Protected-areas and technological progress in agriculture in the Brazilian Legal Amazon: An analysis of the Porter hypothesis

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Jean-Galbert Ongono Olinga[1], Pascale Combes Motel[2], José Gustavo Feres[3], Sonia Schwartz[4]

Abstract:

In this article we analyze whether environmental protection policies in Brazilian municipalities of Legal Amazon drive technical progress in agriculture, thus verifying the Porter hypothesis. Specifically, we investigate whether agricultural firms in municipalities with protected areas (PAs) are technically more performant in agriculture than firms in municipalities without protected areas. We use agricultural census data from 1995/1996 and 2005/2006 and derive estimates of potential production frontier, technical efficiency and total factor productivity as proxies of agricultural performance in a stochastic frontier framework. Next, we run estimates of a panel model with fixed effects, including difference-in-difference estimator, to assess the effect of protected-area policies on efficiency, potential production and total factor productivity changes. Results are consistent with significant changes in potential production and total factor productivity. Because the shift of the potential production across time is a result of technical progress, our estimates show that agricultural firms in municipalities with protected areas improved their technical progress more in year 2006 compared to year 1996.

Keywords:

Protected areas, efficiency, potential production frontier, Porter hypothesis

Codes JEL: C21, Q10, Q24, Q28

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1 Introduction

The process of designating protected areas in Brazil has evolved considerably during the past three decades. Most of the country's lands have been designated integral and sustainable protected areas over this period since 1980 in line with Brazil's goal of tackling ecological, climatic and biological diversity threats due to ongoing deforestation. Based on statistics from the National Institute for Spatial Research (INPE), ongoing deforestation is the result of agricultural activities, urbanization and human habitat evolution, which have accelerated dramatically between 1970 and 2004, causing the loss of an estimated 17% of the Amazon rainforest. In an attempt to halt this destruction, environmental policy instruments, such as protected-areas, payments for environmental services, and annual district blacklist publications, have been implemented (Pagiola et al. 2013; Cisneros et al. 2015; Pfaff et al. 2015). Among these instruments, protected areas have been the subject of particular attention by the international institutions (the World Bank) and the Brazil's federal government. Their increasing implementation in Legal Amazon has been made possible thanks to various programs, such as the "Planaforo" program financed by the World Bank, the federal government's commitment to meeting its Convention on Biological Diversity (CBD, Chart 2) targets and the Amazon's Protected Areas Program (ARPA), jointly managed by Brazil's federal and state governments. The main goal of these programs is to curtail deforestation and protect areas rich in biodiversity.

In 2010, Brazil's National System of Conservation Units statistics indicated that 22.2% of the area of Brazil had been designated as PAs (Verissimo et al. 2011), and approximately 42% of the entire area of the Legal Amazon was made up of protected-areas. They are managed according to their status, which could be local (district level), state or federal. The effectiveness of protected areas has been the subject of numerous studies, with Andam et al. (2008), Nolte et al. (2013) and Pfaff et al. (2014) among the most recent contributions. Most of these studies find that protected-areas overall are helpful environmental policy instruments and effective in slowing down deforestation and conserving and protecting biological diversity. However, some shortcomings, such as weak management enforcement, failure to designate PAs on high pressure deforestation zones and some negative consequences on local development are reducing their effectiveness (Kere et al. 2017, Chiaravalloti et al. 2015 and Pfaff et al. 2015).

Other studies focus on leakages or unintended effects of protected-area policies. In fact, in some cases, the side effects of the protection, such as the displacement of deforestation to surrounding areas, have been observed (Oliviera et al. 2007, Arima et al. 2011 and Amin et al. 2016). The expected impact of the protection can be effectively achieved in the protected area zones but not on a global scale. Indeed, it is possible that the deforestation that would have occurred if no protection was established, happens in the surrounding areas instead (Ewers and Rodrigues 2008, Delacote and Angelsen 2015). Some unintended effects of protected areas are also found in local governance. Sauquet et al. (2014) demonstrate how reward efforts of municipalities that create protected areas in the Brazilian state of Para lead to strategic substitutability in the vicinity due to the propensity to create new protected areas. In other words, conservation units created in a municipality could discourage the creation of other protected areas in the vicinity. Other studies focus on the impact of protected areas on non-environmental targets such as poverty. They explore whether a win-win scenario – that is, a reduction of the deforestation process and the mitigation of poverty among local populations – is possible (Fearnside 2003, Miranda et al. 2016, Karki 2013, Sims 2010 and Andam et al. 2010).

In this study, we are contributing to the literature on the effectiveness of protected-area policies by studying their impact on agricultural performance. Following the insight of the Porter hypothesis which argues that environmental policies can enhance the agricultural performance of firms, we aim to explicitly check whether municipalities that welcomed protected areas in the Legal Amazon have also registered more productive practices than municipalities without protected areas. As conservation policies induce an increasing scarcity of arable land, our intuition is that this scarcity makes farmers stop practicing extensive agriculture and drives them to adopt more efficient practices. One way to understand this is to consider deforestation leakages generated by protected-area policies. The deforestation occuring from agricultural activities in surrounding conservation unit areas could happen with more efficient landuse practices because the protection delivers a signal to producers that the forest must be preserved or used with care. Thus, farmers register this information and develop new practices to increase production in their process of expanding agricultural activities outside of the protected zone.

Some studies have already tested if the Porter hypothesis is verified in the case of pollution abatement policies. They highlight that pollution abatement policies trigger technological progress which improves both productivity and environmental quality. However, the productivity gains are mainly driven by the reallocation of resources across firms rather than by technological changes (Sadeghzadeh 2014). In the same vein, Alpay et al. (2002) also studied the Porter hypothesis focusing on food manufacturing in Mexico. They empirically showed that environmental regulation improved the competitiveness of food manufacturing firms over the long-term, resulting in significant overall changes in their productivity.

In this paper, we apply an empirical framework to demonstrate that protected-area environmental policies promote productive practices in agriculture. We hypothesize that farmers register the signal transmitted by the designation of conservation units in various areas and respond by adopting more efficient practices (Zimmerer, 2011). They adopt new methods or new technologies on restricted areas in order to cover high rents. More specifically, we empirically test whether the designation of protected areas in various municipalities results in the adoption of more efficient practices by firms in these municipalities compared to firms in municipalities without protected areas.

We test this hypothesis by using 1996 and 2006 agricultural census data of Brazilian municipalities with an application of the difference-in-difference model in panel data. The diff-in-diff model compares the agricultural performance among the municipalitites. We compute the technical efficiency, the potential production and the total factor productivity as the main outcomes representing the agricultural performance, using a stochastic frontier analysis. We find that changes in terms of the potential production and total factor productivity in municipalities with protected areas compared to those without protected areas are high and significant in 2006 rather than in 1996. This leads us to a conclusion that protected-area policies drive farmers in protected zones to adopt productive practices in agriculture. The resulting intensification favors the reduction of agricultural land-use and, *in fine,* spare land in the edges of the forest.

The remainder of the paper is organised as follows. Section 2 provides a literature review on the relationship between environmental policies and technological innovation. The analytical framework is presented in Section 3 and our results are outlined in Section 4. Finally, a conclusion is given in Section 5.

2 Environmental policy and technological innovation: a literature review

The debate on the relationship between environmental policy and technical innovation stems mainly from the literature focusing on pollution abatement. In the next sub-section, we outline the traditional view of the debate and introduce insights of the Porter hypothesis. In the second sub-section, we briefly present the literature concerning factors that trigger incentives to improve technical agricultural practices. The third sub-section focuses on the Brazilian case and explores an extension of the Porter hypothesis to agriculture, substituting protected areas for environmental policies.

2.1 The traditional view and the Porter hypothesis

The traditional view of the debate on the impact of environmental policies on firm performance asserts that environmental regulation does not favor technical innovation and negatively affects the productivity, profit and competitiveness of firms (Christainsen and Haveman 1981). As a result, the view asserts, regulated firms are not motivated to invest in new technology favorable to pollution abatement in the short term but, rather, prefer to implement end-of-pipe techniques which will decrease their polluting waste. Such solutions are less effective in terms of enhancing productivity to strenghten a firm’s competitiveness than those that consist in completely changing the technological production process to one that takes environmental standards into account. Indeed, investing in new technology generates new costs, in addition to those introduced by regulations that constrain the firm in the short term (Palmer et al. 1995). The traditional view of the debate supports the notion that the relationship between the regulator and regulated firms is win-lose because firm productivity cannot increase under environmental regulations. On the contrary, productivity may be negatively affected. Although empirical evidence of this argument have been demonstrated in several studies (Hazilla and Kopp 1990 and Norsworthy et al. 1979), another strand of literature survey concerning this debate contradicts this notion and is based on the Porter hypothesis.

The Porter hypothesis supports the idea that stringent and properly designed environmental regulations can trigger innovations that may partially or more than fully offset the costs of complying with them (Porter and Van der Linde 1995). According to Porter and Van der Linde, environmental regulations alert firms of their inefficiencies and of the potential need for technological improvement. Regulations that address environmental targets introduce the concept that a firm’s investment in environmental preservation is compatible with its primary goal of profit maximization (Ambec et al. 2013). In fact, they argue, the production costs of firms increase sharply in the short-term due to regulations. However, if regulations remain stringent over the long term, firms will prefer to invest in new and innovative technologies that adhere to environmental regulations rather than bearing the costs induced by them. As a result, such innovations will spark competition and spread throughout the entire economic sector. The Porter hypothesis argues that new technologies will positively impact sector productivity and simultaneously enable environmental goals to be reached. In this case, the relationship between regulator and regulated can be qualified as win-win.

Empirical and theoretical evidence supporting the positive effects of environmental regulations on technical innovation and productivity have been highlighted in the literature. According to Sadeghzadeh (2014) and Alpay et al. (2002), the stringency of environmental regulations can stimulate technical innovations. They argue that if regulations are more stringent, firms will invest in R&D for innovative technology that is more economically feasible for productivity improvements. Next, we present some trigger factors of the adoption of innovative practices in agriculture.

2.2 Some trigger factors of innovative practice adoption in agriculture

Different factors that trigger innovative practices in agriculture are highlighted in the literature. Among them, the consideration of environmental preservation is presented as a key factor leading to innovative agricultural practices coupled with high rents. Numerous study argue that outcomes such as an increase, both in quantity and quality, of farmers' yields, are achieved when environmental consideration is undertaken in agricultural practices (Lanoie and Llerena 2009, Lutz and Young 1992 and Ibanez and Blackman 2016). According to Ibanez and Blackman (2016) and Blackman and Naranjo (2012), the adoption of eco-certification in agriculture has resulted in environmental benefits, coupled with agricultural performance, in southeastern Colombia and in Costa Rica, respectively. Adhering to environmental standards does not necessarily constrain the performance of agricultural firms. On the contrary, it can trigger the adoption of productive practices leading to larger yields for farmers.

Other studies focus on the scarcity of production factors such as land. They argue that when land scarcity increases, farmers respond by improving their practices in order to get more production in available land. Land scarcity can arise from population growth or from restrictions introduced by conservation unit policies (Boserup 1975 and 1976, Levi 1976, Pingali and Binswanger 1986 and Zimmerer 2011). However, Hertel (2011, 2012) argues that it is not only land scarcity that matters in the process of stimulating efficient practices' adoption. Other element such as the deficiency of various production factors (labor as an example) can result in some productive practices adoption (the replacement of workforce by machineries).

Some other studies cite other factors such as commodity price booms. In fact, in order to take advantage of favorable agricultural commodity prices, farners are likely to develop innovative practices to obtain greater yields (Barbier and Burgess 1996 and Elnagheeb and Bromley 1994). However, innovative practices resulting from commodity price booms do not necessarily favor positive environmental outcomes because they usually result in forest loss increase (Cattaneo 2001). Farmers investigate new areas beyond the forest frontier to achieve greater yields and profit. Among the factors presented above, others are outlined in the literature review and focused on the farm's size, the type of commodities produced (whether industrial or food crops) or the accessibility to the capital in comparison to the factor of labor avaibility (Ruff 2001 and Jayasuriya 2001). We focus in the next sub-section on the Brazilian Legal Amazon case.

2.3 Protected areas and agricultural performance improvement in the Brazilian Amazon

To the best of our knowledge, little work has been done to assess the effect of protected areas on agricultural performance in the Brazilian Legal Amazon. Protected areas in Brazil are considered as an effective environmental policy instrument used to reduce the deforestation process and conserve biological diversity (Andam et al. 2008). Given that they enforce restrictions, constraints or conditions on the use of land for agriculture, PAs often cause opposition between the regulator and farmers concerning conservation targets and the need for land for agricultural activities (Kolk, 1998 ; Fearnside, 2003 ; Brandon et al. 2005). However, these constraints or restrictions can also trigger incentives for farmers to adopt more productive practices on available arable lands.

Basic statistics at the municipal level can deliver preliminary information (Tables 1 and 2). On average, the overall value of agricultural production and the level of capital increased in Brazilian municipalities from 1996 to 2006 while a large portion of land has been converted into PAs. Total workers decreased during the same period (Table 1). In addition, the agricultural production was greater (on average) in municipalities with protected areas than in municipalities without protected areas, though the difference is weakly significant in 1996 (Table 2). Although land use appears higher in municipalities with protected areas, the fact that capital expanded while total workers decreased in 2006 compared to 1996, indicates that incentives from farmers to adopt productive practices were strong in these municipalities (Table 2).[5]

Table 1: Comparison of municipalities over time

Main agricultural variables	Mean		Mean-comparison tests (Municipalities 2006 vs municipalities 1996)
	Municipalities 1996	Municipalities 2006	
Land use in agriculture (ha)	127 944.5	125 699.5	- 2 245.065
Capital	137.0481	167.3659	30.31783***
Total workers in agriculture	4 149.467	3 533.781	- 615.6853***
Production in value (1996 agricultural prices, 1000 R$)	5 758.243	8 564.237	2 805.994***
Protected areas (ha)	35 149.01	88 179.88	53 030.87***
Number of municipalities	645	645	

Source: IBGE and authors. (*), (**), (***) are at the 10%, 5%, and 1% significance levels.

Table 2 : Protected-area versus non- protected-area municipality characteristics

Main agricultural variables	Mean		Mean-comparison tests (Municipalities with PA vs municipalities without PA)
	Municipalities with P.A.	Municipalities without P.A.	
1996 Land use in agriculture (ha)	162 076.4	126 733	35 343.39*
1996 Capital	127.8571	137.1252	- 9.268055
1996 Total workers in agriculture	5 435.518	4 131.469	1 304.049*
1996 Production in value (1000 R$)	7 480.213	5 679.77	1 800.444*
Number of municipalities	**56**	**631**	
2006 Land use in agriculture (ha)	216 549.1	119 413.9	97 135.24***
2006 Capital	326.2143	150.1763	176.038***
2006 Total workers in agriculture	4 665.277	3 407.293	1 257.984***
2006 Production in value in (1000 R$) (1996 agricultural prices)	15 077.37	8 034.427	7 042.941***
Number of municipalities	**112**	**573**	

Source: IBGE and authors. (*), (**), (***) are at the 10%, 5%, and 1% significance levels.

Note that only Integral and Sustainable PAs are taken into account. The main difference between these types of protected areas involves constraints concerning their accessibility. While Integral PAs strictly prohibit human activity (except scientific research) in order to protect their natural resources, Sustainable PAs only moderately restrict human activity and

[5] The fact that land use in agriculture is higher in municipalities with PAs than municipalities without PAs is explained by the PA status. We find that Sustainable PAs cover about 67 million hectares while Integral PAs only account for about 29 million hectares. Sustainable PAs enable co-activities such as agriculture. Integral and Sustainable PAs also differ in their location characteristics. Pfaff et al. (2014) found that in the state of Acre, Sustainable PAs are located in sites under higher clearing threat. This signals higher potential agricultural profitability. Higher agricultural profitability in municipalities with Sustainable PAs can therefore drive the extension of agricultural area.

promote the sustainable use of natural resources (Françoso et al. 2015).[6] The total workers in agriculture refer to the number of men and women over 14 years old working in the agricultural firms in the municipality. There are 645 municipalities without missing value after the merge of the 1996 and 2006 databases. The following section focuses on the empirical strategy, developed to highlight whether the Porter hypothesis is valid with regard to protected areas.

3 Empirical framework

In this article, we empirically test the hypothesis that conservation units are among the factors that trigger the adoption of productive practices in Brazilian municipalities of the Legal Amazon. To do that, a two-step econometric approach is applied. We begin by estimating an oriented-output stochastic frontier model to derive the agricultural performance metrics such as technical efficiency, potential production, and productivity of the municipality. Next, we compare the agricultural performance among the municipalities with protected areas and those without the protected-areas at two different time periods. To achieve this goal, a difference –in –difference (diff –in –diff) model is applied.

The sample counts 740 municipalities. Indeed, in the Brazilian Legal Amazon, there are 772 municipalities. Because we are interested in running estimates with the Brazilian municipalities as units, we keep only those found in the Brazilian Legal Amazon in 1995 since in that year there was an agricultural census, and a few years before a large area of the Brazilian Legal Amazon had become protected (Verissimo et al. 2011). There are exactly 750 Brazilian municipalities found in Brazilian Legal Amazon meaning that 22 municipalities are not in Brazil but belong to other surrounding countries. Ten of these 750 municipalities were subdivided during the period of 1996 to 2006. We choose to drop from the sample municipalities that changed during this period and keep only the unchanged municipalities. We also drop all of the municipalities (54) where we find only indigenous land as protected areas whose status is very specific and would add too much heterogeneity. We run estimates considering only the protected areas that were established in a municipality between 1985 and 2006. The empirical framework is organized as follows: in Sub-section 3.1 we present the data and descriptive statistics. The methodology used to compute agricultural performance with an oriented-output stochastic frontier model is given in Sub-section 3.2. In the next Sub-section 3.3, the diff –in –diff econometric model is described.

3.1 Data

3.1.1 Protected-areas

This study is conducted focusing on the PAs that were created 10 years prior, observing the agricultural data from Brazil's 1995/1996 and 2005/2006 censuses. In other words, we create a dummy variable *treatment* that takes the value one in 1996 if a protected area was created in a municipality during the period of 1985 to 1995 and it takes the value one in 2006 if a protected area was created in a municipality during the period 1996 to 2006. This means that, considering the punctual time period of 1996 and 2006 for which agricultural data are available, the dummy variable *treatment* (protected-areas) takes the value one for each period

[6] The total area under integral protection (under sustainable protection) in Brazil in 1996 was approximately 5 millions hectares (respectively 19 millions hectares) while in 2006, it was approximately 22 millions hectares (respectively 47 millions hectares). Approximately 16 millions hectares were converted into Integral PAs and 28 millions hectares into Sustainable PAs between 1996 and 2006. Corresponding data was taken from Instituto Brasileiro de Meio Ambiente (2010) (IBAMA).

if the protected areas were established between 1985 and 2006. A municipality is considered as a treated municipality if it contains a protected area. In 1996, we count 51 municipalities with PAs and 635 without PAs. In 2006, we count 95 municipalities with PAs and 589 without PAs. There are 44 municipalities that received PA designation during the period of 1996 to 2006. The study is conducted considering only the Integral and the Sustainable PAs.

The process of designating protected areas began in Brazil in 1959 according to the National System of Conservation Units (Verissimo et al. 2011). Up to 1985, the total area of protected areas in Brazil was approximately 124,000 square kms. Between 1990 and 1994, there was an increase in the creation of protected areas thanks to the "Planaforo" programs financed by the World Bank. The "Planaforo" programs focused on protection of areas with strong environmental characteristics (Millikan, 1998). During 1990s, the Brazilian government engaged in a strategy of expanding protected areas in the Amazon in order to meet the biodiversity targets that it set. Several federal conservation units were created until 2002 (Capobianco et al. 2001).

The period spanning from 2003 to 2006 was a peak moment in the establishment of conservation units in the Brazilian Amazon. During this period, most of the conservation units found in 2010 were established (Verissimo et al. 2011). Indeed, the collaboration of the federal and state governments to curb the deforestation process via their support to the Amazon's Protected Areas Program (ARPA) led to the creation of several protected areas. The ARPA's goals are based on the creation and management of the Brazilian Amazon Conservation Units. The ARPA performs between 2003 and 2009 by supporting the creation and the management of approximately 63 conservations units that represent an average of 340,000 square kms of the Brazilian Amazon. The conservation units established meet the classification criteria of the United Nations for Environment Program (UNEP).

3.1.2 Other variables

The agricultural production value variable (*lnproduction_value*) is available on the *Instituto Brasileiro de Geografia e Estatística (IBGE)* or the *Instituto de Pesquisa Econômica Aplicada (IPEA)* website. It lists the value in Brazilian currency (reais $) of crops, livestock, and other agricultural products. To account for the inflation effect, we deflate the agricultural production value of 2006 using the agricultural prices index computed by the *Fundação Getulios Vargas* institution, and which is available as *IPA origem - produtos agropecuários - índice (ago. 1994 = 100)* on the IPEA website. The capital variable (*lncapital*) refers to the number of materials or machinery found on the farm and used for agriculture. Precisely, we compute the capital variable, by municipality, as the sum of trucks, tractors, useful objects, planting machinery and harvest machinery of farms found in a municipality as they are specified and presented on the IBGE and IPEA websites. The land use in agriculture variable (*lnagricultural_landuse*) is aggregated at the municipality level. It has been computed by IBGE and is available on their website. The totalworkers variable (*lntotalworkers*) is the aggregate value of total workers in agriculture, by municipality. Data for this variable are also available on the IBGE website. The variables for precipitations (*lnpre_mun*) and temperature (*lntmp_mun*) have both been taken from the database CRU TS 3.22 of the University of East Anglia, which lists them for every month. A simple average of each variable is computed to obtain the annual value of precipitations and temperature. Numbers of establishments receiving technical assistance (*lntechnical_assistnb*) and using electrical energy (*electricity_nbesth*) have been taken from the IBGE website.

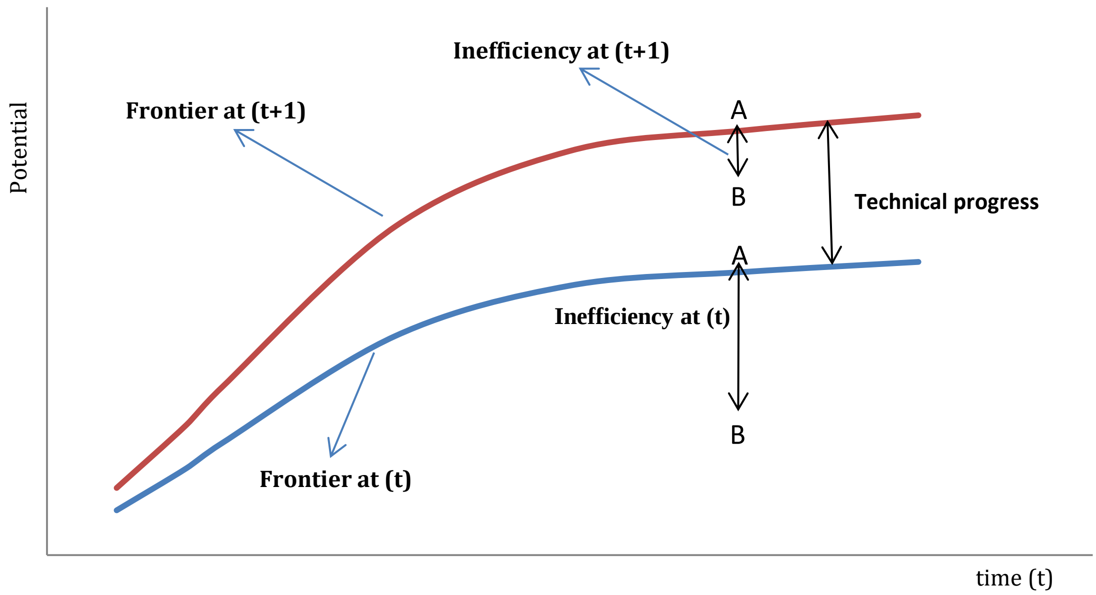
3.2 Agricultural performance: potential production, technical efficiency, and total factor productivity

The technical efficiency, potential production and total factor productivity are derived as the proxies of agricultural performance using an oriented-output stochastic frontier model with panel data.[7] We follow the Kumbhakar and Heshmati (1995) approach, as shown below:

$$\boldsymbol{y_{it} = a_0 + f(x_{it}; \beta, t) - u_{it} + \varepsilon_{it}} \qquad \textbf{(1)}$$
$$\boldsymbol{u_{it} = u_i + \tau_{it}}$$
$$\boldsymbol{\tau_{it} \sim i.i.d.\, N^+(0, \sigma_\tau^2)}$$

where $\boldsymbol{y_{it}}$ is the output (production value in log), $\boldsymbol{x_{it}}$ is the vector of inputs variables (capital, workers and landuse in log), $\boldsymbol{u_{it}}$ is the technical inefficiency, $\boldsymbol{a_0}$ is the constant term, $\boldsymbol{\beta}$ is a vector of coefficients attached to each input and $\boldsymbol{\varepsilon_{it}}$ is the error component. The $\boldsymbol{u_{it}}$ term is broken down into two variables: the $\boldsymbol{u_i}$ component, representing the persistent inefficiency over time, and the $\boldsymbol{\tau_{it}}$ component, representing the residual or time-varying portion of the technical inefficiency.[8] The functional form $\boldsymbol{f(.)}$ is a Cobb-Douglas function without any restriction on parameters, **i** denotes the municipality and **t** is the time period. The reasoning around the stochastic frontier analysis can be summarized in Figure (1) as follows:

Figure 1: Inefficiency and technical progress illustration



[7] The stochastic frontier model assumes that the gap between the maximum possible production (potential production) and the observed production of units is the sum of the technical inefficiency $\mathbf{u_{it}}$ and the error component $\boldsymbol{\varepsilon_{it}}$ (Aigner et al. 1977; Meeusen and van den Broeck, 1977). In this study, we run two different specifications of the stochastic model: the Kumbhakar and Heshmati's (1995) model and the Greene's (2005a) model. We retain the Kumbhakar and Heshmati (1995) stochastic model, although the LR test is in favor of Greene's (2005a) model. The LR test statistic is given by the formula: **-2*[LL(H_0) – LL(H_1)]**, where **LL(H_0)** and **LL(H_1)** are log-likelihood values of the restricted model and the unrestricted model. Indeed, the Greene (2005a) model is subject to incidental parameter. From the stochastic model of Kumbhakar and Heshmati (1995), the technical inefficiency is broken out into two components: the persistent inefficiency ($\boldsymbol{u_i}$) and the time-varying inefficiency ($\boldsymbol{\tau_{it}}$).

[8] The inefficiency is the sum between the persistent inefficiency and the variant inefficiency. The persistent inefficiency refers to the inefficiency that doesn't change over time. It's closely related to the heaviness in unit management. In contrast to the variant inefficiency, which corresponds to the inefficiency that changes with time, the persistent inefficiency explains the reason why some units' inefficiency remains unchanged although the firm is trying to improve the management of its agricultural activities.

As we can observe in Figure (1) above, points that belong to the "frontier" are the best technical realization points representing the potential production.[9] With the stochastic frontier analysis, the "frontier" is obtained by connecting all of the best technical realization points. If the "frontier" is shifted upwards from t to t+1, then positive technological changes have been made. However, if it moves downwards, then there has been a decline in technological changes. Considering that point A is the best technical realization and point B is the observed production of a unit i, the gap between A and B is the sum of the inefficiency and the random noises. The stochastic frontier analysis assumes that the production observed is the result of the potential production, the inefficiency and the random noises occurring during the production process. Kumbhakar and Heshmati (1995) divide the inefficiency into the persistent inefficiency and the time-varying inefficiency. The efficiency is obtained as the exponential value of the inefficiency (exp(-$\boldsymbol{u_{it}}$)).[10] If individuals were perfectly efficient, that is $\boldsymbol{u_{it}} = 0$, and there were no random noises, the observed production $\boldsymbol{y_{it}}$ would equalize the potential production, which is the combination of the inputs $\boldsymbol{x_{it}}$ thanks to the functional form $\boldsymbol{f}(.)$. However, because the inefficiency exists and can arise from anywhere (Müller, 1974), the observed production could stay below the frontier, meaning that it is different from the combination of inputs.

Let's denote $\dot{TFP}$ as the total factor productivity changes representing the productivity changes that are unexplained by the production factor changes, so that we have:

$$\dot{TFP} = \dot{y} - \sum_j S_j \dot{x}_j \qquad (2)$$

S_j is the input j's share in the production cost, j denotes the type of inputs, $\dot{y}$ and $\dot{x}_j$ are the ratio of the production and the ratio of the input j's changes over the time changes. By differentiating the mathematical form of Equation (1) (we remove $\boldsymbol{\varepsilon_{it}}$ the term that brings statistical inference), we obtain:

$$\frac{dy_{it}}{dt} = \sum_j \frac{\partial f(x_{it\,j}, \beta, t)}{\partial x_{it\,j}} \times \frac{dx_{itj}}{dt} + \frac{\partial f(x_{it}, \beta, t)}{\partial t} \times \frac{dt}{dt} - \frac{du_{it}}{dt} \;\Leftrightarrow\; \dot{y}_{it} = \sum_j \varepsilon_j \dot{x}_j + TC - \Delta TE \quad (3)$$

with:

$$TC = \frac{\partial f(x_{it}, \beta, t)}{\partial t} = \frac{\Delta f(x_{it}, \beta, t)}{\Delta t} \quad ; \quad \Delta TE = \frac{du_{it}}{dt} = \frac{\Delta u_{it}}{\Delta t} \quad ; \quad \sum_j \varepsilon_j \dot{x}_j \equiv \sum_j \frac{\partial f\left(x_{it\,j}, \beta, t\right)}{\partial x_{it\,j}} \dot{x}_j$$

and ε_j is the input j's elasticity. By replacing (3) in (2), and arranging as:

[9] "Frontier" refers to the representation of $\boldsymbol{a_0} + \boldsymbol{f}(\boldsymbol{x_{it}}; \boldsymbol{\beta})$ **,** the deterministic part of the stochastic frontier**.**

[10] Kumbhakar and Heshmati (1995) use a four-step approach to estimate the persistent inefficiency and the time-varying inefficiency. Their technical inefficiency estimates are deductible after running either a standard fixed effects panel regression or a standard random effects panel regression. Persistent inefficiency is derived as the difference between the predicted value of a municipality's fixed effects and the maximum predicted fixed effects among all the municipalities. Time-varying inefficiency is derived using another application of a stochastic frontier model with the predicted errors from the first estimation of a standard fixed effects panel model as the dependant variable. In this second stochastic frontier model application, the explanative variable is a vector that contains only the numeral one as a value. The main goal in applying this is to estimate the constant term and the time-varying inefficiency. The time-varying inefficiency (or efficiency) is predicted from this second application, which is the third stage of Kumbhakar and Heshmati's (1995) model. For further explanation, see Kumbhakar, Wang and Horncastle, (2015 pp 270-274).

$$\dot{TFP} = \sum_j \varepsilon_j \dot{x}_j - \sum_j \frac{\varepsilon_j}{RTS}\dot{x}_j + \sum_j \frac{\varepsilon_j}{RTS}\dot{x}_j - \sum_j S_j \dot{x}_j + TC - \Delta TE,$$

we obtain the TFP change decomposition as follows:

$$\dot{TFP} = (RTS - 1)\sum_j \frac{\varepsilon_j}{RTS}\dot{x}_j + \sum_j \left(\frac{\varepsilon_j}{RTS} - S_j\right)\dot{x}_j + TC - \Delta TE$$

where $RTS = \sum_j \varepsilon_j$ is the return to scale. The first term $(RTS - 1)\sum_j \frac{\varepsilon_j}{RTS}\dot{x}_j$ represents the scale component, the second term $\sum_j (\frac{\varepsilon_j}{RTS} - S_j)\dot{x}_j$ is the allocative component, TC is the technological change and ΔTE is the technical inefficiency change (Kumbhakar et al. 2015 pp 286 - 287). Because information concerning input prices is not available, we consider that $\frac{\varepsilon_j}{RTS} = S_j$ following Kumbhakar and Lovell (2000, p. 284). Thus, considering the gap between 1996 and 2006 as one period, the TFP change is broken down as:

$$\dot{TFP} = (RTS - 1)\sum_j \frac{\varepsilon_j}{RTS}\dot{x}_j + TC - \Delta TE$$

$$= (RTS - 1)\sum_j \frac{\varepsilon_j}{RTS}\left(x_{j,2006} - x_{j,1996}\right) + (f(x_{it},\beta)_{2006} - f(x_{it},\beta)_{1996}) - (u_{i2006} - u_{i1996}) \quad (5)$$

Estimating the TFP requires considering the endogeneity of inputs in the production function (Van Beveren 2012 and Levinsohn and Petrin 2003). Marschak and Andrews (1944) report that inputs in the production function are not independently chosen. They are chosen depending on firm characteristics, which generates a simultaneity bias. According to Olley and Pakes (1996), it is a selection bias or "endogeneity of attrition" that matters because firms' decisions to enter or exit the market are motivated by the difference of their productivity in comparison to other firms, i.e., their competitors. Some studies focus on other sources of biases, such as the omitted price or the use of the same technology for multi-product firms (De loecker, 2007).

To account for the endogeneity in a stochastic frontier model, we follow Kumbhakar and Heshmati (1995) and Greene (2005a) who separate the heterogeneity of firms (fixed effects) from the inefficiency of firms.[11] Indeed, as shown by Ackerberg et al. (2007), controlling for the fixed effects overcomes the simultaneity bias. The selection bias from a firm's decision to enter or exit the market, which is determined by the time invariant effect or by the firm's specific effects, is undertaken when controlling for the fixed effects in the estimation procedure. Estimated coefficients of these models are given in Table (4) in the sub-section 4.2 and a simple comparison of outcomes from each methodology is presented.

3.3 Comparison of agricultural performance: the difference-in-difference model

To compare the agricultural performance among the municipalities (municipalities with protected areas versus those without protected-areas), a difference-in-difference model in panel data is applied. The choice of this model is justified by the availability of the agricultural data for two points in time: 1996 and 2006. In addition to this, an increasing adoption of protected areas was observed from 1980 to 2010. In fact, the difference-in-

[11] Kumbhakar and Heshmati (1995) use a four-step approach to estimate persistent inefficiency and time-varying inefficiency, while Greene (2005a) performs a one-step approach. The inefficiency term follows a half-normal distribution in the Greene (2005a) model estimated.

difference estimator computes a double difference: one across time and another across units, treated and non treated (see the estimator below). The main advantage of using this estimator is that it solves the selection bias arising from the non-random units that receive the treatment, and drops all differences among units that are invariant across time (Khandker et al. 2010 pp. 71-78). Indeed, to obtain unbiased estimates when comparing two groups (treated and control group, meaning in our case municipalitities with protected areas and those without, respectively), it's important to ensure that municipalities that received the protected areas have been chosen randomly.

However, Andam et al. (2008) and Joppa and Pfaff (2009) have already demonstrated that some protected-area locations can be biased towards places that are unlikely to face the pressure of the deforestation process or the expansion of agricultural land-use. This is the case when protected areas are created in areas that are not suitable for agriculture. Considering this issue, if the selection bias is not solved, the estimated result of PAs is overestimated. The diff-in-diff estimator then solves the selection bias by computing a double difference across time and across units. Specification of the model is as follows:

$$\mathbf{Y_{it} = \alpha + \beta T_t + \gamma D_i + \delta T_t * D_i + \theta X_{it} + \mu_i + \varepsilon_i} \qquad \mathbf{(1)}$$
$$\boldsymbol{i = 1, 2, \ldots\ldots, n \qquad t = 1996, 2006}$$

Where $\boldsymbol{Y_{it}}$ is the outcome, $\boldsymbol{T_t}$ is a dummy variable that equals 1 for the year **2006** and **0** for **1996** (time), $\boldsymbol{D_i}$ is a dummy variable that equals **1** if PA is found in a municipality and **0** if not (treatment), $\boldsymbol{T_t * D_i}$ is a multiplicative interaction variable of time-dummy variable $\boldsymbol{T_t}$ and treatment-dummy variable $\boldsymbol{D_i}$, $\boldsymbol{X_{it}}$ is vector of control variables that explains the outcomes, $\boldsymbol{\mu_i}$ is vector of individual effects that measures heterogeneity among municipalities, $\boldsymbol{\varepsilon_i}$ is vector of error terms, $\boldsymbol{\alpha}$ is a constant term, $\boldsymbol{\beta}$ is the difference among municipalities with PAs and those without the PAs, $\boldsymbol{i}$ is the municipality and $\mathbf{t}$ represents the years 1996 and 2006.[12] In Equation (1) the largest coefficient is $\boldsymbol{\delta}$. We have:

(1) $\Leftrightarrow$ $\mathbf{Y_{it} = \alpha + \gamma D_i + \theta X_{it} + \mu_i + \varepsilon_i}$ for $T_t = 0$ (1996)
(1) $\Leftrightarrow$ $\mathbf{Y_{it} = (\alpha + \beta) + (\gamma + \delta) D_i + \theta X_{it} + \mu_i + \varepsilon_i}$ for $T_t = 1$ (2006)
(1) $\Leftrightarrow$ $\mathbf{Y_{it} = \alpha + \beta T_t + \theta X_{it} + \mu_i + \varepsilon_i}$ for $D_i = 0$
(1) $\Leftrightarrow$ $\mathbf{Y_{it} = (\alpha + \gamma) + (\beta + \delta) T_t + \theta X_{it} + \mu_i + \varepsilon_i}$ for $D_i = 1$

The expected outcomes considering the different possible scenarios are as follows:

(a) if $\mathbf{T_t = 0 \text{ and } D_i = 0,}$ $\mathbf{E(Y_{it}) = \alpha + \theta X + \mu}$
(b) if $\mathbf{T_t = 0 \text{ and } D_i = 1,}$ $\mathbf{E(Y_{it}) = (\alpha + \gamma) + \theta X + \mu}$
(c) if $\mathbf{T_t = 1 \text{ and } D_i = 0,}$ $\mathbf{E(Y_{it}) = (\alpha + \beta) + \theta X + \mu}$
(d) if $\mathbf{T_t = 1 \text{ and } D_i = 1,}$ $\mathbf{E(Y_{it}) = (\alpha + \beta + \gamma + \delta) + \theta X + \mu}$

where X is the average of $\boldsymbol{X_{it}}$ and μ is the average of $\boldsymbol{\mu_i}$.

The diff-in-diff estimator $\boldsymbol{\delta}$ is given by the difference across time (1996 and 2006) of municipalities that contain PAs **[(d) - (b)]** that is $\boldsymbol{(\beta + \delta)}$, subtracted to difference across time of municipalities that do not contain PAs **[(c) - (a)]** that is $\boldsymbol{\beta}$:

12 Application of a diff-in-diff model as presented above requires two time periods: before and after. The time period before is from 1985 to 1995, and the time period after is from 1996 to 2006. The set of municipalities considered to have received protection in 1995 are those that received protected-areas during 1985 and 1995, both dates included. The set of municipalities considered to have received protection in 2006 are those that received protected-areas during 1996 to 2006, both dates included.

$$\boldsymbol{\delta} = [\![\mathbf{Y}_{\mathbf{i2006}} - \mathbf{Y}_{\mathbf{i1996}}]\!]_{\mathbf{protected}} - [\![\mathbf{Y}_{\mathbf{i2006}} - \mathbf{Y}_{\mathbf{i1996}}]\!]_{\mathbf{non-protected}}$$

The same double difference can be obtained as follows:

$$\boldsymbol{\delta} = [\![\mathbf{Y}_{\mathbf{iprotected}} - \mathbf{Y}_{\mathbf{inon-protected}}]\!]_{\mathbf{2006}} - [\![\mathbf{Y}_{\mathbf{iprotected}} - \mathbf{Y}_{\mathbf{inon-protected}}]\!]_{\mathbf{1996}}$$

In this latter form, the first difference is among municipalities without PAs and those with PAs in 2006 **[(d) - (c)]** given by $(\boldsymbol{\gamma} + \boldsymbol{\delta})$**.** The second difference is among municiaplities without PAs and those with PAs in 1996 **[(b) - (a)]** given by $\boldsymbol{\gamma}$**.** The double difference across municipalities and across time is then given by $\boldsymbol{\delta}$ **,** which is the difference between both the first and second differences. For this study, we use the first specification of the double difference.

Because some selective activities could partly explain the change in TFP or potential production, regardless of the presence of protected-areas, we introduce an exported agricultural product for which data are available to control for that issue. We choose maize as the control variable as it is among the main export products in Brazil and the data are more available by municipality in the Legal Amazon than for other export products (orange, soy, sugar cane, coffee, bananas), as we see in Figure (3) and Table (9) in Appendix.

4 Econometric results

4.1 Descriptive statistics

Descriptive statistics are presented in Table (3) below. As we can observe, the average of the potential production stands approximately at the value 8.37 for Kumbhakar and Heshmati’s (1995) model and 6.82 for Greene’s (2005a) model. The largest and smallest values of the potential production are 10.48 and 5.84, respectively, for the former while they are 8.93 and 4.29, respectively, for the latter. Concerning the technical efficiency, the average is almost the same: (0.85) for the former and (0.82) for the latter. However, Greene's (2005a) methodology induces an important loss of data. There is a difference of means of the total factor productivity and the potential production. Indeed, the constant term is considered in Kumbhakar and Heshmati’s (1995) estimated model and not in Greene’s (2005a). The econometric results are presented in Table (4). Table (5) and Table (6) display information concerning the most performant municipalities and the average performance of the Legal Amazon municipalities, by state. Results and comments are presented in next section.

Table 3: Descriptive statistics

Variable	Variables definition in log	Mean	Std. Dev.	Min	Max	Observations
lnproduction value	Production value in log (r$)	8.24	1.22	3.61	12.15	1246
lncapital	Capital = trucks + tractors + planting and harvest machinery + others tools	4.24	1.52	0	8.86	1130
lntotalworkers	Workers in agriculture	7.90	1.01	4.54	10.65	1246
lnagricultural_landuse	Land use in agriculture (ha)	11.23	1.29	4.54	14.27	1245
lntechnical_assistnb	Number of establishments technically assisted	5.25	1.85	0	9.17	1239
lnelectricenergy_nbesth	Number of establishments using electrical energy	4.79	1.48	0	7.92	1236
lntmp_mun	Temperature	3.28	0.03	3.15	3.33	1370
lnpre_mun	Precipitations	5.10	0.26	4.56	5.74	1370
lnprod_value_maize	Production value of maize (r$)	854.54				
PP_Kumbhakar&Heshmati	Potential production Kumbhakar and Heshmati (1995)	8.37	0.74	5.84	10.48	1128
PP_Greene	Potential production Greene (2005a)	6.82	0.74	4.29	8.93	1128
EFF_Kumbhakar&Heshmati	Efficiency Kumbhakar and Heshmati (1995)	0.85	0.04	0.59	0.95	1126
EFF_Greene	Efficiency Greene (2005a)	0.82	0.23	0.06	1	908
TFP_Kumbhakar&Heshmati	Total Factor Productivity Kumbhakar and Heshmati (1995)	7.30	0.62	5.17	9.13	1126
TFP_Greene	Total Factor Productivity Greene (2005a)	5.62	0.74	2.37	7.48	908

Source: IBGE and authors, PP = Potential Production, TFP = Total Factor Productivity, EFF = Technical Efficiency

4.2 Stochastic model results

Estimated coefficients of both of models are presented in Table (4). Statistical characteristics and the Likelihood Ratio test (LR test) are in favor of Greene's (2005a) model. However, in the literature, this model is subject to the incidental parameters problem (see Greene (2005b) and Chen et al. (2014)).[13] Thus, we retain the model of Kumbhakar and Heshmati (1995). We note that the coefficients of inputs in Table (3) of the frontier are statistically significant. The distribution of the variables of interest (TFP and potential production) is presented in Figure (2). We also note that the coefficient estimated for the inefficiency from Kumbhakar and Heshmati (1995) does not appear in the table because the authors' procedure is done in four steps and the inefficiency is derived in the second step.

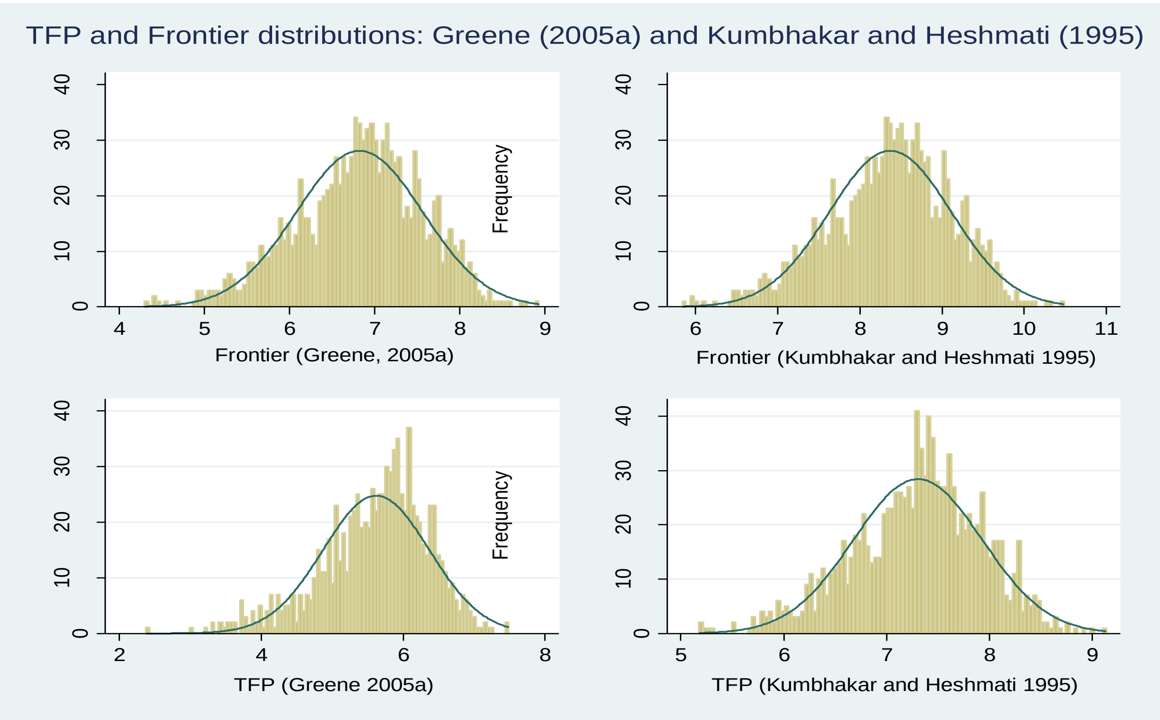
[13] The incidental parameters arise when the number of parameters to be estimated increase with units. The consistency of estimated parameters is not guaranteed even if the number of units is too large ($N \rightarrow \infty$). In fact, the value of standard errors could depend on the ratio between units and their corresponding parameters to estimate. Related to the Greene (2005a) model, fixed effects parameters are increasing with the units. And because it's a stochastic frontier method, applying the first difference estimator to drop fixed effects doesn't solve the problem (Greene, 2005b). For further information about the incidental problem, see Lancaster (2000), Chen et al., (2014) or Greene (2005b).

Table 4: Results of both stochastic frontier models

	Greene (2005a)	Kumbhakar and Hesmati (1995)
(Dependant variable: lnproduction_value)		
lncapital	0.203***	0.203***
	(0.0244)	(0.0347)
lntotalworkers	0.485***	0.485***
	(0.0410)	(0.0582)
lnagricultural_use	0.186***	0.186***
	(0.0463)	(0.0659)
_cons	.	1.548**
		(0.649)
Usigma		
_cons	-1.472***	.
	(0.0469)	
Vsigma		
_cons	-44.52	.
	(1819.8)	
N	908	1126
bic	158.5	543.2
aic	33.39	523.1
Likelihood	9.305	-257.6

Source: IBGE and authors, standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01

Figure 2: TFP and potential production distributions



Source: IBGE and authors

As already explained above, to compute the inefficiency score, the authors predict the error term of the estimation of the first step (a panel model estimated with fixed effects) and apply a stochastic model with this error as the dependent variable. The independent variable is a vector (n×1) with only number 1 as elements. The constant term is not considered in this step. For more information concerning the Kumbhakar and Heshmati's (1995) procedure, see Kumbhakar, Wang and Horncastle (2015 pp 270-274).

Table 5: The 5 best performance by year (Greene 2005a and Kumbhakar and Heshmati 1995)

Greene (2005a): Potential production				Kumbhakar and Heshmati (1995): Potential production			
States	Municipality	Year	Potential production	States	Municipality	Year	Potential production
Rondonia	Cacoal	1996	8.368816	Rondonia	Cacoal	1996	9.917612
Rondonia	Alta Floresta D'Oeste	1996	8.386981	Rondonia	Alta Floresta D'Oeste	1996	9.935799
Para	Santarém	1996	8.515141	Para	Santarém	1996	10.06399
Maranhoa	Santa Luzia	1996	8.530299	Maranhoa	Santa Luzia	1996	10.07914
Matogrosso	Alta Floresta	1996	8.935153	Matogrosso	Alta Floresta	1996	10.48398
Maranhoa	Balsas	2006	8.245398	Maranhoa	Balsas	2006	9.794218
Matogrosso	Sorriso	2006	8.439184	Matogrosso	Sorriso	2006	9.988002
Para	Cametá	2006	8.573029	Para	Cametá	2006	10.12184
Para	Santarém	2006	8.72075	Para	Santarém	2006	10.26956
Para	São Félix do Xingu	2006	8.759463	Para	São Félix do Xingu	2006	10.30835
Greene (2005a): TFP				**Kumbhakar and Heshmati (1995): TFP**			
States	Municipality	Year	TFP	States	Municipality	Year	TFP
Para	Santarém	1996	6.92731	Rondonia	Cacoal	1996	8.628022
Rondonia	Machadinho D'Oeste	1996	6.928358	Rondonia	Alta Floresta D'Oeste	1996	8.667054
Para	Conceição do Araguaia	1996	7.100948	Para	Santarém	1996	8.742864
Rondonia	Pimenta Bueno	1996	7.138488	Maranhao	Santa Luzia	1996	8.743059
Rondonia	Ouro Preto do Oeste	1996	7.14418	Matogrosso	Alta Floresta	1996	9.13577
Maranhao	Balsas	2006	7.049474	Rondonia	Machadinho D'Oeste	2006	8.514956
Matogrosso	Sorriso	2006	7.215153	Para	Altamira	2006	8.531937
Para	Cametá	2006	7.253284	Para	Cametá	2006	8.82847
Para	Santarém	2006	7.45588	Para	Santarém	2006	8.914034
Para	São Félix do Xingu	2006	7.488978	Para	São Félix do Xingu	2006	8.979321

Source: IBGE and authors

We can also observe in Figure (2) that the TFP and the potential production are higher with the Kumbhakar and Heshmati (1995) model. A large share of all municipalities (more than 25%) has a potential production score which stands between [6.5, 7.5] with Greene's (2005a) model, while it is [8.3, 9] with Kumbhakar and Heshmati's (1995). Concerning the TFP, more than 25% of all municipalities stand in an interval of [5.7, 6.5] with Greene's (2005a) model, while it is [7.2, 7.8] with Kumbhakar and Heshmati's (1995).[14]

In Table (5), we present the 5 most productive municipalities using each methodology. We can observe that the most performant municipalities for the potential production as the outcome are always the same regardless of which of the two methodologies used. This is not the case when considering the total factor productivity (TFP). Indeed, although both methodologies separate the inefficiency to the fixed effects, they each specify the inefficiency in the model differently (see Greene 2005a and Kumbhakar, Wang and Horncastle, 2015 pp 270-274)).

[14] We note that the TFP in this case is not the total factor productivity change ($\dot{TFP}$), but the TFP at year t. As example: $\mathrm{TFP}_{2006} = (\mathrm{RTS}-1)\sum_j \frac{\varepsilon_j}{\mathrm{RTS}}\left(x_{j,2006}\right) + \mathrm{f}(\mathrm{x}_{\mathrm{it}}, \beta)_{2006} - (\mathrm{u}_{\mathrm{i}2006})$. Then, because the gap between 2006 and 1996 is considered as one period in the study ($t_{2006} - t_{1996} = 1$), the double difference presented below will deliver the TFP change as presented in Equation (5).

Table 6: Agricultural firm performance by Legal Amazon states (mean of municipalities)

states	PP_Kumbhakar & Heshmati	PP_Greene	EFF_Kumbhakar& Heshmati	EFF_Greene	TFP_Kumbhakar & Heshmati	TFP_Greene
Acre	8.63323	7.084455	0.85933536	0.8530231	7.542431	5.94861
Amazonia	8.166467	6.617726	0.85364564	0.7743883	7.124348	5.412025
Amapa	7.219032	5.670324	0.85866962	0.806478	6.299547	4.728326
Maranhao	8.332004	6.783272	0.85730487	0.8097876	7.291228	5.639527
Matogrosso	8.708728	7.159956	0.85686028	0.8187959	7.526134	5.82642
Para	8.487508	6.938754	0.85755436	0.8317719	7.39478	5.703878
Rondonia	8.964354	7.415583	0.86140679	0.8800988	7.836081	6.185599
Roraima	8.235424	6.686663	0.86018789	0.8384194	7.19927	5.565641
Tocantin	7.953084	6.404351	0.856903	0.8238208	6.976449	5.248936

Source: IBGE and authors

In Table (6), we present the agricultural performance distribution, by state. We can observe that Rondonia has the best performance regardless of the methodology used. This is in adequacy with results from Avila et al. (2010). Indeed, the state Rondonia is located within the arc of deforestation. It can be assumed that recently cleared lands (i.e. land located in the arc of deforestation) are more fertile than older ones. Thus, with protection of various areas in this state, farmers develop incentives to perform agricultural practices which improve their yields.

4.3 Diff-in-diff model results

The diff-in-diff model is applied using the potential production, the technical efficiency and the TFP as the dependent variables. In Table (7), the first sub-table presents the results of the diff-in-diff model, with the maximum possible production as the main outcome. In this sub-table, the first column refers to all protected areas, the second column to protected areas with "integral protection" status and the third column to protected areas with "sustainable status." The estimated coefficient of the double difference, that is, the coefficient of variable **treatment*time** in the first column, is significant and positive. This means that, on average, the difference in 2006 to 1996 of the potential production of the agricultural firms in municipalities without protected areas is lower than that of the agricultural firms in municipalities with protected-areas.[15] Because changes in the potential production are the result of technological progress, these estimations suggest that, on average, productive practices in agriculture have more emerged in 2006 than in 1996 among the agricultural firms in municipalities with protected areas than the municipalities without protected-areas. In other words, municipalities with PAs technically progressed in agriculture, reaching a level of 0.201 higher score than the municipalities without PAs. Consequently, in this case the Porter hypothesis is confirmed.

The double difference coefficient is also significant in another column of municipalities with Sustainable protected-areas. Interpretation of results for this column is the same as for the first column. However, considering municipalities with areas under integral protection, the double difference coefficient is not significant, meaning that the Porter hypothesis is not verified in this case. The protection of various areas in the Legal Amazon does not only lead to forest and biodiversity conservation, as demonstrated by Andam et al. (2008) and Nolte et al. (2013). It also results in the adoption of more productive practices in agriculture. The same interpretation is done with results presented in the last sub-table, with the total factor

[15] $[\![\mathbf{Y}_{\mathbf{i2006}} - \mathbf{Y}_{\mathbf{i1996}}]\!]_{\mathbf{protected}} > [\![\mathbf{Y}_{\mathbf{i2006}} - \mathbf{Y}_{\mathbf{i1996}}]\!]_{\mathbf{non-protected}}$

productivity as the main outcome. We can observe that municipalities with PAs are more performant, with a total factor productivity change which stands at a level of 0.171 higher score than the municipalities without PAs.

Coefficients estimated in Table (7), in the first column of the second sub-table, show that the double difference coefficient of the efficiency is negative and not significant. This suggests that the difference in 2006 to 1996 of the efficiency in agricultural firms in municipalities with protected areas is not significantly different from those without protected areas. Although there are positive changes in productive practices among the municipalities with protected-areas, protection does not improve efficiency of municipalities across time. There is an inertia in the inefficiency among the municipalities. More technically, as presented in Figure (1) above, municipalities tend to displace their potential production across time without significantly reducing the distance gap to the frontier. We note that the outcome referring in this second sub-table in Table (7) is the variant efficiency.

As a robustness check, an identical framework is applied using performance computed from Greene's (2005a) model. Results are globally the same related to the potential production changes (technical progress) but change for the total factor productivity, following the loss of data in the estimation procedure. These results are presented in Table (8) in the Appendix.

Table 7: Diff-in-diff model results using agricultural performance from Kumbhakar and Heshmati's (1995) methodology

	PP Integral+sus	PP Integral_P	PP Sustainable_P	EFF Integral+sus	EFF Integral_P	EFF Sustainable_P	TFP Integral+sus	TFP Integral_P	TFP Sustainable_P
time	-0.643***	-0.588***	-0.651***	-0.0596***	-0.0629***	-0.0566**	-0.547***	-0.500***	-0.555***
	(0.0949)	(0.0906)	(0.0973)	(0.0226)	(0.0225)	(0.0229)	(0.0853)	(0.0809)	(0.0831)
treatment	-0.0168			-0.00141			-0.0118		
	(0.0831)			(0.0162)			(0.0703)		
Treatment*time	**0.201****			**-0.00939**			**0.171****		
	(0.0843)			**(0.0165)**			**(0.0704)**		
treatment_ip		-0.0360			-0.0276			-0.0199	
		(0.119)			(0.0287)			(0.0951)	
treatment_ip*time		**0.205**			**0.0207**			**0.164**	
		(0.135)			**(0.0266)**			**(0.112)**	
treatment_usosus			0.00567			0.00695			0.00384
			(0.0907)			(0.0157)			(0.0732)
treatment_usosus*time			**0.192****			**-0.0238**			**0.167****
			(0.0893)			**(0.0161)**			**(0.0714)**
technicalassist_nb	0.0577***	0.0541***	0.0567***	0.00269	0.00289	0.00273	0.0497***	0.0467***	0.0489***
	(0.0160)	(0.0163)	(0.0165)	(0.00377)	(0.00365)	(0.00363)	(0.0138)	(0.0145)	(0.0140)
electricity_nbesth	0.139***	0.134***	0.138***	0.00977*	0.0104**	0.00949*	0.118***	0.114***	0.118***
	(0.0235)	(0.0243)	(0.0236)	(0.00523)	(0.00501)	(0.00523)	(0.0205)	(0.0197)	(0.0204)
tmp_mun	9.989***	8.949***	10.97***	2.907***	2.912***	2.807***	8.248***	7.378***	9.107***
	(3.231)	(3.202)	(3.147)	(0.760)	(0.748)	(0.742)	(2.903)	(2.786)	(2.783)
pre_mun	0.129	0.117	0.119	0.0408	0.0392	0.0406	0.119	0.110	0.110
	(0.205)	(0.231)	(0.202)	(0.0476)	(0.0474)	(0.0469)	(0.185)	(0.192)	(0.177)
prod_value_maize	0.0517***	0.0529***	0.0529***	0.000236	0.000234	0.000251	0.0430***	0.0440***	0.0440***
	(0.0140)	(0.0146)	(0.0141)	(0.00356)	(0.00339)	(0.00335)	(0.0131)	(0.0128)	(0.0137)
_cons	-26.05**	-22.55**	-29.21***	-8.938***	-8.951***	-8.609***	-21.20**	-18.28*	-23.97***
	(10.77)	(10.78)	(10.48)	(2.557)	(2.537)	(2.508)	(9.748)	(9.355)	(9.297)
N	1096	1096	1096	1094	1094	1094	1094	1094	1094
bic	-762.6	-740.9	-759.0	-4038.8	-4039.3	-4042.5	-1103.0	-1080.6	-1100.0
aic	-807.6	-785.9	-804.0	-4083.8	-4084.3	-4087.5	-1148.0	-1125.6	-1145.0

Source: IBGE and authors. Standard errors in parentheses * $p<0.1$, ** $p<0.05$, *** $p<0.01$; PP = potential production, EFF = Technical efficiency, TFP = Total factor productivity

5 Concluding remarks

Protected areas in the Brazilian Legal Amazon have been expanding during the two last decades. They are considered as an important environmental policy instrument used to mitigate the deforestation process, biodiversity losses and climate change. Because the enforcement of PA restrictions constrains farmers, there is a sort of land scarcity that is increasing with the expansion of PAs. This scarcity inspires farmers to adopt technical practices that favor the intensification of agriculture and improve technical progress in the available or remaining unprotected land.

This study is applied in order to investigate the potential effect of protected areas in agriculture. The study belongs to the strand of empirical studies that focus on the effectiveness of conservation policies. We employ two-step econometric approach, the first step referring to the stochastic frontier analysis and the second to the difference-in-difference model. The empirical results show that protected areas drive farmers to practice more intense agriculture by adopting technical practices or new technologies than farmers whose land is not under protection. Because farmers want to maintain their benefits considering constraints or restrictions from protection, they are prone to develop innovative practices that help achieve both environmental and maximum agricultural production. According to the empirical strategy applied in the study, technical progress has been increasingly growing in municipalities that receive protected-area designation. Based on this result, we can verify the Porter hypothesis.

For policy-maker, these findings could be interesting and very useful. Indeed, to avoid an inverse effect of protected areas on agriculture, the government must support its environmental policy by offering technical assistance to producers in the short term. Helping them to adopt more efficient practices, machinery and new technology will increase their incentives to develop more of the same types of practices. Consequently, farmers will reach their agricultural goals and policy-makers will be satisfied with the long-term policy outcomes, achieving a win-win policy.

This article does not analyze whether these changes in agricultural practices have an effect on poverty or inequality in the area of the study. The paper does not analyze whether the productive practices cause side effects such as land degradation or land pollution. Further research could consider these points.

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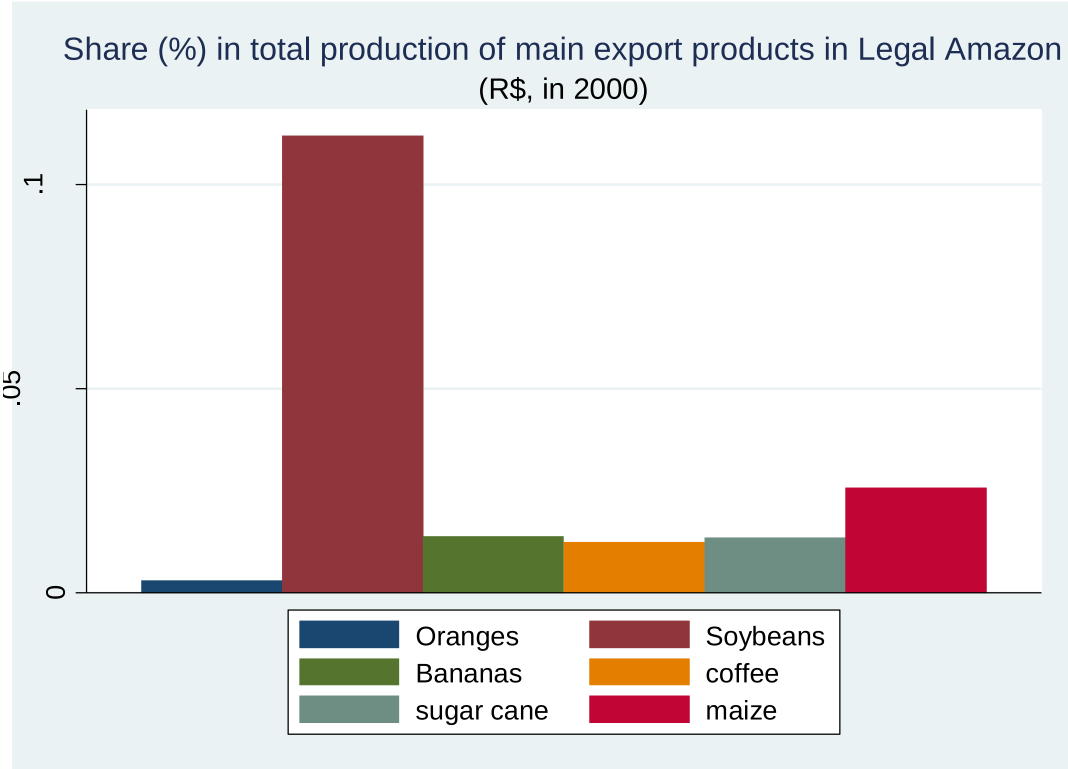
7 Appendix

Table 8: Diff-in-diff model results using agricultural performance from Greene's (2005a) methodology

	PP Integral+sus	PP Integral_P	PP Sustainable_P	EFF Integral+sus	Eff Integral_P	EFF Sustainable_P	TFP Integral+sus	TFP Integral_P	TFP Sustainable_P
time	-0.643***	-0.588***	-0.651***	-0.319***	-0.328***	-0.307***	-1.017***	-0.995***	-1.001***
	(0.0955)	(0.0866)	(0.0975)	(0.110)	(0.100)	(0.112)	(0.189)	(0.194)	(0.191)
treatment	-0.0168			0.00305			-0.0241		
	(0.0774)			(0.0759)			(0.141)		
Treatment*time	**0.201****			**-0.0288**			**0.0991**		
	(0.0804)			**(0.0773)**			**(0.143)**		
Treatment_ip		-0.0360			-0.0889			-0.242	
		(0.123)			(0.112)			(0.269)	
Treatment_ip*time		**0.205**			**0.0836**			**0.333**	
		(0.144)			**(0.115)**			**(0.270)**	
Treatment_ususus			0.00567			0.0268			0.0589
			(0.0839)			(0.0779)			**(0.133)**
treatment_ususus*time			**0.192****			**-0.0798**			**-0.0193**
			(0.0860)			**(0.0820)**			(0.139)
lntechassist_nb	0.0577***	0.0541***	0.0567***	0.00945	0.00992	0.00933	0.0705**	0.0691**	0.0701**
	(0.0159)	(0.0156)	(0.0160)	(0.0177)	(0.0166)	(0.0182)	(0.0312)	(0.0330)	(0.0318)
lnelectricenergy_nb	0.139***	0.134***	0.138***	0.0445*	0.0467**	0.0432*	0.194***	0.195***	0.191***
	(0.0237)	(0.0223)	(0.0238)	(0.0241)	(0.0236)	(0.0233)	(0.0451)	(0.0425)	(0.0422)
lntmp_mun	9.989***	8.948***	10.97***	16.05***	15.99***	15.72***	31.36***	30.52***	31.44***
	(3.282)	(3.073)	(3.176)	(3.613)	(3.533)	(3.668)	(5.969)	(6.486)	(6.098)
lnpre_mun	0.129	0.117	0.119	0.196	0.192	0.194	0.424	0.403	0.414
	(0.205)	(0.225)	(0.220)	(0.226)	(0.214)	(0.217)	(0.399)	(0.394)	(0.411)
lnprod_value_maize	0.0517***	0.0529***	0.0529***	-0.00745	-0.00759	-0.00718	0.0451	0.0460	0.0461
	(0.0150)	(0.0148)	(0.0150)	(0.0166)	(0.0155)	(0.0158)	(0.0304)	(0.0291)	(0.0298)
_cons	-27.59**	-24.10**	-30.76***	-53.00***	-52.76***	-51.89***	-100.7***	-97.79***	-100.9***
	(10.94)	(10.21)	(10.62)	(12.13)	(11.90)	(12.37)	(20.16)	(21.86)	(20.51)
N	1096	1096	1096	884	884	884	884	884	884
bic	-762.7	-741.0	-759.1	-315.5	-316.0	-317.2	723.2	720.7	724.2
aic	-807.7	-786.0	-804.1	-358.5	-359.1	-360.3	680.2	677.6	681.2

Source: IBGE and authors. Standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01; PP = potential production, EFF = Technical efficiency, TFP = Total factor productivity

Figure 3: Export products in Brazil's Legal Amazon (% of total production)



Source: IBGE and authors

Table 9: Missing data for the main export products

	Oranges	Bananas	Soybeans	Coffee	Sugar cane	Maize
Number of missing data (number of municipalities in 1996 and 2006)	661	306	1086	1085	777	162
Number of available data (number of municipalities in 1996 and 2006)	711	1066	286	287	595	1210

Source: IBGE and authors