How Much Did We Lose/Gain As A Result of Soybean Export Facility Opening in the Amazon?

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ABSTRACT

Brazilian Amazon is a priority region for both conservation and development because of the region's high value of ecosystem services and high poverty rate. However, economic development often comes at the expense of conservation. In 2003, Cargill opened a soybean export facility in Santerém in the northern Brazilian Amazon. In this paper, I use year specific effect and difference-in-difference (DID) regressions to estimate the impact of the port facility opening on deforestation and on tradeoffs between the value of agricultural production and carbon sequestration. I find that the opening of the port facility increased deforestation by about 164 km^2 in 2003 and 2004. The value of lost carbon is over $100 million, which is equivalent to the increased profit from agricultural production assuming 3% discount rate and social cost of carbon at $120.8 per ton of carbon in 2004 US dollar value. These results suggest that the construction of the port facility may be justified given the high poverty rate in the region and that the farmers would have to be paid for their loss of profit if we were to preserve carbon.

Keywords: deforestation, Amazon, responsible soy, environmental regulation

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I. Introduction

The Brazilian Amazon has a high priority for both conservation and development. The region has rich biodiversity and carbon storage that are of global significance, and at the same time it has the highest poverty rate of any region in Brazil. Brazil has more than 25% of the estimated total carbon stock in the 15 countries that have the highest carbon pool in sub-Saharan Africa, Latin America, Asia, and Oceania (Saatchi 2011). However, as of 2013 about 15% of total legal Amazon area had been deforested through agricultural expansion, leading to a massive release of carbon and loss of biodiversity. This agricultural expansion in the Brazilian Amazon has generated income and employment and has contributed to the economic development of the region, yet many people still remain in poverty: 37 out of 143 municipalities in Pará state had a poverty rate over 50% in 2003 (IBGE 2014a).

Efficient land use planning requires estimation of the impacts from new economic incentives and the resulting tradeoffs among ecosystem services. The estimation of impacts and tradeoffs can be used for benefit/cost analyses to find efficient practices that maximize net benefits from conservation and/or development. Failure to estimate the impacts of changes in economic incentives and resulting tradeoffs will likely lead to inefficient land use decisions. Many past development strategies have generated inefficient results because they have not utilized accurate values of ecosystem services (Balmford et al. 2002; MEA 2005). The estimation of impacts and tradeoffs is particularly important in many developing countries because they have high value of ecosystem services and people depend directly on natural resources for food and income. Impact assessments of new economic incentives and estimation of the resulting tradeoff value of ecosystem services will contribute to efficient land use decisions that can provide both income for the local people as well as a variety of ecosystem services, such as carbon sequestration.

In this paper, I investigate the impact of the opening of a new soybean export facility on the amount of deforestation and the resulting tradeoff between agricultural production and carbon sequestration in the Santarém area. In 2003, the agricultural multinational company Cargill opened a soybean export facility in Santarém, located on the confluence of the Amazon and Tapajos Rivers (Figure

1) within the northern region of the Brazilian Amazon. I first run regressions to estimate the impact of the opening of the port facility opening on deforestation. I then construct a counterfactual land-use land-cover map using the results from the deforestation regression to compare the tradeoff between agricultural production and carbon sequestration. I also calculate the break-even price of carbon to compensate farmers for their lost profit from agricultural production if the land were preserved.

I find that the average deforestation rate increased from 1.52% in 2002 to 5.48% in 2003 and 11.70% in 2004, which are equivalent to an area of 164 km^2. The comparison of tradeoff values varies depending on the discount rate used. The value of the lost carbon in the study area exceeds the value of the increased agricultural production at a 3% discount rate, and the discount rate at which the social cost of carbon (IWG 2015) is less than the agricultural value is 5%. I also find that the break-even price of carbon to compensate farmers for their loss of agricultural profit is $92.4 and $55.4 per ton of carbon, assuming 3% and 5% discount rates, respectively. The results suggest that careful consideration of benefits and costs prior to the opening of the port facility might have increased the net benefits from these ecosystem services. This tradeoff between agricultural production and carbon sequestration implies that considering other ecosystem services, such as water purification, might change the net benefit to be negative. These estimates of the break-even price of carbon provide quantitative estimates of how much farmers should be compensated if Brazil were to preserve those lands to increase net benefits from various ecosystem services.

In the conservation and land use planning literature, impact evaluation studies have used program evaluation methods to quantitatively measure the amount of avoided deforestation as a result of conservation programs. Blackman (2013) provides a good review of studies that are *ex-post* analyses of the impact of various forest conservation policies such as protected areas (PA) and payment for ecosystem services (PES). However, most of these studies do not consider other associated costs or benefits from conservation programs such as the cost of implementing the conservation project or the benefits of conservation on ecosystem services. Ignoring the associated costs and benefits from conservation programs can be misleading because the marginal costs and benefits of additional forest cover spatially vary significantly (Vincent 2015).

This study contributes to the land use planning literature by evaluating the impact of the opening of a port facility on deforestation and the resulting tradeoff between agricultural production and carbon sequestration. It bridges the gap between the impact evaluation and the tradeoff of ecosystem services' analysis (e.g., Koh and Ghazoul 2010; Goldstein et al. 2012) literature by translating the change in deforestation resulting from the port facility opening into the change in the value of carbon and agricultural production. The discussion on these two ecosystem services is necessary for land use decisions because agricultural production increases farmers' income, which can mitigate poverty in the Amazon area, while carbon sequestration affects climate that has global implications.

This study can inform policies for efficient land use that promote both economic development for the poor and the provision of other ecosystem services. It will lead to better land use decisions not only for governments but also for other stakeholders, including private companies and global initiatives such as United Nation's program on Reducing Emissions from Deforestation and Forest Degradation. The following sections proceed with background of the deforestation in the Santarém and Belterra region, empirical estimation methods, and regression estimation results, followed by conclusions.

II. Background

Deforestation in the Brazilian Amazon and in the municipalities of Santarém and Belterra

The cumulative cleared forest area in the Brailian Amazon in 2010 was 742,782 km^2, which is about 14% of the total Legal Amazon area in Brazil and is bigger than the size of Texas (696,241 km^2). The history of major deforestation goes back to 1970s and 1980s, when there were both land speculation and tax and subsidy incentives to clear forest for large-scale cattle ranching (Fearnside 2005). The deforestation rate peaked in 1995, which might be explained by economic recovery following a successful currency reform, i.e., Plano Real, in 1994. The deforestation rate has steadily decreased since then when the land value decreased from 1994 to 1997. However, the rate has reformed to an upward trend after 1997, largely due to increased deforestation in the states of Mato Grosso, Rondônia, and Pará (Macedo et al. 2012) for cattle ranching and crop production spurred by macroeconomic factors such as the inflation rate. Yet since 2004 the deforestation rate has been in a decreasing trend as a result of various factors such as a stronger Brazilian currency, increased enforcement of regulations from the Brazilian government, and increased engagement of private companies in reducing deforestation. Focusing on Santarém, the history of major deforestation dates from the 1970s, when black pepper plantations were developed and the government started to construct transportation infrastructure. The cumulative deforestation rate in the municipality of Santarém was 16% (3,756 km^2) in 2000, and it had reached 20% (4,586 km^2) in 2010.

To a certain extent the pattern of deforestation around Santarém and Belterra (S&B) area is reflected in the patterns for Amazon as a whole as is shown in the Figure 2. This figure presents the annual deforestation rate over the remaining forest cover in the Amazon, in Pará state, and in the two municipalities of S&B and the surrounding 10 municipalities[2]. The Amazon, Pará state, and S&B and the surrounding municipalities all have decreasing trends, with some fluctuations from 2001 to 2011. It appears that the deforestation patterns of Amazon and Pará state were similar, while Pará state has had a highest deforestation rate compared to other regions during this period. The deforestation rate pattern in the S&B and surrounding 10 municipalities was different from that of the other regions between 2002 and 2004, which is around the time when Cargill opened the soybean export facility in 2003. The rate increased by 145% in the S&B and surrounding 10 municipalities, which is more than four times and seven times higher than that increase in Pará state (32%) and in the Amazon area (20%), respectively. The differences in these deforestation rates have become smaller in more recent years, while the deforestation rates have become relatively higher in S&B and the surrounding 10 municipalities relative to other regions after 2006.

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[2] The surrounding 10 municipalities are Alenquer, Aveiro, Curuá, Juruti, Monte Alegre, Óbidos, Placas, Prainha, Rurópolis, and Uruará, which surround the municipalities of S&B. The total area of these 10 municipalities is 136,443 km^2, making it 5 times larger than the combined area of S&B.

Soybean Export Facility Opening in the municipality of Santarém

The soybean expansion in the municipality of Santarém is primarily due to the soybean export facility opening in 2003 by Cargill, which might have caused further deforestation in 2000s. Cargill opened a soybean export facility at the port in Santarém (Figure 1) to avoid congestion in the southern port of Santos and to decrease transportation cost. Since then, production of soybeans has increased in the region; the percentage of soybean planted area over total crop planted area changed from 1% in 2002 to 28% in 2005 in Santarém and Belterra (IBGE 2014b). It is not clear whether this high increase in soybean plantation was followed by increased deforestation in the region by looking at government statistics.

III. Methods

I model changes in two ecosystem services, i.e., agricultural production and carbon sequestration, as a result of soybean export facility opening in 2003 in the region of S&B. The analysis is composed of two parts: 1) Regression analysis on the impact of the soybean export facility opening on deforestation and 2) Estimation of the tradeoff between the value of agricultural production and carbon sequestration using the results from the regression analysis.

I estimate a regression to measure the impact of the new soybean export facility opening on deforestation in the region of S&B using two different estimation methods. The first method, year specific effects on deforestation, estimates whether there is any year between 2001 and 2010 that has higher deforestation than the other years. The results from this first regression give a general idea of which years the port opening potentially had a significant impact on deforestation. Then, I run difference-in-diffearences (DID) regression to measure the impact of the port facility opening on deforestation. I measure the specific impact of the port facility opening on deforestation by dividing and comparing impacted (treatment) and non-impacted (control) groups of properties by the port facility opening using the same data.

Secondly, I estimate the tradeoff between the value of agricultural production and carbon sequestration by projecting the land use land cover (LULC) if there had not been the opening of the soybean export facility in 2003 using the regression estimation results. The projected LULC is compared to the actual LULC to estimate the tradeoffs.

Year Specific Effects on Deforestation

The first regression estimation method is often used in event analyses to evaluate the impact of a certain event on a response variable. The deforestation rate regression is estimated as follows:

$$Y_{it} = \alpha_i + \sum_{t=2001}^{2010} \beta_t T_t + \sum_{t=2001}^{2010} \delta_t T_t X_i + u_{it} \tag{1}$$

where Y_{it} is the deforestation rate, which is the percentage of area of deforestation in property *i* relative to the remaining forest cover at time period *t* and α_i is an individual fixed effect to control for the farmers' and properties' characteristics that affect deforestation rates. T_t is a vector of time dummy variables for the years 2002 to 2010, year 2001 being the base year. X_i is a set of physical characteristic variables that are time invariant including distance to the soybean unloading facility and soil quality that affect farmers' deforestation behaviors, and u_{it} is an error term.

The parameters β_t and δ_{t} in equation (1) jointly indicate time-specific effects in each year. They account for the impacts of possible shocks on deforestation in each year such as change in the degree of governmental enforcement of environmental regulations or economic shock from changes in prices of agricultural products. Therefore, the significance of the coefficients β_t and δ_t will reflect whether the impact of the port opening is significant in each year. It is expected that the coefficient β_t will be positive and significant for the years following the opening of the port facility in 2003, showing the immediate effect of the port facility opening on deforestation. The standard errors for the total effects of single time and physical characteristic variables, which include both their direct effect and interaction effects, are estimated using the delta method, which uses a first-order Taylor approximation to estimate the standard error of the transformed parameters.

Constructing Control and Treatment Groups

I construct control and treatment groups to evaluate the impact of the soybean export facility opening on deforestation. Setting up a control group is challenging given that this is not a randomized control trial and that the soybean export facility opening might have affected all the properties in the region.

In order to construct a control group that has not been affected by the facility, I find a variable that can be used to divide the properties into two groups: relatively higher deforestation after 2003 (treatment group) and little change in deforestation after 2003 (control group). Among other variables, the distance to the soybean unloading facility is a significant factor that determines whether a property is affected by the new soybean export facility opening. The farther a property is from the port, the less likely there will be an increased deforestation of the property as a result of the port facility opening. The variables measuring the distance from the places where major economic activities occur such as major city and market place are one of the significant variables that are included in most deforestation regressions (see the Table 1A in Blackman 2013).

I define all the properties that are farther than 80 km from the soybean unloading facility as the control group while the properties within 80 km from the soybean unloading facility are defined as the treatment group. Figure 3 shows scatter plots of each property's percentage of deforestation by distance to the soybean unloading facility from 2001 to 2004. On average, the properties that are more than 80 km away from the soybean unloading facility have lower deforestation rates than those that are closer than 80 km throughout all years. The pattern of deforestation in the figure shows that there had been an increased deforestation in the properties that are closer to the port since 2003, when the port facility opened in the region. Note in particular that the rate of deforestation did not change much after 2003 for the properties that are more than 80 km away from the soybean unloading facility. To check the sensitivity of the results, I change the threshold value of 80 km to values from 60 km to 100 km.

The statistics of each group using the 80 km threshold indicate that both groups have similar land quality, yet treatment group properties are located nearer from major roads. Table 1 shows the comparison of the mean of each variable used between control and treatment groups as defined by the distance to the soybean unloading facility. The properties in the treatment group are less than half distance away from the soybean unloading facility and have higher average deforestation rates by 2.2% compared to the properties in the control group. Both groups are less than 8 km away from a major federal and state roads, while the properties in the control group are located farther from them. The land quality is similar for both of the groups with the average difference of 0.6.

Impact of the Port Opening on Deforestation

I use the difference-in-differences (DID) regression method to evaluate the impact of the port opening on deforestation because it can eliminate time-invariant characteristics that affect both control and treatment groups by double differencing. Instead of dividing the period to two periods of before and after the port facility opening, I estimate the DID estimator in each year to estimate the effect of the port facility opening on deforestation in each specific year. I estimate the following regression (Imbens and Wooldridge 2009).

$$Y_{it} = \alpha_i + \sum_{t=2002}^{2010} \beta_t T_t + \gamma G_i + \sum_{t=2002}^{2010} \tau_{DIDt} T_t G_i + \delta X_i + u_{it} \tag{2}$$

where T_t is a vector of time dummy variable from the year 2002 to 2010, which is equal to one when t is the corresponding year; G_i is a group dummy variable equal to 1 if the property *i* is in a treatment group and 0 otherwise; X_i is a set of physical characteristic variables, including distance to federal and state roads and soil quality, which affect the deforestation rate; and u_{it} is an error term that is assumed to be independent of both *T* and *G*.

The main parameter of interest is the set of τ_{DIDt} coefficients, which indicate the difference in deforestation rates between the control ($G_i=0$) and treatment groups ($G_i=1$) in a given year *t* ($T_t=1$); they indicate the marginal effect of the port opening on deforestation in a given year *t*. I expect the value of τ_{DIDt} for the years in or immediately after 2003 (i.e., $t=2003$ and $t=2004$) to be positive and significant, indicating that the opening of the port facility increased deforestation. A vector of coefficients, β_t, represent the year-specific effects on deforestation for the control group.

Projected Land Use Land Cover (LULC) Map

The LULC map is projected under the scenario that the new soybean export facility did not open in the S&B region. Comparing the projected map and the original map, I evaluate the impact of the port facility opening on tradeoffs between agricultural production and carbon sequestration. The projected LULC map is created firstly by changing the deforestation rates of the treatment group using the estimation results from equation (2). Then deforestation maps for 2003 and 2004 with and without the port facility opening are merged with the LULC map of 2002.

The total area of deforestation that happened as a result of the port facility opening at time period t, $\mathrm{Def}_{\mathrm{t}}^{\mathrm{port}}$, is estimated by multiplying τ_{DIDt} from equation (2) and the total remaining forest cover in all properties. The properties that have high predicted value of deforestation $\widehat{y_{\iota t}}$ from equation (2) for property *i* within the treatment group are reforested until the sum of the total reforested areas reaches the estimated total area of deforestation in a given year *t*.

Tradeoffs Between Agricultural Production and Carbon Sequestration

I calculate the change in the value of agricultural production and carbon sequestration by using the actual and projected LULC maps to quantitatively measure the welfare change of the local people and change in the value of carbon sequestration in the S&B area. Although the opening of the new soybean export facility was not intended to affect the welfare of the farmers in the S&B area, an increased economic incentive as a result of the soybean export facility opening did have an impact on the welfare of farmers. One of the indicators that can serve as a direct measure of welfare change is the change in the value of agricultural production caused by the opening of the new soybean export facility. The change in the amount of carbon sequestration as a result of LULC change after the opening of the soybean export facility is of local and global significance because of its impact on regional and global climate change.

I calculate the per hectare profit of planting soybeans in the S&B area by using crop price data from USDA's ERS, yield data from Instituto Brasileiro de Geografia e Estatistica (IBGE 2014b), and cost data from Huerta and Martin (2002). The estimated profit per hectare from soybean production in 2004 was \$336 given that the soybean price in 2004 was \$288.5 per ton, the average yield of soybeans was 2.7 ton per hectare, and the cost of soybean production was \$443 per hectare. For simplicity, I assume that all farms are identical, including physical characteristics and input levels, given the data limitation. I also assume that farmers grow soybeans in the study area because it is one of the four major crops in terms of hectares planted, and it has a higher value of crop production per hectare than other crops and the planted area has increased in 2004 (IBGE 2014b). Thirdly, I assume that the cost of soybean production is the same across different properties, and that it equals the values estimated in Huerta and Martin (2002), who conducted an analysis of the production cost of soybeans in Brazil. This cost of soybean production includes both variable and fixed costs.

I calculate the change in the amount of above-ground biomass carbon using the current and counterfactual LULC maps and the average storage amount of carbon per hectare for each LULC from Baccini et al. (2012), which is shown in Table 5. I consider changes in biomass under the assumption that the change in the soil organic carbon is zero between current and counterfactual LULC maps. I calculate the change of carbon sequestration by estimating the area change for each classification of LULC going from original to projected LULC to be multiplied by the amount of carbon sequestered per hectare for each LULC classification.

I calculate the lost values of carbon storage and gained value of agricultural production as a result of the port facility opening by using the discount rate and social cost of carbon from the literature. Using the appropriate discount rate, the social cost of carbon is the key element in the benefit/cost analysis and has been the main discussion topic among many economists. I set the social cost of carbon to \$40 per ton of carbon dioxide in 2014 US dollar value (\$32.9 in 2004 US dollars) and set the corresponding constant discount rate to 3% from the Interagency Working Group (IWG) on the Social Cost of Carbon, released in 2013 and updated in 2015 (IWG 2015). These rates are calculated averages based on business as usual and optimistic socio-economic and emission trajectories using three models: the Dynamic Integrated model of Climate and the Economy (DICE) (Nordhaus 2014), the Framework for Uncertainty, Negotiation and Distribution (FUND) (Anthoff and Toll 2013), and the Policy Analysis of the Greenhouse Effect (PAGE) (Hope 2013).

IV. Data

Land Use Land Cover

The deforestation maps from the Brazilian National Institute for Space Research (INPE) between 2001 and 2010 (INPE 2015) are used to calculate the deforestation rates in each property in the study area to be used as the dependent variable for the regression estimations. The actual and counterfactual LULC maps in 2004 are constructed using the LULC map in 1999 from Lu et al. (2013) and INPE's deforested area map from 2001 to 2003 in the S&B area. I use the same six land use classifications as those in Lu et al. (2013), which are forest, savanna, other vegetation (secondary succession and plantation), agro-pasture, impervious surface, and water.

Constructing Variables

The deforestation rate, distance, and land quality variables are calculated using the ArcMap software. The deforestation rate from 2001 to 2010 is calculated as the percentage of deforested area over the remaining forest cover in each property in a given year. The remaining forest cover is used to calculate the deforestation rate to give a relatively higher deforestation rate for the properties with less remaining forest cover. The distances to the soybean unloading facility and to the major road variables are calculated as the shortest Euclidean distance between a point or a line and an edge of a property. The location of the port is identified as a point using spatial coordinates and road shape files downloaded from Brazilian Agricultural Research Corporation (Embrapa 2013). The land quality variable is calculated for each property by using area weighted average of agricultural aptitude in each property. The original data were downloaded from Embrapa (Embrapa 2013). The definition and statistics of each variable used in the model are given in Table 1.

Control and Treatment Groups

The property boundary data of the control and treatment groups come from two sources: SIMLAM system (SEMA 2012), which is the Environmental Registry System (CAR) of the Pará State Environmental Agency (SEMA) and the Responsible Soy Project, which is a joint collaboration between Cargill and The Nature Conservancy (TNC). I downloaded all available property boundaries from CAR. CAR was a voluntary property registration system of the state government before the change in the Forest Code in 2012. Currently, every farmer is required to be registered for the CAR. Although not all properties in the region of S&B have been registered in the system, it is the only publicly available data, which contain 228 properties in the region of S&B. I also use property boundary data from the Responsible Soy project that was started in 2005 by Cargill and TNC to prevent increased deforestation as a result of the soybean export facility opening in the region. Through the project TNC recorded the property boundary of all properties registered with the project to monitor deforestation in each property. Combining all properties in both data sets, the total number of properties is 529.

The area of all properties in the data set does not represent all properties in the S&B region, but it is equivalent to about half of the total area of agricultural establishments in S&B region. The total area of all properties in the data set is 178,273 ha, while the total area of agricultural establishments was 353,840 ha in S&B (IBGE 2006). The properties in the data set might represent a mix of commercial farmers and farmers that are more environmentally conscious. The properties from TNC's data might represent a group of producers that are more commercial as opposed to being subsistent because they are selling their products to Cargill. The properties from the CAR data set might represent a group of producers that are more conscious about the environment. Therefore, the combined data set represents both potentially high deforesting and low deforesting producers.

V. Results

The main question of interest is how the opening of the new soybean export facility has changed deforestation in the S&B area and the resulting impact of LULC change on the value of agricultural production and carbon sequestration. In this section, I first present the results from two regressions on the impact of the opening of the port facility on deforestation. Then I present estimates of the monetary benefits and costs that have been incurred from the port facility opening.

Evidence from Empirical Models

Tables 2 and 3 using year specific effect and DID regressions, both of which suggest that there was a positive and significant immediate impact of the port facility opening in 2003 on deforestation in 2003 and 2004.

Table 2 from the year specific effect regression shows that there was a large increase in the deforestation rate in 2003 and 2004 after the port opened in 2003. The year alone effects excluding interaction terms' effects in the second column suggest that the year alone effects on deforestation rates during 2003 (8.8%) and 2004 (15.3%) were the highest among all the years. In 2005 the deforestation rate was not significantly high while it becomes significantly high again in 2006 and 2007. The calculated average marginal effect in the third column shows a similar trend, with significantly high deforestation rates in 2003 (5%) and 2004 (12.3%) compared to other years. It is notable that the values of the average marginal effect for the years 2003 and 2004 are more than twice those of any other years. The interaction effect of the year dummies and the distance to soybean unloading facility variable shows that it has negative and significant effect on deforestation, which means that the properties closer to the soybean unloading facility tend to have higher deforestation rates. The land quality variables are not significant in most of the years.

The positive year-specific effects in 2003 and 2004 and the absence of a significantly high effect of year on deforestation in 2005 suggest a deforestation-increasing effect of the port facility opening in 2003. It is likely that farmers increased deforestation in their properties to increase soybean production around the year 2003, when the port facility opened. The lower marginal effects in following years might reflect mixed effects of increased governmental enforcement of environmental regulations and a diminishing impact of the port facility opening as time progresses.

The DID estimation results using control and treatment groups from Table 3 indicate that the opening of the new soybean export facility increased deforestation in the treatment group by 5.5% in 2003 and 11.7% in 2004. Table 3 shows the average marginal effect of port opening on deforestation by comparing control and treatment groups using data between 2001 and 2010. The year specific effects for the control group indicate no significant effects in all years, while the treatment group had higher deforestation rates compared to the control group in 2002-2004, 2006, and 2009. Similar to the results shown in Table 2, the deforestation rates in the treatment group were the highest in 2003 (5.5%) and 2004 (11.7%) and the significant effect of the year disappears in 2005. The effects of physical characteristics also show that closer proximity to a major road and higher land quality are associated with higher deforestation rates.

The high deforestation rates in the treatment group in 2003 and 2004 compared to those in the control group are distinct from any other years between 2002 and 2010. The rates of difference between control and treatment groups in 2003 (5.5%) and 2004 (11.7%) are 89% and 303% higher than the third highest difference in deforestation rates between the control and treatment groups, that for 2006 (2.9%). These significantly high differences in deforestation rates between control and treatment groups, along with no significant difference between them in 2005 is credible evidence of the port facility opening's immediate impact on deforestation. Farmers can continue to produce crops on the land that was already deforested. This makes the opening of the port facility a one-time shock that can increase deforestation during the years immediately following that opening. The results from the DID estimator shows that farmers have adjusted their behaviors to the shock of a new port facility opening by increasing their production area by deforesting their properties during the years 2003 and 2004.

To check the robustness of the results, I change the threshold value that divides properties into control and treatment groups. The results, shown in Table 4, suggest that the change of the value of the threshold variable (distance to the soybean unloading facility) that defines the treatment and control groups does not affect the positive and significant impact of the port opening on deforestation in 2003 and 2004. The magnitude of the coefficient changes slightly, but there is not much variation in the coefficients of the impacts of the port facility both in 2003 and 2004 as the threshold value changes. The change of the threshold by 5 km from between 70 km and 90 km changes the values less than 10% from 5.2% to 5.6% and 11.1% to 11.8% for the impacts in 2003 and 2004, respectively. Further change in the values down to 60 km or up to 100 km changes the value a little more than the changes within the 70 km to 90 km range, but the values are still less than 20% of the values from the middle value at the 80 km threshold. This means that the impact of the port opening on deforestation is robust to changes in the threshold value.

Change in LULC

Using the regression results from the empirical models, I predict the amount of forest land that would exist in the counter-factual case that the port was never built. The total area of forest in the treatment group was 99,010 ha and 93,594 ha in 2003 and in 2004, respectively. The area that was deforested as a result of the port facility opening is 16,369 ha calculated by the sum of 5.5% (5,421 ha) of the total forested areas in 2003 and to 11.7% (10,948 ha) of those in 2004. I reforest those deforested areas in each property until the sum of the predicted area of deforestation becomes 16,369 ha. The counter-factual case map in 2003 and 2004 are combined with the LULC map of 1999 along with deforested areas in 2001 and 2002 to construct an original map with the port facility opening and a counter-factual map without it. Figure 4 shows an example areas from original and counter-factual LULC maps.

The conversion reveals that total area of 8,359 ha, which is composed of 5,874 ha of primary forest and 2,486 ha of secondary forest, had been converted to Agropasture area as a result of the port facility opening. Table 5 shows calculated areas of each LULC map between original map and projected LULC map without the port facility opening.

Tradeoffs Between Agricultural Production and Carbon Sequestration

The comparison of the values between agricultural production and carbon sequestration using the social cost of carbon and the profit values from the literature shows that the value of carbon sequestration is equivalent to the increased value of agricultural production within the deforested area as a result of port facility opening.

The comparison between the total increased value of agricultural production and the value of released carbon differs depending on the discount rate that is used. Table 6 shows how agricultural production and carbon values compare to each other using a 3% discount rate. The per year profit from soybean production is $335.95/ha. Assuming an infinite stream of benefits using the discount rate of 3% makes the profit from soybean production $11,198/ha. Multiplying the total area converted to agropasture and the infinite stream of profit per hectare yields a total gained value of agricultural production of $93,606,868. The table also shows that 770,438 tons of carbon had been lost due to the conversion from forest and other vegetation to agropasture land after the port facility opening. Using 3% discount rate, a social cost of carbon in 2015 from the IWG estimate is $120.8 per ton of carbon in 2004 US dollars ($32.9 per ton of carbon dioxide). Using this value makes the total lost value of carbon $122,369,979, which makes the dollar value of released carbon greater than the gained value of agricultural production.

Using a 5% discount rate makes the value of agricultural production higher than the value of carbon. Using a 5% discount rate changes the infinite stream of gained value of agricultural production to $56,164,121, while social cost of carbon changes to $36.2 per ton of carbon in 2004 US dollars using the estimates by IWG. This makes the lost value of carbon $36,710,994, which is lower than the gained value of agricultural production ($56,164,121).

The break-even price of carbon that can compensate farmers for their loss of agricultural production under an infinite stream of profit would be $92.4 and $55.4 per ton of carbon, assuming 3% and 5% discount rates, respectively. This is the price that would have had to have been paid to farmers to preserve the carbon storage in the study area. This shows that the current social cost of per ton of carbon estimates from IWG ($120.8) is higher when using the 3% discount rate while it ($36.2) is lower when using the 5% discount rate in 2004 US dollars. The current social cost of carbon may not outweigh the lost value of agricultural production, depending on the discount rate used in the northern Brazilian

Amazon. The high cost of carbon in the Amazon area is consistent with other recent studies, which indicate a high value of carbon in the Amazon (Johnston et al. 2014; O'Connell et al. 2015).

The quantitative estimates of agricultural production and carbon values provide information on the increased income of farmers and on the lost value of carbon due to increased agricultural production within the deforested area. The results showed that the values are comparable to each other and that the break-even price of carbon is lower than the estimated social cost of carbon at a 3% discounting rate but higher than that at a 5% discount rate. These results imply that the net benefit of expanding soybean production in the Amazon is close to the value of released carbon, and one would have to pay the break-even prices that are comparable to the social cost of carbon estimates from IWG to keep farmers from clearing land if we were to preserve carbon.

VI. Discussion

Land use planning requires estimation of the impacts of alternative land uses and the resulting tradeoffs among different ecosystem services to be able to find the best land use that maximizes net benefits from conservation and development. In this paper, I measured the impact of the opening of a new soybean export facility on deforestation and resulting tradeoffs between agricultural production and carbon sequestration in the S&B region, located in the northern Brazilian Amazon.

The results showed that the opening of the new soybean export facility increased average deforestation rates by 5.5% and 11.7% in 2003 and 2004, respectively, which implies a 16,369 ha conversion of forest land into agricultural land. It increased the income of local farmers from additional agricultural profit but released significant amounts of carbon into the atmosphere. Overall, the increased value in agricultural production is approximately equal to the lost value of carbon, although the comparison between them varies depending on the discount rate used for the calculation. The break-even price of carbon for farmers to forgo their agricultural profit in the study area is estimated to be $92.4 and $55.4 per ton of carbon, assuming 3% and 5% discount rates, respectively.

These quantitative estimates of the change in deforestation rates and of the tradeoff values between agricultural production and carbon sequestration provide useful information about whether the impact of the new soybean export facility opening in the S&B area has increased net value. The study estimated how much welfare, represented in terms of total profit, has been generated for the local people and how much carbon value has been lost. The increased welfare for the local people that is roughly equivalent to the value of lost carbon might be an evidence to support the opening of the port facility given high poverty rates in the area. The poverty rates were 43.1% and 28.4% in 2003 in the municipalities of Santerém and Belterra, respectively (IBGE 2006). Even though the net benefit from the opening of the port facility is close zero, the opening of the port facility may be justified because it provided an additional income source for the local poor people.

On the other hand, an argument against the opening of the port facility can be made because of the significant volume of lost carbon that has the value equivalent to the value of increased agricultural production. Carbon sequestration is a global public good that affects everyone. IWG estimated the social cost of carbon using various economic and biophysical models, but the full impact of climate change due to the release of carbon is still unknown. Also, considering other ecosystem services that could worsen because of increased agricultural production in this area, such as water quality, will likely increase the lost values. There are many water springs and streams in this region, which have been affected by increased agricultural production. These additional considerations of other ecosystem services will likely make the lost value of ecosystem services outweigh the increased value of agricultural production. In that case, the net value of ecosystem services from opening of the port facility will be largely negative and it would be in the society's best interest not to open the port facility.

If we assume that the port facility needs to be built in the area to generate additional income opportunities for the poor local people, society would want to maximize net benefits from ecosystem services including agricultural production, carbon sequestration, and others such as water purification. An efficient land use planning that maximizes the net value of ecosystem services prior to the opening of the port facility would require more spatially explicit information. This study was restricted to do the analysis at a municipality level because the information on carbon storage and agricultural production such as the price of crops, yields, and production costs are based on simple assumptions and are not spatially explicit. Further, detailed data on actual carbon storage per pixel by LULC in this region, variation of yields, and costs of producing different crops would make it possible to plan land use in a way that maximizes the net values of ecosystem services. It will identify areas with high values of ecosystem services and enable targeted development and conservation strategies for efficient use of land.

With increasing concerns for degrading the environment and its impact on ecosystem services, it is becoming even more important to quantitatively measure the impact of economic development on values of ecosystem services to reflect them in the future land use decisions. Despite some caveats such as coarse spatial resolution of the data, this study shows how one can measure the impact of new economic incentives on the environment and measures the resulting tradeoff values between carbon and agricultural production. This type of impact assessment and quantification of tradeoffs would be helpful for similar land use planning decisions in the Amazon. It will ultimately help in generating higher net gains from new land use decisions by applying/modifying methods presented in this study and by using spatially explicit data during the planning process.

References

Anthoff, D. and R.S.J. Tol. 2013. The Uncertainty about the Social Cost of Carbon: A Decomposition Analysis Using FUND. Climatic Change 117(3): 515-530.

Baccini, A., Goetz, S. J., Walker, W. S., Laporte, N. T., Sun, M., Sulla-Menashe, D., Hackler, J., Beck, P. S. A., Dubayah, R., Friedl, M. A., Samanta, S., and Houghton, R. A. 2012 Estimated Carbon Dioxide Emissions from Tropical Deforestation Improved by Carbon-Density Maps. Nature Climage Change 2: 182-186.

Balmford, A., A. Bruner, P. Cooper, R. Costanza, S. Farber, R.E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumoer, R. Turner. 2002. Economic Reasons for Conserving Nature. Science 297:950-953.

Blackman, A. 2013. Evaluating Forest Conservation Policies in Developing Countries Using Remote Sensing Data: An Introduction and Practical Guide. Forest Policy and Economics 34: 1-16.

EMBRAPA. 2013. Zoneamento ecológico-econômico (ZEE) da Rodovia BR-163. http://zeebr163.cpatu.embrapa.br/index.php

Fearnside P.M. 2005. Deforestation in Brazilian Amazonia: History, rates, and consequences. Conservation Biology 19:680–688.

Goldstein J, Caldarone G, Duarte T K, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolny S, Daily G C, 2012a, Integrating ecosystem services into land-use planning. Proceedings of the National Academy of Sciences 109: 7565–7570.

Hope, C. 2013. Critical issues for the calculation of the social cost of CO2: why the estimates from PAGE09 are higher than those from PAGE2002. Climatic Change 117(3): 531-543.

Huerta, A.I. and M.A. Martin. 2002. Soybean Production Costs: An Analysis of the United States, Brazil, and Argentina. Selected Paper Presented at the 2002 AAEA Annual Meeting. Long Beach, CA.

IBGE. 2006. CIDADES@, IGBE. http://www.cidades.ibge.gov.br/xtras/home.php?lang=_EN

IBGE. 2014a. Mapa de Pobreza e Desigualdade - Municípios Brasileiros – 2003. http://cidades.ibge.gov.br/

IBGE. 2014b. Municipality agricultural production. http://www.sidra.ibge.gov.br/bda/pesquisas/pam/default.asp?o=18&i=P

Imbens, G.W. and J.M. Wooldridge. 2009. "Recent Developments in the Econometrics of Program Evaluation." Journal of Economic Literature 47:5-86.

INPE. 2015. Projeto PRODES. http://www.obt.inpe.br/prodes/index.php

IWG. 2015. Techinical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis – Under Executive Order 12866. Interagency Working Group on Social Cost of Carbon, United States Government. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf

Johnston, J.A., C.F. Runge, B. Senauer, J. Foley, and S. Polasky. 2014. Global Agriculture and Carbon Trade-offs. Proceedings of the National Academy of Sciences 111(34): 12342-12347.

Koh L.P., J. Ghazoul. 2010. Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. Proceedings of the National Academy of Sciences 107:11140-11144.

Lu, D., G. Li, E. Moran, S. Hetrick. 2013. Spatiotemporal Analysis of Land-Use and Land-Cover Change in the Brazilian Amazon. International Journal of Remote Sensing 34(16): 5953-5978.

Macedo M, DeFries R, Morton D, Stickler C, Galford G, Shimabukuro Y. 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. Proceedings of the National Academy of Sciences 109: 1341–1346

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and Human Well-Being. Island Press, Washington, DC

Nordhaus, W. 2014. Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches. Journal of the Association of Environmental and Resource Economists. 1(1/2): 273-312.

O’Connell, C.S., K. Carlson, S. Cuadra, K. Feeley, J.A. Foley, S. Polasky, P. West. 2015. Tradeoffs in Amazonia between agricultural production and key environmental variables are spatially misaligned and undermine conservation cobenefits. Dissertation Chapter, University of Minnesota

Ramalho Filho, A. and L.C. Pereira. 1995. Sistema de Avaliaçao da Aptidao Agricola das Terras. EMBRAPA, Rio de Janeiro.

Saatchi, S.S., N.L. Harris, S. Brown, M. Lefsky, E.T. Mitchard, W. Salas, B.R. Zutta, W. Buermann, S.L. Lewis, S. Hagen, S. Petrova, L. White, M. Silman, A. Morel. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. Proceeding of National Academy of Science. 108: 9899-9904.

SEMA 2012. Sistema Integrado de Monitoramento e Licenciamento Ambiental. http://monitoramento.sema.pa.gov.br/simlam

Vincent, J.R. 2015. Impact Evaluation of Forest Conservation Programs: Benefit-Cost Analysis, Without the Economics. Environmental and Resource Economics. Published online.

Table 1.Variable descriptions, means, and standard deviations (S.D.)

Variable	Description	Mean (S.D.)		
		Control	Treat	Total
		N=52	N=477	N=529
Deforestation rate in each year between 2001 and 2010 (%)	The percentage of deforested area over remaining forest cover	1.34 (4.84)	3.51 (13.66)	3.30 (13.07)
Distance to the soybean unloading facility (km)	Euclidean distance from a property to Cargill's soybean delivery facility	92.11 (10.86)	41.52 (15.80)	46.49 (21.52)
Distance to a major road (km)	Euclidean distance from a property to the nearest federal or state road	7.53 (8.47)	4.14 (4.98)	4.47 (5.50)
Land quality	Area-weighted land quality based on the classification of Ramalho and Pereira (1995). Scores range from 0 (no production capability) to 7 (most productive soil)	5.75 (1.58)	5.15 (1.91)	5.21 (1.89)

Table 2. Regression results for the year specific effects on deforestation

Variables	Coefficient (Standard error)	Average year specific effects (Standard error)
Average individual fixed effect	0.84*** (0.27)	
Year Specific Effects		
T_{2002}	3.61*** (1.08)	
T_{2002} × Dist. to soy unloading place	-0.04*** (0.01)	0.86** (0.40)
T_{2002} × Land quality	-0.21 (0.18)	
T_{2003}	8.82*** (1.91)	
T_{2003} × Dist. to soy unloading facility	-0.15*** (0.03)	4.96*** (0.65)
T_{2003} × Land quality	0.60 (0.31)	
T_{2004}	15.30*** (2.74)	
T_{2004} × Dist. to soy unloading facility	-0.36*** (0.04)	12.27*** (1.10)
T_{2004} × Land quality	2.65*** (0.49)	
T_{2005}	-0.01 (0.96)	
T_{2005} × Dist. to soy unloading facility	-0.02 (0.02)	1.03** (0.47)
T_{2005} × Land quality	0.34 (0.22)	
T_{2006}	7.49*** (1.95)	
T_{2006} × Dist. to soy unloading facility	-0.09*** (0.02)	2.28*** (0.62)
T_{2006} × Land quality	-0.17 (0.29)	
T_{2007}	3.39** (1.43)	
T_{2007} × Dist. to soy unloading facility	-0.02** (0.01)	0.68 (0.43)
T_{2007} × Land quality	-0.31 (0.21)	
T_{2008}	2.92* (1.53)	
T_{2008} × Dist. to soy unloading facility	-0.04** (0.02)	1.06** (0.46)
T_{2008} × Land quality	0.03 (0.26)	
T_{2009}	2.89*** (1.07)	
T_{2009} × Dist. to soy unloading facility	-0.06*** (0.02)	1.33*** (0.51)
T_{2009} × Land quality	0.27 (0.22)	
T_{2010}	1.55* (0.92)	
T_{2010} × Dist. to soy unloading facility	-0.03*** (0.01)	0.14 (0.36)
T_{2010} × Land quality	0.01 (0.18)	

***, **, and * indicate 1%, 5%, and 10% level of significance, using standard errors adjusted for individual property. Standard errors for the average year specific effects were calculated using the delta method.

Table 3. Average marginal effects of the port opening on deforestation using data from 2001 and 2004

Variables	Equation (2) Coefficient (Standard error)
Treat	-0.06 (0.56)
Year Specific Effects – Control group	
T_{2002}	-0.51 (0.36)
T_{2003}	0.02 (0.52)
T_{2004}	1.72 (1.19)
T_{2005}	1.54 (1.38)
T_{2006}	-0.32 (0.47)
T_{2007}	0.58 (0.82)
T_{2008}	1.11 (0.84)
T_{2009}	-0.31 (0.56)
T_{2010}	-0.35 (0.62)
Year Specific Effects – Treatment group	
T_{2002}	1.52*** (0.57)
T_{2003}	5.48*** (0.90)
T_{2004}	11.70*** (1.76)
T_{2005}	-0.57 (1.47)
T_{2006}	2.90*** (0.83)
T_{2007}	0.12 (0.94)
T_{2008}	-0.06 (0.98)
T_{2009}	1.83** (0.80)
T_{2010}	0.55 (0.73)
Physical Characteristics (X_i)	
Distance to a major road	-0.07*** (0.03)
Land quality	0.58*** (0.10)

***, **, and * indicate 1%, 5%, and 10% level of significance, respectively. Standard errors are calculated using the delta method.

Table 4. The sensitivity of the port facility opening effect by different distance threshold that is used to distinguish control and treatment groups

	Port Facility Opening Effect – treatment group	
Distance to the soybean delivery facility (km)	T_{2003}	T_{2004}
60	6.06***	14.13***
	(1.02)	(1.79)
65	5.07***	12.49***
	(1.01)	(1.88)
70	5.19***	11.80***
	(1.02)	(1.97)
75	5.55***	11.21***
	(1.06)	(2.21)
80	5.48***	11.70***
	(0.90)	(1.76)
85	5.16***	11.65***
	(1.07)	(2.16)
90	5.58***	11.11***
	(1.26)	(2.74)
95	5.08***	12.18***
	(1.49)	(2.07)
100	4.45**	11.37***
	(1.80)	(2.46)

Table 5. The land use and land cover (LULC) composition in 1999 and change in LULC with and without port facility opening in 2004 and the amount of carbon storage in each land use and land cover (LULC) classification

LULC	1999	2004	2004 -No port facility	Increase
Agropasture (ha)	82,438	110,843	102,483	-8,359
Forest (ha)	922,569	899,140	905,014	5,874
Impervious Surfaces (ha)	9,207	9,207	9,207	0
Other Vegetation (ha)	167,531	162,622	165,108	2,486
Savanna/Cerrado (ha)	5,149	5,081	5,080	0
Water (ha)	20,870	20,870	20,870	0

Table 6. The amount of carbon sequestration in each land use and land cover (LULC) classification and the value of carbon and soybean production change as a result of port facility opening

LULC	Area (ha)	Carbon Storage[a] (ton/ha)	Total Carbon Storage (ton)	Total Carbon Storage Value[b] ($)	Agricultural Value[c] ($)
Agropasture	8,359	29	242,425		93,606,868
Forest	-5,874	139	-816,478	-122,369,979	
Other Vegetation	-2,486	79	-196,385		

[a] Baccini et al. 2012

[b] Assuming $120.8 per ton of carbon value in 2004 US dollars (IWG 2015)

[c] Assuming $335.95 per hectare of profit from soybean production (Huerta and Martin 2002; IBGE 2015)

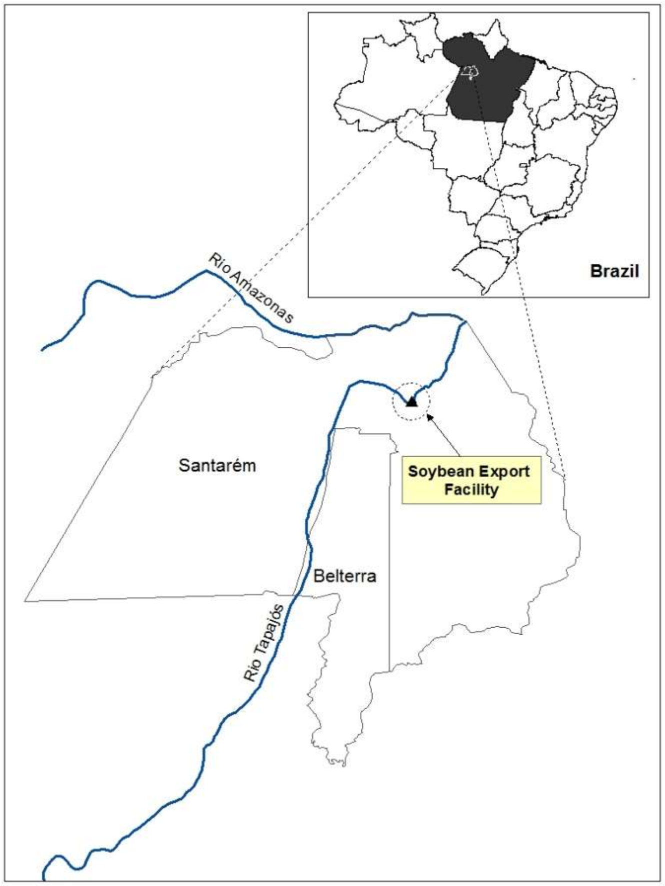
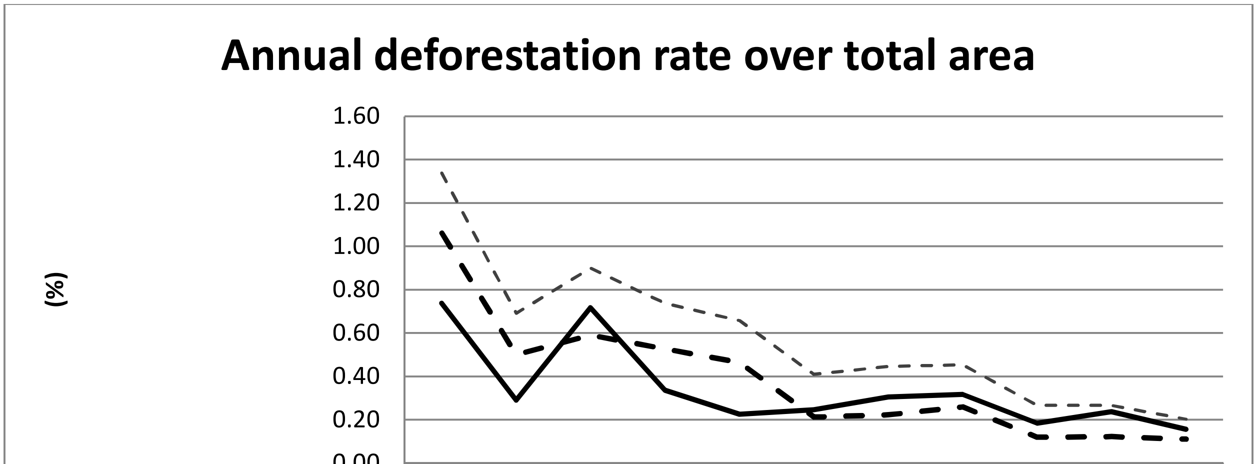


Figure 1. The location of Cargill soybean export facility in Santarém near the confluence of the Amazon and Tapajos Rivers in northern Brazil.



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Amazon	1.06	0.50	0.59	0.53	0.47	0.21	0.22	0.26	0.12	0.12	0.11
Pará	1.34	0.69	0.90	0.74	0.66	0.41	0.45	0.45	0.27	0.27	0.20
S&B and surrounding 10	0.74	0.29	0.72	0.34	0.23	0.25	0.30	0.32	0.18	0.24	0.16

Figure 2. Comparison of the annual percentage of deforested land over the remaining forest area in Amazon, Pará, Santarem and Belterra (S&B) and surrounding 10 municipalities

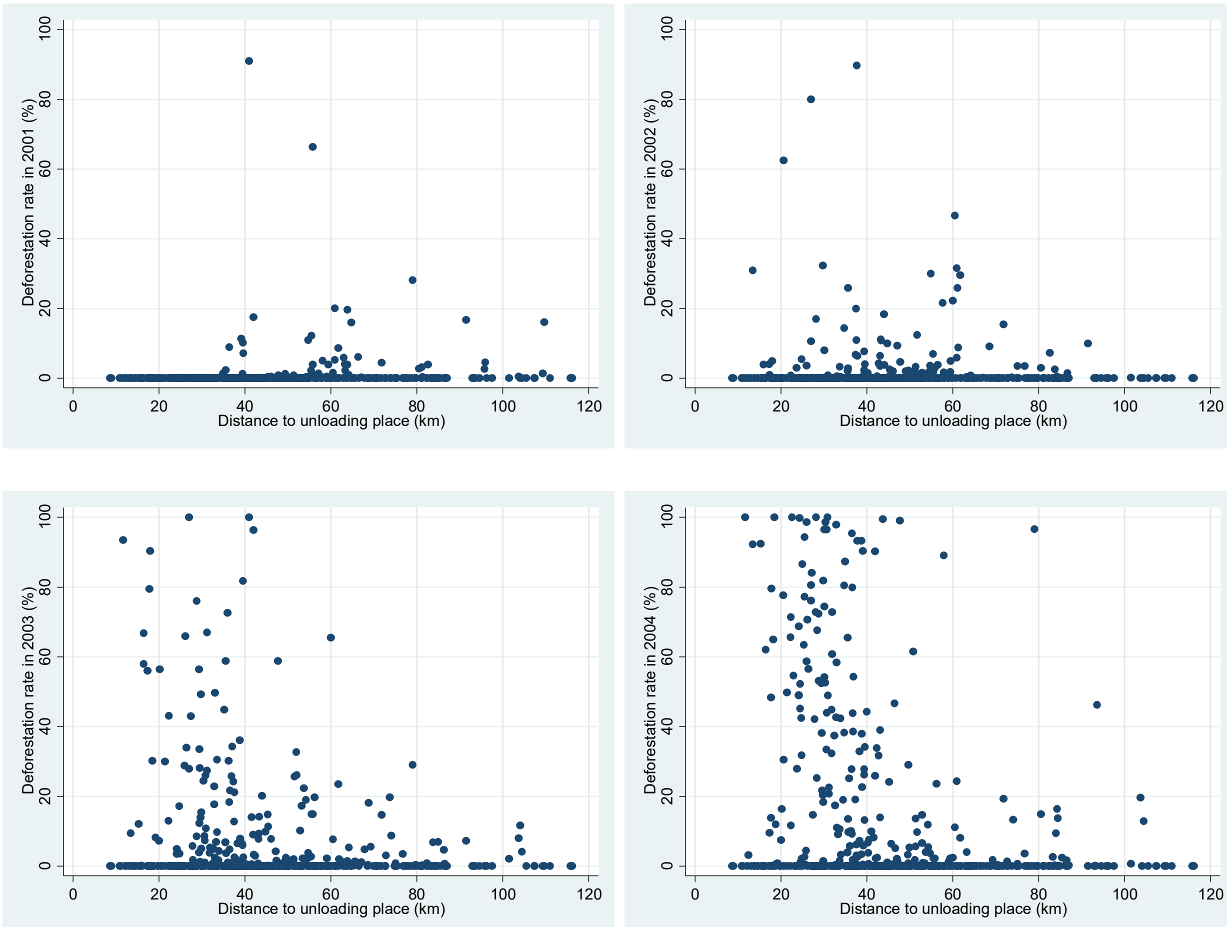


Figure 3. Scatter plots of each property's percentage of deforestation by distance to the soybean unloading place place from 2001 to 2004

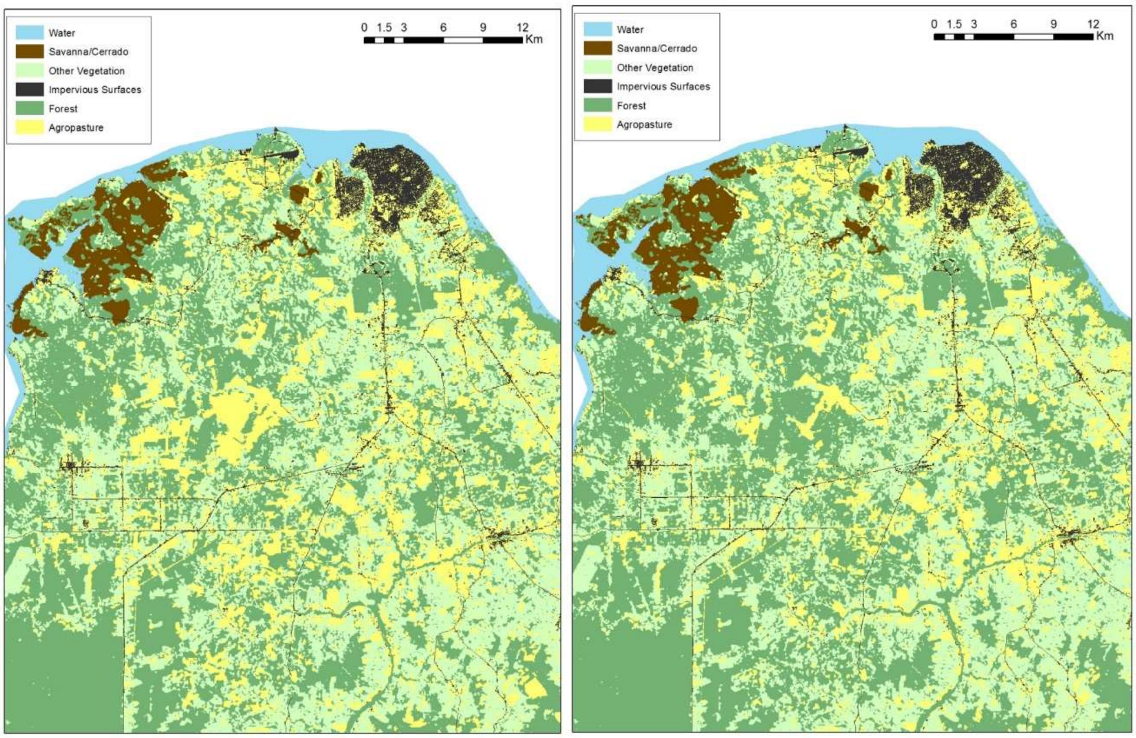


Figure 4. Original LULC (left) and projected LULC without opening of a new soybean export facility in 2004