factor analysis, because many variables exhibit high multicollinearity. This method applies regression techniques to estimate, based on the observed variations between correlated variables, a smaller number of latent variables or factors capable of explaining the observed variables[5]. The observed variables should consist of a linear combination of latent variables plus an error term, in order to determine factors that explain as much of the variance between the observed variables as possible.

Given the set of variables $= x_{1,} x_2, \ldots , x_n$, with the corresponding averages $\mu_1, \mu_2, \ldots , \mu_n$, suppose

$$x_i - \mu_i = a_{i1}F_1 + a_{i2}F_2 + \ldots + a_{ik}F_k + \varepsilon_i,$$

where a_{ij} represents constant values; F_j denotes unobserved variables, mutually independent of the error and with zero mean; and ε_i is an error term with zero mean and a finite variance ψ. In matrix terms,

$$x - \mu = AF + \varepsilon,$$

where A is a matrix of constants, or a loading matrix; and F is the vector of unobserved variables or factors. Thus, since $cov(x - \mu) = \Sigma$, the following is given:

$$\Sigma = AA' + \psi,$$

which allows us to estimate A and F for a given sample.

The main advantage of this method is in reducing the number of variables. Thus, it is commonly used to reduce a large number of observed variables to a smaller number of factors. However, factor analysis is also used when the observed variables have measurement errors.

3.3 Robustness analysis

It is possible to jointly estimate the markup in the sector and the scale returns resulting from the technology adopted. Harrison (1994) suggested including in (4) the firm-specific term f_{it}, which controls the possible specific productivity, resulting in

[5] See Lawley and Maxwell (1973), Bartholomew et al. (2008), and Hair et al. (2006).

$$\Delta \ln\left(\frac{Y_{it}}{K_{it}}\right) = \mu\left[\alpha_L \Delta \ln\left(\frac{L_{it}}{K_{it}}\right) + \alpha_T \Delta \ln\left(\frac{T_{it}}{K_{it}}\right) + \alpha_I \Delta \ln\left(\frac{I_{it}}{K_{it}}\right)\right] + (\beta - 1)\Delta \ln(K_{it}) + \Delta \ln(A_{it}) + \ln(f_{it})$$

This equation can be simplified as:

$$dY = \mu dx + (\beta - 1)dK + dA + f \quad (6)$$

In this work we tested two specifications of the model, in the first we include constant returns to scale and in the second we relax this hypothesis. The pooled least squares (models 1 and 2) and fixed effects (models 3 and 4) methods were used.

3.4. Estimating the net present value of the expected future income

From the results obtained, it was possible to estimate the participation of producers in the product generated and, subsequently, the estimated present value of future income by using the present value formula,

$$\Pi = \int_{\tau}^{\tau+n} \pi(t) e^{-rt}\, dt,$$

where π (t) is the production function estimated by the borders was stochastic discount rate. The adjustment of this function over time is done by using a polynomial model,

$$\ln \pi(t) = \ln y = at^2 + bt + c,$$

where y is the actual income 2000, and t is the time in years. The net present value of the expected income can then be calculated by

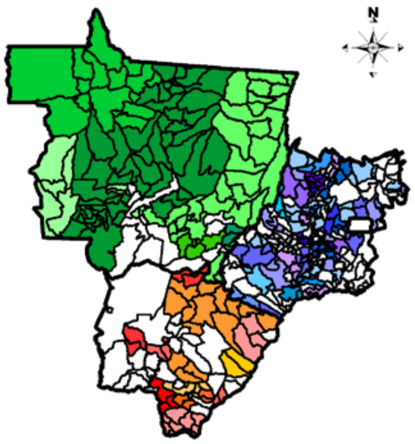
$$\Pi = \int_{\tau}^{\tau+n} e^{at^2+bt+c-rt}\, dt,$$

corresponding to the projected income discounted by the interest rate.

4. Data

The data used were obtained from the Agricultural Censuses conducted by the IBGE in the years cited. These sought to gather information related to the production factors present in all years. The Census data from 1995/1996 were not used due to methodological differences between this and the other censuses considered, as well as the lack of observations in this year regarding some variables used.

To compare data over years, we used Minimum Comparable Areas (MCA) provided by IPEA for the period 1970 to 2006. This concept incorporates the initial municipal area and its changes along the periods. Thus, to the Midwest region, the observations on 252 municipalities in 1970, 253 in 1975, 280 in 1980, 363 in 1985, and 466 in 2006 were condensed per year into 222 MCA. In the case of the Amazon region, the municipalities of the state of Mato Grosso were disregarded, as was done in the Midwest, because this state had been utilized for agricultural activities earlier than the rest of the region. The rest of the municipalities belonging to the Amazon region accounted for a total of 630 observations for the year 2006.



Source: Own elaboration from IPEA data.

Figure 1 – Minimum Comparable Areas

For the labor factor, we considered the following Census data: number of employees, number of partners, responsible person and unpaid family members. The capital data used refer to the number of tractors, plows, and harvesters used in the property. The land was measured based on the rural area[6]. The annual production value excluded the rural industry and was set in constant 2000 Brazilian Real[7].

In the analysis of variables related to the factors labor and capital, high multicollinearity was observed among the selected variables. Thus, it was necessary to perform factor analysis. The available data for each year with respect to capital (number of tractors, plows, and harvesters used) represented only part of the total capital involved in agricultural production; however, the capitalization of the firm positively affected all observed variables. Furthermore, the possibility of measurement errors in the data relating to capital and labor was greater than in those related to land, due to the changes in methodology adopted by the IBGE over the years.

The number of observations (222 in the Midwest; in the Amazon region, 630 for variables related to labor and 500 for those related to capital) and the number of observable variables (three for each latent variable) were consistent with those mentioned in the literature for generating robust results[8]. The estimation method used was the factor analysis. The factors were standardized to make the sum of the coefficients equal 1, enabling comparisons between years and regions.

Figures 2, 3, 4, and 5 show the spatial distribution and evolution over time of each of the variables. The descriptive statistics are provided in Annex II.

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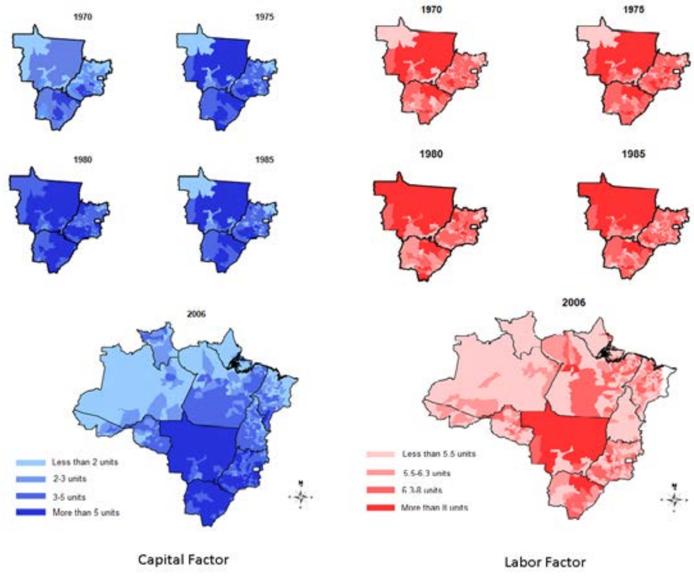
[6] The methodology for calculating the total area of farms was changed in the 2006 Agricultural Census, which began to take into account, in addition to the uses already computed in previous censuses, forest areas and/or natural forests for permanent preservation and legal reserves; forest and/or natural forests (exclusive areas of preservation and agroforestry systems); areas cultivated with forest species also used for crops and grazing animals; areas occupied by ponds and lakes; and ponds and/or water areas for public utilization, aquaculture structures, improvements, or paths. To avoid the distortion of estimates and to allow comparisons between different years, the total area minus the area devoted to the above-mentioned uses was considered for the year 2006.

[7] The annual production value, presented in the local currency, was set to 2000 real to allow comparisons between years. For this, we used the implicit GDP agricultural deflator calculated by the IPEA.

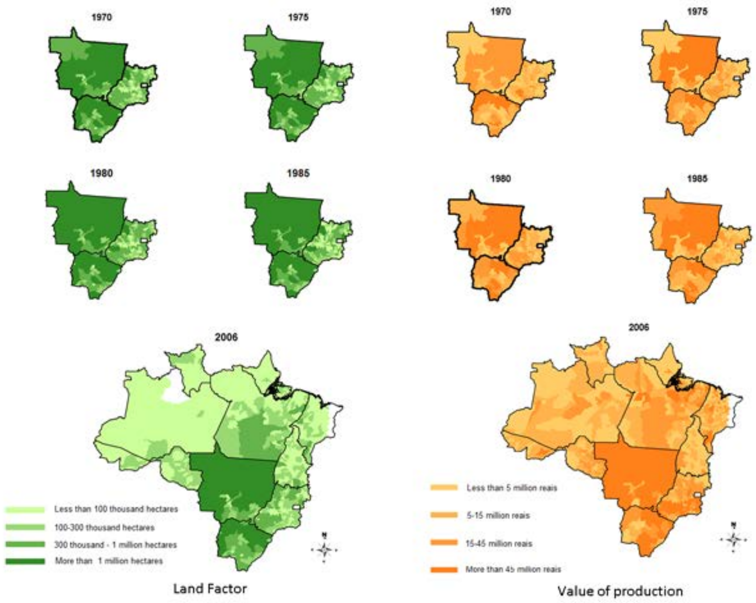
[8] HAIR et al. (2006).



Source: Own elaboration from the IBGE Agricultural Census.

Figure 2 - Use of capital and labor factors

There was a clear trend toward increased use of capital intensity over time, probably as land was occupied and it became difficult to increase production by expanding the cultivated area. This growth, however, occurred at decreasing rates, reaching a more stable capital value between 1985 and 2006. The number of observations with zero capital falls from 12 MCA in 1970, to 3 in 1975, and 1 in 1980. From 1985 onward, all counties have used some form of capital.



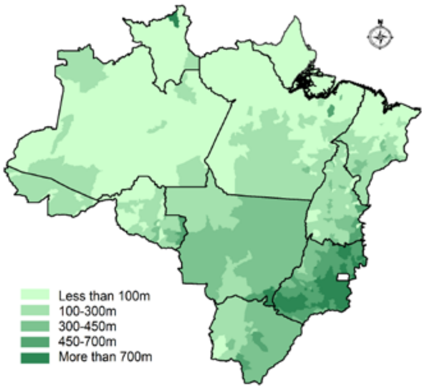
Source: Own elaboration from the IBGE Agricultural Census.

Figure 3 - Use of land cost and value of production

With regard to labor, the trend differed from that presented by capital: the use of factor initially grew (between 1970 and 1975), after, it began to diminish, at an increasing rate, characterizing the increase in agricultural labor productivity, as discussed in the literature that analyzes the results of the Agricultural Census (Gasques & Conception, 2000; Gasques et al., 2010).

In the Midwest region, land was the production factor that showed lesser variation over time. Nevertheless, its use presented a clear movement, increasing until 1985 and then decreasing between then and 2006. This dynamic is consistent with the occupation of new frontier areas, which decreases the amount of land used as the region develops and becomes urbanized.

The production value behaved as expected, tending to increase over time in the Midwest region, although the year 1985 showed a decreasing trend.



Source: IPEA/University of East Anglia.

Figure 4 - Average altitude (in meters above sea level)

Given the evidence in the literature on the Amazon regarding the strong influence of climatic factors, especially rainfall, on the higher suitability of certain areas for agricultural production (Margulis, 2003), which determines their higher productivity, some controls related to the climate and topology of the municipalities were also considered, such as altitude and estimates of average quarterly rainfall and temperature.

The control variables for climate represented the historical averages for each county and thus did not vary from one year to another. To avoid a multicollinearity problem in the climate data, due to the low variations in temperature throughout the year, especially in the Amazon but also in the Midwest, we used a single control variable for temperature whenever possible. However, the rainfall was fairly significant, as predicted in the literature.

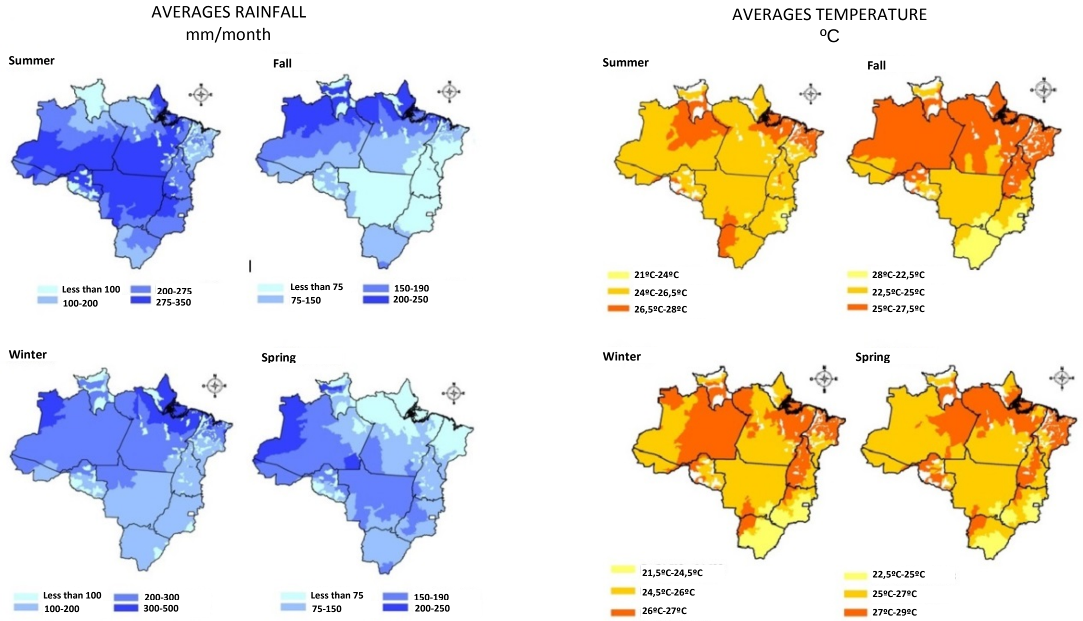
5. Results

The production function estimated for each year is given by

$$\ln Y_i = \beta_0 + \beta_1 \ln T_i + \beta_2 \ln K_i + \beta_3 \ln L_i + v_i - u_i$$

For v_i, we adopted the normal distribution most commonly seen in such models. For inefficiency, we tested the half-normal, truncated normal, and exponential distributions. The estimations done with the exponential distribution showed convergence problems. The results of the half-normal and truncated normal distributions, however, were very similar. Thus, we present herein only the results obtained with the half-standard distribution.

We estimated two production functions: Cobb-Douglas and translog. The results obtained with the translog function pointed to the non-significance of the interactions between the variables, which suggests that the Cobb-Douglas function best describes the production technology used.



Source: IPEA/University of East Anglia.

Figure 5 - Estimates of average quarterly rainfall (mm/month) and average temperature (°C)

To enable a comparison of results between different years, we set the restriction

$$\beta_1 + \beta_2 + \beta_3 = 1$$

This restriction also contributes to the interpretation of the estimated coefficients, which, in this way, represents the participation of each factor in the agricultural income. We achieved an alternative specification test for the function, which pointed to the inexistence of increasing returns to scale. The presence of increasing returns to scale would prevent the adoption of the restriction. As discussed in Section 3.3, we tested both the presence of increasing returns to scale and the perfect competition hypothesis. Table 1 shows the results.

Table 1 – Robustness test results

	1	**2**	**3**	**4**
Constante	-0.1200**	0.03089	-0.05985*	0.09549**
	(0.02631)	(0.02428)	(0.03130)	(0.03090)
Dx	1.514**	0.7057**	1.726**	1.030**
	(0.05692)	(0.07569)	(0.08584)	(0.1039)
dK	-	-0.5070**	-	-0.4701**
		(0.03735)		(0.05139)
Solow residual	-0.12000	0.0000	-0.059850	0.095490
	(0.40324)	(0.33032)	(0.26004)	(0.21388)
Obs	379	379	379	379
R^2 adjusted	0.6516	0.7656	0.6896	0.7889

Notes:

(i) The values in parentheses are the standard errors

(ii) * 10% significance

(iii) ** 5% significance

A significance test on the fixed effects *dummies* suggested that this estimator explains the observed data better than does the pooled least squares. Therefore, the coefficients in models (1) and (3) are biased toward omission of the *dK* variable. Comparing models (2) and (4), the null hypothesis about the absence of fixed effects is rejected; hence, the parameters of interest are those in model (4). Considering the significance of the *dK* coefficient, decreasing returns to scale are possible. A specific test on dx showed that this coefficient is not different from 1, which indicates a competitive market. The results also indicated an average productivity growth of 9.5% in the analyzed years.

Tables 2 and 3 show the results obtained by the stochastic frontier estimate under the conditions considered.

Table 2 – Results without climatic controls

	1970	1975	1980	1985	2006	AL
β_0	8.7520*	9.2001*	9.6751*	9.6966*	13.3176*	10.1679*
β_1	0.1840*	0.1606*	0.1215*	0.0888*	-0.2556*	0.1241*
β_2	0.2430*	0.3586*	0.4846*	0.6955*	0.9986*	0.1687*
β_3	0.5731*	0.4808*	0.3938*	0.3330*	0.2570*	0.7071*

* 1% Significance ** 5% Significance *** 10% Significance ^{NS}Not significant

Source: Own elaboration.

Table 3 – Results with climatic controls

	1970	1975	1980	1985	2006	AL
β_0	8.2779*	0.8446 ^{NS}	4.5550*	5.8229**	5.9835***	0.5285**
β_1	0.1063*	0.2014*	0.1643*	0.0707*	-0.2472*	0.1239**
β_2	0.1647*	0.2829*	0.3656*	0.5212*	0.9878*	0.1993*
β_3	0.7290*	0.5157*	0.4701*	0.4082*	0.2594*	0.6769*
RainSum	-	-	-	-	1.2223**	0.4706**
RainW	-1.2004*	-1.1435**	-2.5195*	-1.6807*	-	-1.0185**

RainF	0.2585*	0.3500*	0.4687*	0.3582*	0.2078***	0.4282*
RainSp	0.8400**	0.8535**	1.5157*	1.0348*	-	-
TempF	-0.2446*	0.1266*	0.0340*	0.0245**	-	3.4284***
Height	0.9909 ^{NS}	2.4052 ^{NS}	2.4975 ^{NS}	1.8442 ^{NS}	-	0.0119 ^{NS}

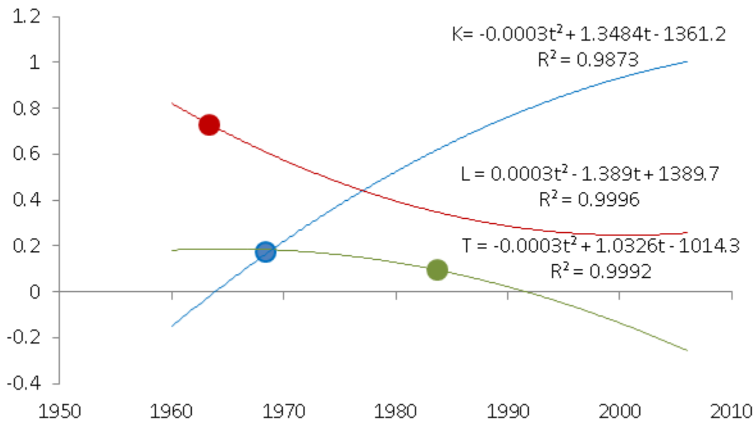
* 1% Significance ** 5% Significance *** 10% Significance ^{NS}Not significant

Source: Own elaboration.

Despite the existence of minor variations between them, the coefficients of the different production factors showed very similar movements in all estimations when different climate controls were inserted: the coefficient of capital grew at a more or less constant rate, whereas the coefficients of labor and land decreased, the first one at descent rates and the second one at increasing rates. In the case of labor, the coefficient stabilized from the mid-1990s onward.

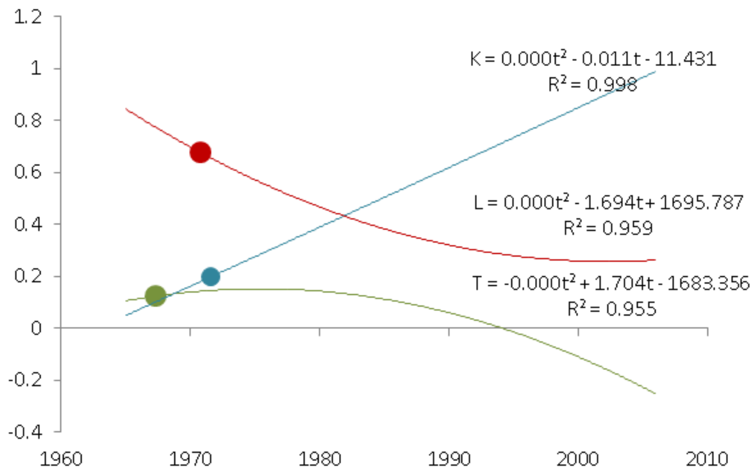
As previously mentioned, we tried to use only one temperature variable in the estimations due to the strong presence of multicollinearity between these variables. The controls for temperature, as well as rainfall, were significant, but the results indicated that altitude does not interfere with agricultural production in these regions. This observation is quite reasonable when considering the cultures prevalent in the Amazon and Midwest regions.

The climate controls in the Midwest region exhibited similar behavior between the years 1970 and 1985 but changed significantly between 1985 and 2006. One possible explanation for this observation is that newly available technologies allowed the producer to soften the effects of weather, especially temperature, on production.



Source: Own elaboration.

Figure 6 - Variation coefficient without controls over time



Source: Own elaboration.

Figure 7 - Variation coefficient with controls over time

The data shown in Figs. 6 and 7 indicate that, without control variables for the climate of municipalities, it is not possible to find correspondence between the production frontiers in the Amazon and the Midwest region. Once climatic variables are considered, however, the current stage of agricultural production in the Amazon region becomes very close to that observed in the Midwest between 1970 and 1975. This is in agreement with the original assumption and reinforces the notion that producers in the Amazon region can form their expectations based on the development of farming that occurred in the Midwest. With these results, it was possible to move to the next stage, which consists of predicting the future production in the Amazon and estimating the net present value.

To estimate the future value of agricultural production in the Amazon, first we projected the used quantities of the factors of production. For this purpose, regressions were applied to the factors (land, capital and labor), each year, for each MCA in the Midwest region, taking the quantities of the factors observed in the initial year. The results of these regressions are as follows:

$$T_1 = \underset{(0.0013)}{1.0101}\ T_0, \quad R^2\text{adjusted} = 0.9996$$

$$T_2 = \underset{(0.0079)}{1.0050}\ T_0, \quad R^2\text{adjusted} = 0.9865$$

$$T_3 = \underset{(0.0018)}{0.9809}\ T_0, \quad R^2\text{adjusted} = 0.9992$$

$$K_1 = \underset{(0.0245)}{1.3007}\ K_0, \quad R^2\text{adjusted} = 0.9268$$

$$K_2 = \underset{(0.0277)}{1.3687}\ K_0, \quad R^2\text{adjusted} = 0.9160$$

$$K_3 = \underset{(0.0317)}{1.3594}\ K_0, \quad R^2\text{adjusted} = 0.8916$$

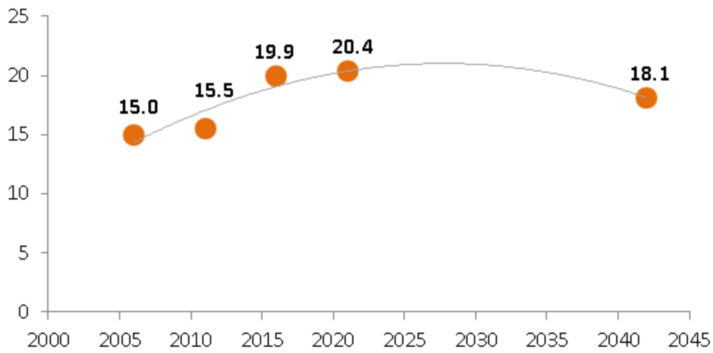
$$L_1 = \underset{(0.0057)}{0.9823}\ L_0, \quad R^2\text{adjusted} = 0.9926$$

$$L_2 = \underset{(0.0075)}{0.9748}\ L_0, \quad R^2\text{adjusted} = 0.9869$$

$$L_3 = \underset{(0.0077)}{0.8473}\ L_0, \quad R^2\text{adjusted} = 0.9817$$

In the case of the Midwest, the period corresponding to the current state of the production frontier in the Amazon region, that is, between 1970 and 1975, was considered as period zero. Period 1 corresponds to the observations in 1980, period 2 to those in 1985, and period 3 to those in 2006. In the case of the Amazon, period zero corresponds to the observations in 2006; period 1 to the projections for 2014, period 2 to the projections for 2019, and period 3 to the projections for 2040.

Considering the changes in the use of factors over time, it was possible to estimate the production figures for the Amazon region, which correspond to the 34 years following 2006. These values were calculated with the following equations, which used the coefficient β_i shown in Table 3.

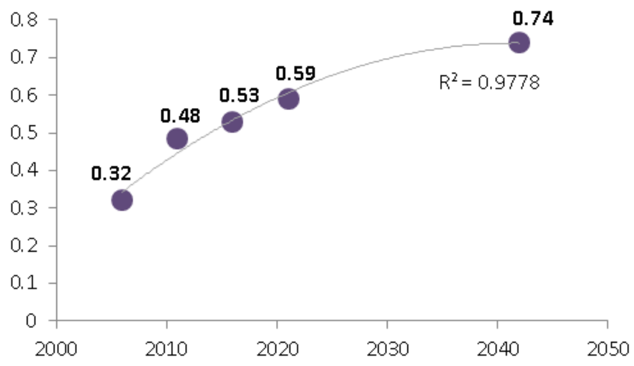


Source: Own elaboration.

Figure 8 – Average production value in the Amazon (in logarithmic scale)

An interesting observation is that, although the average utilization of the factors initial capital and land in the Amazon is similar to that in the corresponding period in the midwest region, the amount of labor is much lower. When one takes into account that there is a drop in the use of labor over time, the decrease in the estimated production value between periods 2 and 3 is understandable.

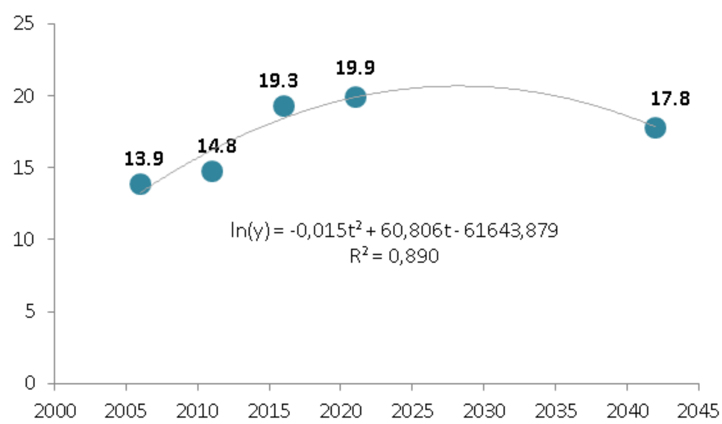
The next step in estimating the net present value of the income of the land in the Amazon is to estimate the portion of this amount that the landowners appropriate. Considering the hypothesis that these are capitalist owners, such portion is represented by the sum of the coefficients β_1 and β_2. Figure 9 shows the evolution of this coefficient over time.



Source: Own elaboration.

Figure 9 – Producer income share of total income of the agricultural sector

The income of a landowner in the Amazon (in logarithmic scale) for each period is given by $\ln[(\beta_1 + \beta_2)e^Y]$. If there is no expansion of agriculture in the region, production is expected to stay at the current level, represented by the dotted line in Fig. 10. If, on the other hand, there is agricultural development, through the expansion of deforestation, income is expected to grow according to the projections along the solid line in Fig. 10.



Source: Own elaboration.

Figure 10 – Expected producer income in the Amazon (in logarithmic scale)

The present value of that income stream is calculated as described in Section 3.3, shown as the area under the trend line in Fig. 10, even applying a discount rate r. As the formation expectation is done by a private agent, we do not expect it to be worth a discount rate that takes into account the social and environmental effects of the production, to assess future income. For this reason we chose to discount the income stream by a real market´s interest rate, because this is more relevant from the point of view that the private rate of environmental services mentioned in the literature. Table 4 shows the results obtained by using real interest rates of 2%, 5%, and 8%.

Table 4 - Present value of projected income stream (in logarithmic scale)

	Discount rate		
	2%	5%	8%
Annual income	13.9	13.9	13.9
Net present value	22.86	22.24	21.64
Average income expected	19.28	18.65	18.05
Relative increase (per year)	12.90%	10.90%	9.10%

Source: Own elaboration.

The first row of Table 5 shows the logarithmic value of the producers' current income, in values of 2000 real. The second row presents the net present value of the projected income stream for each real interest rate considered. The third row shows the average annual income that the landowner expects to attain. Finally, the fourth row presents the expected average increase in annual revenue.

The uncertainty of land tenure in the region can lead agents to deduct time at higher rates. Margulis (2003) pointed out that producers are risk-averse, citing their willingness to accept compensation below the expected value of future production.

6. Conclusion

In recent decades in Brazil, increasing importance has been given to reducing carbon emissions, which result primarily from the advance of the agricultural frontier into the Amazon rainforest. This brings out the dilemma between development and environmental preservation, since deforestation is associated with increases in both local and regional income and development. In this context, it becomes urgent to discuss the valuation of natural resources and the generation of alternative income for regions where the agricultural frontier is expanding into forested areas.

The valuation of natural resources, which are also public goods, should take into account the opportunity cost that the preservation of natural resources and environmental services impose on the people in agricultural frontier regions. The estimation of that cost should not only consider the current income generated by agricultural producers but must also take into account the expected future income of these producers given the continuation, or even expansion, of their activities and prospects.

Thus, this work sought to evaluate the specific case of producers in the Brazilian Amazon region. The initial hypothesis that the current stage of development in this region is similar to that in the midwest region during the 1970s proved to be reasonable, given the results of the estimation of production frontiers for the two regions. Therefore, it is not incorrect to assume that producers in the Amazon region can form their expectations of future income on the basis of the profitability of farming that has occurred in the midwest region from the 1970s to the present.

The projections based on the results of this work show that producers in the Amazon can expect, in the next four decades, an increase in average income of about 9% to 13% per year compared to the current rate. Any strategy to contain the spread of agriculture in the Amazon rainforest in Brazil must take into account the expectation of gain to ensure that environmental preservation does not become detrimental to local populations.

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8 – Annexes

AI - Results of primary factor analysis

Results of the factor analysis to labor variables

Ano	L1	L2	L3
CO 1970	0.4050	0.4385	0.1564
CO 1975	0.3957	0.4210	0.1831
CO 1980	0.3927	0.3672	0.2309
CO 1985	0.3928	0.3763	0.2308
CO 2006	0.3573	0.3656	0.2769
AL 2006	0.3486	0.3538	0.2975

Source: Agricultural Census (IBGE). Own calculations.

Results of the factor analysis to capital variables

Ano	K1	K2	K3
CO 1970	0.3576	0.3596	0.2826
CO 1975	0.3483	0.3469	0.3047
CO 1980	0.3462	0.3433	0.3103
CO 1985	0.3583	0.3601	0.2814
CO 2006	0.3495	0.3418	0.3085
AL 2006	0.3904	0.3825	0.2269

Source: Agricultural Census (IBGE). Own calculations.

AII – Descriptive statistics

Descriptive statistics of capital factor

Year	Obs	Average	Standard Deviation	Minimum	Maximum
1970	222	2.231	1.466	0.000	6.234
1975	222	3.101	1.524	0.000	7.008
1980	222	3.821	1.458	0.000	7.879
1985	221	4.070	1.512	0.611	8.351
2006	222	4.131	1.383	0.800	8.945
AL	500	2.431	1.145	0.000	5.582

Source: Agricultural Census (IBGE). Own calculations.

Descriptive statistics of labor factor

Year	Obs	Average	Standard Deviation	Minimum	Maximum
1970	222	6.042	1.051	1.897	8.817
1975	222	6.163	1.091	2.469	9.326
1980	222	6.002	1.112	3.117	9.687
1985	221	5.974	1.165	2.946	9.857
2006	222	5.174	1.118	1.835	10.788
AL	630	4.899	1.019	2.042	8.152

Source: Agricultural Census (IBGE). Own calculations.

Descriptive statistics of land factor

Year	Obs	Average	Standard Deviation	Minimum	Maximum
1970	222	316.488	695.906	3.398	5,733.446
1975	222	353.149	815.861	3.941	6,867.526
1980	222	425.944	1,228.152	3.107	12,400.000
1985	222	447.692	1,327.724	3.725	13,400.000
2006	222	327.65	1,013.700	4.029	10,700.000
AL	627	64.161	79.412	96	944.25

Source: Agricultural Census (IBGE). Own calculations.

Descriptive statistics of production

Year	Obs	Average	Standard Deviation	Minimum	Maximum

1970	222	5,823,336	9,587,428	85,282	78,100,000
1975	222	7,498,618	10,500,000	77,273	75,200,000
1980	222	9,474,108	16,000,000	203,641	121,000,000
1985	222	7,899,182	15,100,000	135,534	141,000,000
2006	222	57,700,000	259,000,000	251,827	3,410,000,000
AL	630	9,290,998	16,900,000	64,41	256,000,000

Source: Agricultural Census (IBGE).

Descriptive statistics of climatic variables in the Amazon Legal region

		Obs	Average	Standard Deviation	Minimum	Maximum
Rainfall average (mm/month):	Summer	496	246.4	45.5	37.7	338.3
	Winter	496	245.6	89.1	103.4	496.1
	Fall	496	68.2	68.3	2.1	393.6
	Spring	496	100.3	51	8.4	235
Temperature average (°C)	Summer	496	26.3	0.6	24.6	27.3
	Winter	496	26.2	0.5	24.8	27.1
	Fall	496	26	0.8	23.2	27.4
	Spring	496	27.1	0.6	25.4	28.7
Height average		542	146	128.2	2	920

Fonte: IPEA/University of East Anglia.

Descriptive statistics of climatic variables in the Midwest region

		Obs	Average	Standard Deviation	Minimum	Maximum
Rainfall average (mm/month)	Summer	222	248.9	33.06	158.2	337.9
	Winter	222	118.2	12.63	90.8	227.2
	Fall	222	17.1	15.15	3.2	76.2
	Spring	222	138.4	15.28	83.9	179.2
Temperature a (°C)	Summer	222	24.9	1.08	22.4	28.1
	Winter	222	24.1	1.07	21.6	26.7
	Fall	222	22.1	1.5	18.5	25.1
	Spring	222	25.1	1.06	22.6	27.3
Height average		222	566.8	227.7	90	1189

Fonte: IPEA/University of East Anglia.