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PRICES, LAND USE AND DEFORESTATION:

EVIDENCE FROM THE TAPAJÓS BASIN

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Prices, Land Use and Deforestation: Evidence from the Tapajós Basin*

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Abstract

This paper examines the impact of changes in agricultural land use on deforestation at the local level in the Tapajós basin in the Brazilian Amazon. We use exogenous variation in crop to beef relative prices to investigate the effects of pasture to crop conversion on deforestation. Our findings indicate that increases in crop to beef relative prices increase the rate of pasture to crop conversion. The results also indicate that these increases reduce the rate of deforestation. The magnitude of our estimates implies that land conversion reduced deforestation at the local level in 5,300 square kilometers from 2002 to 2012. This represents almost 15% of the deforestation observed in the region during this period. We propose a simple economic model which ties these results to different input-intensities in cattle ranching and crop cultivation.

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1 Introduction

One important feature of the development of the Brazilian agricultural frontier over the last decades is the conversion of pastures into cropland. Existing research indicates that this land use change is associated with substantial intensification of agricultural practices and improvements in socioeconomic indicators (e.g. VanWey et al. (2013) and Bragança, Assunção, and Ferraz (2015)). Nevertheless, there are concerns that pasture to cropland conversion might affect deforestation (e.g. Lapola et al. (2010) and Richards, Walker, and Arima (2014)).

Understanding the environmental consequences of this change in land use is, therefore, important to guide public policies focused in combining economic development and forest conservation in the Tapajós basin. These policies seem of particular significance given the relevance of the region in the expansion of the national food production (e.g. Rada (2013)) and the importance of preserving tropical forests such as the ones which cover more than 80% of its original vegetation (e.g. Stern (2007), Kindermann et al. (2008) and IPCC (2014)).

This paper provides evidence that pasture to cropland conversion generated positive environmental externalities at the local level in the Tapajós basin in the period 2002 to 2012. I use variation in relative crop to beef prices as an exogenous source of variation in the relative return of soy cultivation and cattle ranching to estimate the local effects of land conversion on deforestation. My research design combines time-series variation in prices with cross-sectional variation in initial production to build a local price indexes for soy and beef. This procedure is standard in the economic literature and is based in the intuition that a change in the price of a product is more important in municipalities more specialized in this product's production.[1]

I use the local soy and beef price indexes to construct our the relative price index. The baseline estimates regress deforestation on the relative price index conditional on a set of covariates, fixed effects and state-specific trends. The covariates include the price indexes for each product to control for the effect of the price levels on overall agricultural expansion. This ensures that relative prices are capturing changes in the relative return across different land uses rather the impact of changes in absolute price levels.

The results indicate that a increase in relative soy to beef prices generates an expansion in

[1] See Bartik (1991) for the original application and Goldberg and Pavcnik (2007), Topalova and Khandelwal (2011), Kovak (2013) and David, Dorn, and Hanson (2013) for subsequent applications.

soy cultivation and a reduction in deforestation. My preferred specification suggests that a increase in one hectare in soy cultivation is connected to a decrease in 0.39 hectares in deforestation. The magnitude of this impact is substantial and it implies that the increase in 13,500 square kilometers in soy cultivation saved 5,300 square kilometers of tropical forests in the Tapajós basin alone from the period 2002 to 2012. This represents almost 15% of the observed deforestation in the period. The effect is concentrated in municipalities in the agricultural frontier in which intensive agriculture expanded fast over the past decade without a sizeable reduction on forest coverage.

These estimates are robust to several alternative specifications. The magnitude of the coefficients changes little with the use of alternative price indexes and the addition of alternative covariates. Statistical inference is also robust to different assumptions on the variance of the estimators. Moreover, outliers do not seem to drive the empirical results.

I tie these findings to a simple economic model describing land use. In the model, farmers can either leave their land as forest or use it for two agricultural activities (crop cultivation and cattle ranching). The model assumes that crop cultivation is more intensive in capital (tractors, fertilizers etc.) and labor (agronomists, agricultural technicians, tractor operators etc.) than cattle ranching. This theoretical model predicts that a change in land use can affect deforestation through its effect on input prices. Input prices will increase if land allocation shifts towards the more input-intensive product and decrease if it shifts towards the less input-intensive product. These changes in input prices will affect deforestation as it will influence farmers' choice to clear forests. In particular, an increase in input prices will induce low productivity cattle ranchers out to leave agriculture while a decrease in input prices will induce low productivity cattle ranchers to enter the sector. Deforestation will fall in the former scenario and grow in the latter.

The displacement effect discussed above is important to explain the environmental benefits associated with the expansion of intensive agriculture at the local level. However, it is important to notice that this effect can generate more deforestation elsewhere as suggested in the literature (e.g. Lapola et al. (2010), de Sa, Palmer, and di Falco (2013) and Richards, Walker, and Arima (2014)). Simulations point out that the positive local level environmental externalities identified in this paper mitigate a substantial share of the negative spillover effects discussed in the existing literature. Therefore, this article contributes to the literature providing evidence that changes in land use towards more intensive activities can have positive environmental externalities. This result can have important implications for public policies as taxes and subsidies can be used to generate variation in relative returns across agricultural activities and induce changes in land use.

This evidence is also connected with a growing literature investigating the relationship between agriculture and deforestation. Assunção et al. (2014) provides evidence that electrification also reduced deforestation in Brazil during the period 1960 to 2000. Assunção and Bragança (2015) documents that technological innovations reduced deforestation in Central Brazil during the period 1960 to 1985. These studies also suggest that agricultural intensification is the main mechanism connecting these episodes with mitigation of forest clearing. In their contexts, changes in production possibilities affect farmers' choices and deforestation while, in mine context, changes in relative prices affects these variables.

The evidence from this paper is also related to the literature discussing the impact of prices on deforestation in the Brazilian Amazon (Angelsen and Kaimowitz, 1999; Assunção, Gandour, and Rocha, 2012; Pfaff, 1999). This literature discusses the role of absolute prices for deforestation in the region. I contribute to this literature providing evidence that relative prices matter for deforestation. This paper is also to Roberts and Schlenker (2013) as it highlights that the prices of all agricultural products affect the land allocation for a given product.

The remaining of the paper is organized as follows. Section 2 describes the evolution of occupation and land use in the Tapajós basin over the past decades. Section 3 presents an economic model to guide the empirical analysis. Section 4 describes the data sources and the empirical design used in the empirical estimates. Section 5 reports the main results and several robustness exercises. Section 6 uses the empirical estimates to simulate deforestation in the region in different counterfactual scenarios. Section 7 presents some concluding remarks on the results and their implications.

2 Background

The Tapajós river is an important tributary of the Amazonas River. It is located in the southern Amazon, starting in the municipality of *Juruena* in the state of Mato Grosso and ending in the municipality of *Santarém* in the state of Pará. Its total extension is 810 kilometers and is formed by the union of rivers *Juruena* and *Teles Pires*. According to the Brazilian Statistical Office (IBGE), the river forms a hydrographic basin covering 49 municipalities with an area exceeding 500,000 square kilometers.

The location of the river and its basin is presented in Figure 1. The Tapajós basin covers most of the northern areas of the state of Mato Grosso (57% of its total area) as well as the south-eastern areas of the state of Pará (43% of its total area). The basin includes 40 municipalities in the former state and 9 municipalities in the latter.

This region have increased its economic importance over the decade, becoming an increasingly important area for crop and beef production. The value of the crop production in the Tapajós basin increased from R$ 6.2 billion to R$ 13.7 billion, whereas the number of cattle expanded from 7.2 to 10.9 million heads from 2002 to 2012.

Agricultural expansion have brought concerns regarding environmental degradation in the region. About 80% of the region's area was naturally covered by forests. Around 20% of the original forest cover was cleared until 2002 while 27% of the original forest cover was deforested until 2012. To give an idea of the concerns regarding deforestation in the region, the Tapajós basin includes 7 of the 41 municipalities in which the Brazilian Environmental authorities concentrate anti-deforestation efforts due to their high incidence of forest clearing.

These environmental concerns have increased due to the existence of large infrastructure projects across the region. The Brazilian government is sponsoring the construction of dams as well as the improvement of waterways and roads. These projects have faced substantial opposition from environmental organizations which argue that further occupation and agricultural expansion in the region might generate further degradation in the region. In particular, transportation projects will reduce freight costs and stimulate agricultural activities in the Tapajós basin.

Changes in land use that lead to agricultural intensification offer an alternative to combine agricultural development and forest protection in the region. Therefore, it is important to understand whether changes in land use affect deforestation in order to guide policies aimed at limiting environmental degradation in the region. The region's recent experience seems to be relevant to this evaluation given the extent of pasture to cropland conversion observed in the region over the last decades.

3 Economic Model

Suppose there is a continuum of land owners of mass 1. Each land owner is indexed by i and hold a plot of size 1. A plot can be used either for cattle ranching (beef production) or crop cultivation (soy production). It can also be left idle in which case it remains as forest area. Land owners are heterogeneous and are characterized by a productivity parameter A_i. This parameter is a function of the land owner competence and the geographic characteristics of the plot. We assume that A_i is distributed according to $G(.)$ in the support $[0, \infty]$.

The return of cattle ranching is A_i, while the return of crop cultivation are ΔA_i. The parameter Δ captures differences in return across the two activities. We assume that $\Delta > 1$. Let the price of beef be P_b and the price of soy be P_s. Land revenues are under the different land use are either $P_b A_i$ or $\Delta P_s A_i$.

Costs to use the plot are different in cattle ranching and in crop cultivation. We assume it costs l_b units of labor and k_b units of capital to use a plot as pasture and $l_s > l_b$ units of labor and $k_s > k_b$ units of capital to use it as cropland. Empirical evidence supports these assumptions and indicates that crop cultivation is more intensive in inputs than cattle ranching in the Brazilian agricultural frontier (Assunção and Bragança, 2015).

Combining revenues and costs, we obtain the following profit functions under cattle ranching and crop cultivation:

$$\pi_b(A_i) = P_b A_i - w l_b - r k_b \tag{1}$$

$$\pi_s(A_i) = \Delta P_s A_i - w l_s - r k_s \tag{2}$$

Farmers choose their plot's land use comparing profits across different activities. Land will remain idle whenever $\pi_b(A_i) < 0$ and $\pi_s(A_i) < 0$. A plot will be used as pasture when $\pi_b(A_i) > 0$ and $\pi_b(A_i) > \pi_s(A_i)$. It will be used as cropland when $\pi_s(A_i) > 0$ and $\pi_s(A_i) \geq \pi_b(A_i)$.

These inequalities can be combined to determine the sorting pattern of different farmers under different prices and parameter values. Assume that $1 < \Delta(P_s/P_b) < (w l_s - r k_s)/(w l_b - r k_b)$. This assumption states that revenues in crop cultivation are higher than in cattle ranching. But this difference in revenues is not sufficient to compensate for differences in costs across all farmers. These conditions enable me to characterize land use choices in the following proposition.

Proposition 1. *Farmer's optimal land use choices can be summarized using the following conditions:*

1. *Farmers will leave land idle when $A_i < \underline{A}$;*
2. *Farmers will use land as pasture $\underline{A} \leq A_i < \overline{A}$;*

3. *Farmers will use land as pasture* $A_i \geq \overline{A}$,

in which $\underline{A} = (wl_b - rk_b)/P_b$ *and* $\overline{A} = (w(l_s - l_b) - r(k_s - k_b))/(\Delta P_s - P_b)$.

Proof. See the appendix. ■

Figure 2 provides a graphical illustration of the results from proposition 1. Cattle ranching profits are depicted by the green line whereas crop cultivation profits are depicted by the dark green line. Profits increase as farmers become more productive. The intersection between cattle ranching profits and the horizontal axis determines the threshold $\underline{A}$ above which cattle ranching is profitable. Notice that at this point profits in cattle ranching are higher than profits in crop cultivation.[2] This situation persists until the intersection between the cattle ranching and crop cultivation profits. This intersection determines the threshold $\overline{A}$ above which crop cultivation is more profitable than cattle ranching. The thresholds $\underline{A}$ and $\overline{A}$ characterize the farmers' choices. Individuals with low productivity (below $\underline{A}$) will leave their land idle, individuals with intermediate productivity (above $\underline{A}$ and below $\overline{A}$) will use their plots as pastures and individuals with high productivity (above $\overline{A}$) will use their plots as cropland.

Proposition 1 enables us to define the equilibrium share of forests ($A_f = G(\underline{A})$), pastures ($A_b = G(\overline{A}) - G(\underline{A})$) and cropland ($A_s = 1 - G(\overline{A})$). These equilibrium shares determine the demand for labor and capital in the agricultural sector:

$$D_l(w) = l_s A_s + l_b A_b \text{ and } D_k(r) = k_s A_s + k_b A_b$$

Factor prices are determined combining the demand curves above with the local supplies of labor and capital. We assume that there is spatial segmentation across municipalities. Segmentation reflects the existence of moving costs or information asymmetries in the financial sector. Supply curves will be positively related to factor prices under this assumption. Let labor supply be $S_l(w)$ (with $S_l'(w) > 0$) and the capital supply be $S_k(r)$ (with $S_k'(r) > 0$). Market clearing implies:

$$D_l(w) = S_l(w) \text{ and } D_k(r) = S_k(r) \tag{3}$$

The competitive equilibrium in the model is the set (A_f, A_b, A_s, w, r) such that land use is optimal and Equation (3) holds.

[2] The assumption $1 < \Delta(P_s/P_b) < (wl_s - rk_s)/(wl_b - rk_b)$ ensures that cattle ranching becomes profitable before crop cultivation.

Proposition 2. *An increase in the relative crop to beef price induces pasture to cropland conversion (A_s increases and A_b decreases) and reduces deforestation (A_f increase).*

Proof. See the appendix. ■

Figure 3 presents the intuition of proposition 2. Dashed lines represent profit curves in the initial situation whereas solid lines represent profit curves after the increase in relative prices. An increase in the relative price makes the profit curve for crop cultivation steeper. This induces farmers to convert pastures into cropland and increases the total demand for labor and capital and their respective equilibrium prices. These price increases shift profit curves for both cattle ranching and crop cultivation down. The downward shift in cropland profits reduces the incentives that farmers have to convert pastures into cropland. However, in equilibrium, some farmers will still be induced to convert their pastures into cropland and the threshold $\overline{A}$ will fall. In addition, the downward shift in cattle ranching profits will induce some farmers to stop ranching and leave their land idle and the threshold $\underline{A}$ will increase. These changes in the sorting behaviour across agricultural activities lead to increases in cropland (A_s) and forests (A_f) and decreases in pastures (A_b).

Proposition 2 indicates that factor prices are important to understand the effects of cropland expansion on deforestation. Pasture to crop conversion requires more labor, machines, fertilizers and other specialized inputs. Thus, it increases these input demands and prices to the extent that there is some spatial segmentation across municipalities. These increases in input prices will force out business farmers with low A_i. The model provides a rationale for the displacement effects studied elsewhere in the literature. These displacement effects can have important consequences for deforestation in other localities (Lapola et al., 2010; Richards, Walker, and Arima, 2014). But these effects can also influence deforestation at the local level which must be considered when evaluating the environmental effects of cropland expansion.

4 Data and Empirical Design

4.1 Data Sources

The main outcome used throughout the empirical analysis is the deforestation rate. Deforestation data comes from satellite images processed in the realm of the Project for

Monitoring Deforestation in the Brazilian Amazon (*PRODES - Projeto de Monitoramento do Desmatamento da Amazônia Legal*). PRODES' team treats the raw satellite images to spot deforested areas located throughout the Brazilian Amazon. Images are compared across periods to determine which areas have been cleared in a given period. These areas are added to produce municipal level measures of deforestation covering all municipalities of the region. PRODES coverage is affected by the presence of clouds and non-observed areas.

I use deforestation data covering the period 2002 to 2012 across the 49 municipalities located in the Tapajós basin. Deforestation in year t is the total forest area cleared from August 1 in year $t-1$ to July 31 in year t. I divide the total deforestation by the municipal area to calculate the share of the municipal area cleared in a given period. This is the main dependent variable used in the paper. Other variables from the PRODES dataset are used as controls in some specifications. These variables are initial forest area, non-observed areas and cloud presence.

In order to examine the effect of relative prices on deforestation, I also construct local price indexes for the main agricultural products in the region (soy and beef). Each price index is constructed combining price information P_{ot} of the product o in period t with the initial production S_{os} of this product in municipality m:

$$p_{mot} = \mathrm{P}_{ot}\mathrm{S}_{mo}$$

in which p_{mot} is the price index for each product (b for beef and s for soy). In the baseline specification, I define S as the ratio between the number of cattle and the municipal area for the case of beef and the ratio between the soy area and the municipal area. I use data from 2000-2001 to define these measures of initial production. These price indexes are combined to produce the relative crop to beef price index P_{mt} which is the main independent variable in the empirical exercises. This variable is defined as:

$$P_{mt} = \frac{p_{mst}}{p_{mbt}}$$

In the baseline analysis, all price indexes are standardized (mean equal to zero and variance equal to one). I provide evidence that our results are robust to functional form. Data on agricultural prices comes from the *Secretaria de Agricultura do Paraná* which collects monthly prices of several agricultural products. Notice that such prices are exogenous to local growing conditions in the Tapajós basin. Data on initial production comes from the *Pesquisa Agrícola Municipal* and the *Pesquisa Pecuária Municipal*. The *Pesquisa Agrícola Municipal* provides yearly information on area, production and production value for all crops and municipalities in Brazil. The *Pesquisa Pecuária Municipal* provides information on the cattle stock across all municipalities in Brazil. Both datasets are collected from the Brazilian Statistical Office (IBGE). I also use these datasets to calculate the change in soy area and the number of cattle between periods. These variables are important to examine whether changes in relative prices are mapped in changes in changes in land use as suggested in the theoretical model.

4.2 Descriptive Statistics

Table 1 reports descriptive statistics for the main dependent variables we use in throughout the paper. Column 1 presents the sample average in 2002 while column 2 depicts the sample average in 2012. Column 3 reports the increase between these periods. Total deforestation grew from 16% to 21.5% of the average municipal area in the period 2002 to 2012. The increase in deforestation was accompanied by increases in total cropland from 6.5% to 11.9% of the average municipal area. This expansion in cropland was driven by expansion in soy and maize cultivation (respectively, from 4.5% to 7.2% and from 0.9% to 3.0% of the average municipal area). The Tapajós basin also experienced an expansion in cattle ranching in the period as the number of cattle per square kilometer grew from 14 to 21 cattle heads. As the *Pesquisa Agrícola Municipal* does not contain information on pastures, it is not possible to know whether this increase in cattle ranching was a result of changes in the intensive or the extensive margin.

Data on prices indicates increases in soy and beef prices in the period. Growth in soy prices was smaller than in beef prices and relative soy to beef prices fall a little. This is the main relative prices measure studied in this paper. Notice that I exclude maize prices in calculating our relative price index despite its importance on total cropland. This is done because most maize cultivated in the region is cultivated in a second growing season (*safrinha*) and its cultivation is more related to soy prices than maize prices. The appendix provides some evidence on this relationship.

Figure 4 presents the variation in prices throughout the whole period to present a more complete picture in price variation. Relative prices increase from 2002 to 2005 and decrease afterwards. From 2005 to 2007, the decline in relative prices is due to a larger drop in soy prices compared to beef prices. From 2008 to 2010, the variation in relative prices is connected to larger increases in beef compared to soy prices. In 2011 and 2012, the evolution in relative prices is related decreases in soy prices and increases in beef prices.

Figure 5 presents the basic correlation between relative prices and deforestation in the data. Increases in relative prices are correlated with decreases in deforestation as suggested in the theoretical model. An increase in one standard deviation in relative prices is associated with a decrease in 18% of a standard deviation in annual deforestation (0.14 square kilometers). Figure 6 reports that increases in relative prices are also correlated with increases in soy cultivation and decreases in the number of cattle. Therefore, the structure of the data seems to indicate that pasture to cropland conversion is associated with lower deforestation. However, it is important to take this evidence with caution since it can be a result of omitted variable bias.

4.3 Empirical Design

To investigate the causal effect of land use on deforestation in the Tapajós basin, the research design uses exogenous variation in prices. The baseline analysis regresses deforestation y on municipality m and period t on the crop to beef relative price index P in the previous period controlling for fixed effects:

$$y_{mt} = \beta P_{mt-1} + \alpha_i + \theta_t + \varepsilon_{mt} \tag{4}$$

The price definition uses initial exposures variables (cropland area and number of cattle) to construct the municipal relative price index. This can create spurious correlation between relative prices and deforestation to the extent that the initial exposure variables can influence changes in y_{mt} over time. I mitigate this concern adding state-specific trends ($\rho_s * t$) and a set of covariates ($\mathbf{X_{mt}}$) as additional controls:

$$y_{mt} = \beta P_{mt-1} + \gamma' \mathbf{X_{mt}} + \alpha_i + \theta_t + \rho_s * t + \varepsilon_{mt} \tag{5}$$

The identification assumption on the equation above is that - conditional on state trends and covariates - changes in deforestation would be similar across municipalities in the *Tapajós* basin in the absence of changes in relative prices. The main covariates in the $\mathbf{X_{mt}}$ matrix are the price levels for crop and beef. These price levels control for the effect of absolute prices on deforestation, enabling me to examine the effect of changes in relative returns across land uses rather than changes in overall agricultural returns. Another important variable included in some specifications is the initial forest area (interacted with time dummies). This covariate controls for differences in the evolution of deforestation that are associated with initial differences in available forest area.

Estimation weights observations using the square root of the municipal area as in Schlenker, Hanemann, and Fisher (2006) and Deschênes and Greenstone (2007). Standard errors are clustered at the municipal level to correct for the existence of serial correlation in our price index (Bertrand, Duflo, and Mullainathan, 2004). I provide evidence that the results are robust to using the municipal area as weights. I also provide evidence that the results are robust to using Conley (1999) standard errors allowing for spatial dependence.

Additional regressions use specifications similar to equation 4 and 5 but using crop cultivation and number of cattle as the dependent variables. Estimation using these dependent variables requires the same identification assumptions discussed above.

5 Main Results

5.1 Relative Prices and Pasture to Crop Conversion

Table 2 reports evidence on the relationship between relative prices and agricultural activities in the Tapajós basin. Columns 1 to 3 depict the impact of relative prices on soy cultivation while columns 4 to 6 depict this impact on the number of cattle. Soy cultivation refers to the change in the share of the municipal area cultivated with soy and number of cattle refers to the the change in the number of cattle per square kilometer.

Column 1 provides evidence that growth in relative soy to beef prices lead to an expansion in soy cultivation. The coefficient is significant at the 10% level (p-*value* 0.09) and its magnitude is substantial. One standard deviation increase in relative prices increase soy cultivation in 0.95% of the total municipal area (about 40% of a standard deviation in the annual change in soy cultivation). Column 1 also shows that absolute soy prices also lead to an expansion in soy cultivation whereas there is no effect of absolute cattle prices on this variable.

Column 2 adds the initial forest area (as percentage of the municipal area) interacted with time dummies as an additional covariate to examine whether the effect from column 1 are connected to initial differences in land use. This is a concern to the extent that initial differences in land use can affect both the local price indexes and the changes in crop cultivation. The results indicate that the relationship between relative prices and soy cultivation is robust to this control. The coefficient on relative prices increases from 0.95 to 1.09 and remains significant at the 10% level (p-*value* 0.08). It is also interesting to notice that the coefficients on absolute prices change much more than the coefficient on relative price suggesting that differential trends is a much more important concern in interpreting these coefficients.

Column 3 further adds state-specific trends to investigate whether differences between the evolution of policies and economic environment in the states of *Mato Grosso* and *Pará* drive the results from the previous columns. Both coefficients and the standard errors change little with the inclusion of this additional covariate. The overall evidence from columns 1 to 3 suggests that farmers react to changes in relative returns shifting agricultural land use. The results indicate that increases in the relative crop to beef return cause shifts from pasture to cropland whereas decreases in the relative crop to beef return lead to cropland to pasture conversion. This pattern is consistent with the theoretical model discussed before.

The impact of relative prices on the number of cattle provide additional evidence on the influence of relative returns on land use. Columns 4 to 6 evaluate the effect of relative prices on the change in the number of cattle per square kilometer. It is important to notice that the changes in the number of cattle are the result of changes in cattle ranching in the intensive and extensive margin. Therefore, this is an imperfect measure to describe land allocation to cattle ranching. We use it as the dependent variable as there is no measure of land allocation to cattle ranching in our data.

Column 4 provides evidence that growth in relative prices lead to a decline in cattle ranching. One standard deviation in relative prices cause a decrease in 1.1 heads per square kilometer (about 30% of an standard deviation in the annual change in the number of cattle). It also provides evidence that higher cattle prices increase the number of cattle while higher soy prices decrease it.

Columns 5 and 6 add the initial forest and state-specific trends as additional controls. The estimates of the impact of relative prices on the number of cattle increase a lot. One standard deviation in relative prices cause a decrease in 2.3 heads per square kilometer (about 60% of an standard deviation in the annual change in the number of cattle). This change in the coefficients suggest differences in trends in the evolution in the number of cattle affected the estimates from the previous column. The overall evidence from columns 4 to 6 suggests that farmers respond to changes in relative prices in a pattern consistent with the theoretical model. There is evidence that increases in the relative crop to beef price displaces cattle ranchers despite the limitations in our cattle ranching data.

5.2 Relative Prices and Deforestation

Table 3 reports the effects of relative crop to beef prices on annual deforestation. I measure annual deforestation as the share of the municipal area cleared in each year. Column 1 reports the results including absolute prices as controls. Column 2 adds the initial forest area interacted with time dummies as an additional covariate. Column 3 adds state-specific trends as controls. Column 4 adds the area with clouds and the areas non-observed as additional controls.

The evidence suggests that growth in relative prices reduces deforestation. Columns 1 and 2 point out that an increase in one standard deviation in relative prices decreases annual deforestation in 0.65% of the municipal area. This effect corresponds to about 40 to 60% of the standard deviation in deforestation. Standard errors are small which results in significant estimates at the usual statistical levels (p-*values* is 0.00 in column 1 and 0.03 in column 2).

Deforestation decreased more in the *Mato Grosso* than in the *Pará* over the period studied in this paper. This differential will bias estimates of the effect of relative prices on deforestation to the extent that states have different initial intensities in crop and beef production. Column 3 accounts for the differences in the evolution in deforestation adding state-specific trends as additional covariates. Point estimates decline in about one third and p-*values* increase with the inclusion of these variables. But the effect remains significant (p-*value* is 0.06) and its magnitude indicates that an increase in one standard deviation in relative prices decreases annual deforestation in 0.43 of the municipal area. This effect corresponds to about 40% of the standard deviation in deforestation. Column 4 adds non-observed areas and cloud coverage as additional controls to mitigate concerns that non-classical measurement error in the dependent variable bias our estimates. The coefficient on relative prices changes little and remains significant.

The overall evidence from Table 3 suggests that increases in the relative return of input-intensive agricultural activities reduce deforestation whereas decreases in this relative return increase deforestation. This pattern is consistent with the theoretical model and indicates that changes in land use can have an important effect on deforestation at the local level in the Tapajós basin.

5.3 Robustness Exercises

The baseline price indexes combine initial information on soy and beef production with price information to produce local price indexes for these agricultural products. The intuition for these indexes is that price changes will affect more municipalities that are more specialized in a particular product.

A potential problem with this price index is that the price index will be zero for all municipalities with no production in the baseline. This is not a problem for the beef price index as there is cattle ranching in all municipalities in all periods. But it is a potential problem for the soy price index as the number of municipalities producing this crop increases in the period. I deal with this issue using initial crop cultivation instead of initial soy cultivation as an alternative to calculate local prices. Table 4 presents the results. Coefficients and standard errors are similar to the ones obtained in Table 3 suggesting that our estimates are robust to alternative price definitions.

Another potential issue with the price index is that it excludes maize prices in its construction. However, the descriptive statistics indicate that maize cultivation is also relevant in the region both in levels and rate of expansion suggesting maize prices might also be relevant in determining relative prices across the Tapajós basin.[3] I deal with this problem incoporating maize prices in the calculation of the relative price index. Table 5 reports the results of regressions re-estimating the main model using a measure of crop prices combining information on both soy and maize prices and initial cultivation to construct the prices indexes. The results are quite similar than the ones in the main analysis in terms both of magnitude and significance of the main coefficients.

These findings indicate that maize and soy expansion are correlated since there are agronomic benefits of rotating land between these crops (Livingston, Roberts, and Rust, 2008). The estimates also corroborate the literature on agricultural expansion in Brazil which suggests that maize cultivation is a product of soy cultivation in the Brazilian agricultural frontier (Assunção and Bragança, 2015).

It is also important to examine whether the estimates are robust to the weighting procedure. The baseline weights are constructed using the idea that the statistical analysis should weight more observations in larger municipalities without enabling larger municipalities to drive the results. Table 6 re-estimates our baseline regressions exploring alternative weighting methods: municipal area (columns 1 to 4) and no weights (columns

[3] See Table 1.

5 to 8).

Coefficients on relative prices are negative across all specifications in Table 6. On the one hand, columns 1 to 4 provide evidence that magnitudes rise when we place greater emphasis in larger municipalities. On the other hand, columns 5 to 8 indicate that magnitudes fall when we place less emphasis in these municipalities. Standard errors are in general small with estimates significant across all specifications. The overall evidence seems to suggest that the evidence is not affected by the choice of the weighting scheme.

A final specification test investigates whether inference is robust to allowing spatial dependence in the error term. Table 7 examines this issue and re-estimates standard errors using the Conley (1999) procedure to allow for spatial correlation of the error term. I report standard errors computed using three different cut-offs: 100 kilometers, 300 kilometers and 500 kilometers. Conley (1999) standard errors are smaller than the baseline standard errors for all distance cut-offs considered and estimates are significant at 5% level. Thus, the baseline estimates use a quite conservative inference procedure.[4]

6 Counterfactuals

To further understand the implications of our findings, I present some counterfactual simulations of the effects of changes in land use on deforestation under different scenarios. In order to produce these counterfactuals, I combine the coefficients of the impact relative prices on land use (Table 2) and deforestation (Table 3) to obtain elasticities describing the effect of land use changes on deforestation.

I use the more saturated specifications to perform the simulations. This provides a conservative measure of the environmental externalities associated with cropland expansion in the Tapajós basin. The results indicate that one standard deviation increase in relative soy to beef prices cause an expansion in soy cultivation of 1.09% of the municipal area a reduction in deforestation of 0.43% of the municipal area. A simple Wald estimator combining these elasticities points out that a change of 1% of the municipal area from pastures to soy cultivation decreases deforestation in 0.39% of the municipal area.

Using this estimate, I calculate the forest area that would have been cleared in the absence of the change in agricultural land use observed in our data. From 2002 to 2012, the soy cultivation increased in 2.6 percentage points from 4.6 to 7.2% of the municipal area. Our

[4] I use the code from Hsiang (2010) to estimate these spatial standard errors in a panel setting.

Wald estimator implies that this decreased deforestation in 1.02% of the municipal area. In absolute terms, the deforestation would have been 5,300 square kilometers larger in the absence of the 13,750 square kilometers expansion in soy cultivation. This represents almost 15% of the 35,900 square kilometers of forests cleared throughout the period 2002 to 2012.

Figures 7 and 8 depict these local level impact of land use changes on deforestation across the 49 municipalities from the Tapajós basin. Figure 7 reports this effect as a percentage of the municipal area, whereas Figure 8 reports it in square kilometers. The simulations point out that the local environmental benefits from the expansion in crop cultivation are concentrated in municipalities such as *Nova Mutum*, *Sorriso*, *Sinop* and *Vera* along the agricultural frontier in central areas of the state of Mato Grosso.

The mechanism discussed in this paper concerns local level effects of cropland expansion on deforestation. There is a growing literature which investigates the spillover effects from cropland expansion in other areas. This literature argues that cattle ranchers that leave a region due to cropland expansion relocate and increase deforestation in other areas. Therefore, evaluating the total impact of cropland expansion on deforestation requires combining the local level effects we estimate in this paper with spillover effects. However, it is difficult to estimate these spillover effects due to the existence of the reflection problem (Manski, 1993). Some researchers even argue that this problem cannot be overcome in the absence of clear exogenous variation (Gibbons and Overman, 2012).

Nevertheless, there are some attempts in the literature to calculate this spillover effect either using simulation or spatial econometrics. While one should be cautious cautious about these calculations, I can use them to compare our direct effect with the indirect effect discussed in the existing literature. Lapola et al. (2010) simulates that an expansion in one square kilometer in cropland in a region generates an expansion in deforestation in about one hectare in other regions. Richards, Walker, and Arima (2014) estimates an indirect effect of cropland expansion on deforestation of 0.45 for a similar period to the one studied in this paper. Our findings thus suggest that the local effect mitigate from 40 to 90% of the negative spillover effect of cropland expansion on deforestation. This further points out to the importance of the effect documented in this article.

7 Conclusion

This paper provides evidence that changes in land use affect deforestation in the Tapajós basin in Brazil. Using exogenous variation in crop to beef relative prices, we estimate that an increase in relative prices generates both conversion of pastures into cropland. We also estimate that these relative prices increases generate a reduction in deforestation. This effect suggests that changes in land use have important consequences for forest conversation in this region.

I use a simple economic model to explain our findings. The model assumes that crop cultivation is more intensive in capital (tractors, fertilizers etc.) and labor (agronomists, agricultural technicians, tractor operators etc.) than cattle ranching. Therefore, input prices will increase if land allocation shifts towards the more input-intensive product and decrease if it shifts towards the less input-intensive product. These changes in input prices will affect deforestation as it will influence farmers' choice to clear forests. In particular, an increase in input prices will induce low productivity cattle ranchers out to leave agriculture while a decrease in input prices will induce low productivity cattle ranchers to enter the sector. Deforestation will fall in the former scenario whereas it will grow in the latter.

The theoretical model and the empirical evidence point out that changes in land use in the direction of input-intensive agriculture (using tractors, fertilizers etc.) have the potential to generate positive local level environmental externalities. It is important to notice that negative general equilibrium effects might overcome these positive local level effects discussed in the paper. However, our paper suggests that policies focused in inducing the adoption of modern inputs have the potential to generate both economic development and protect forests in some circumstances.

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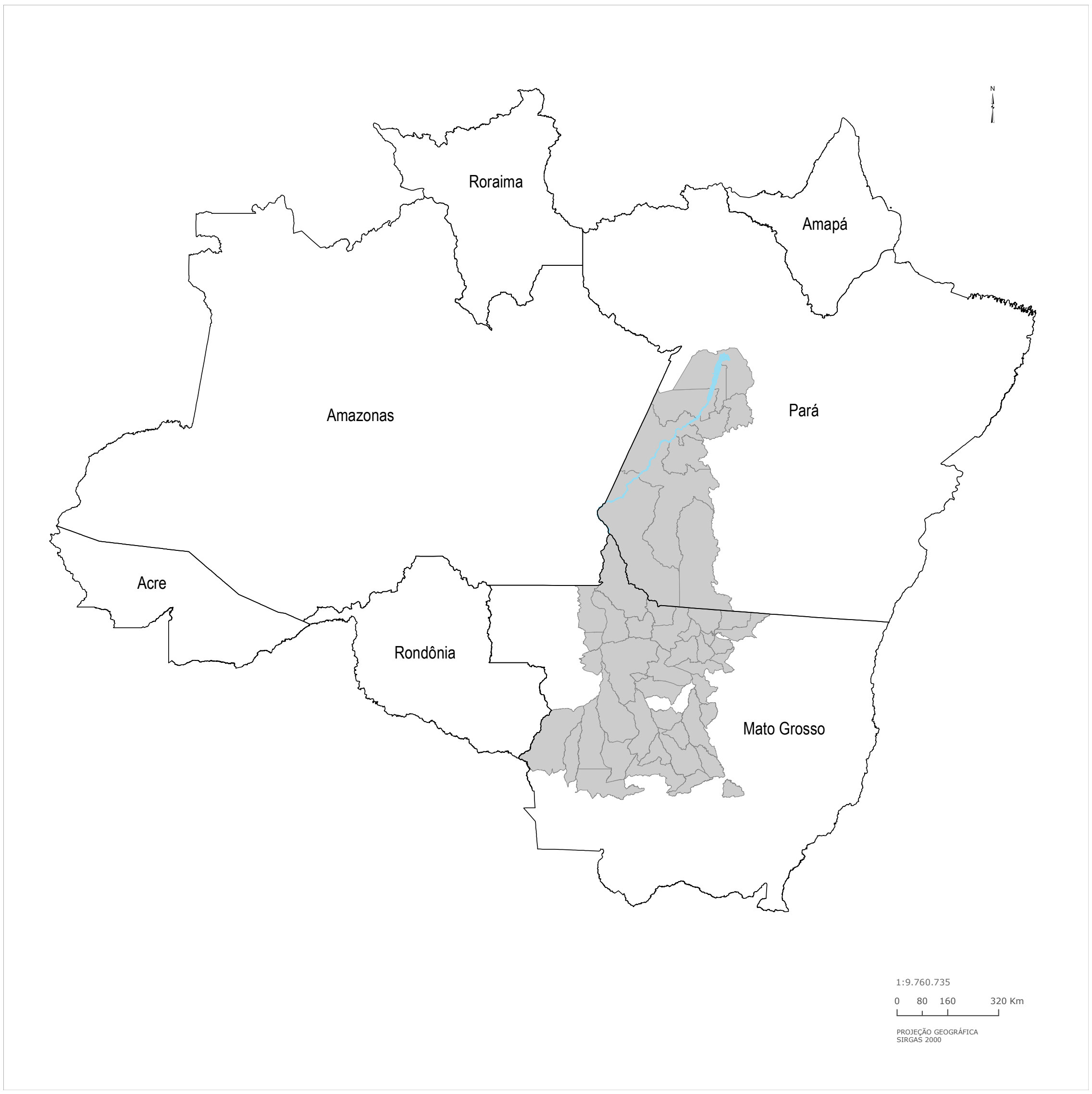

Figure 1: The Tapajós Basin

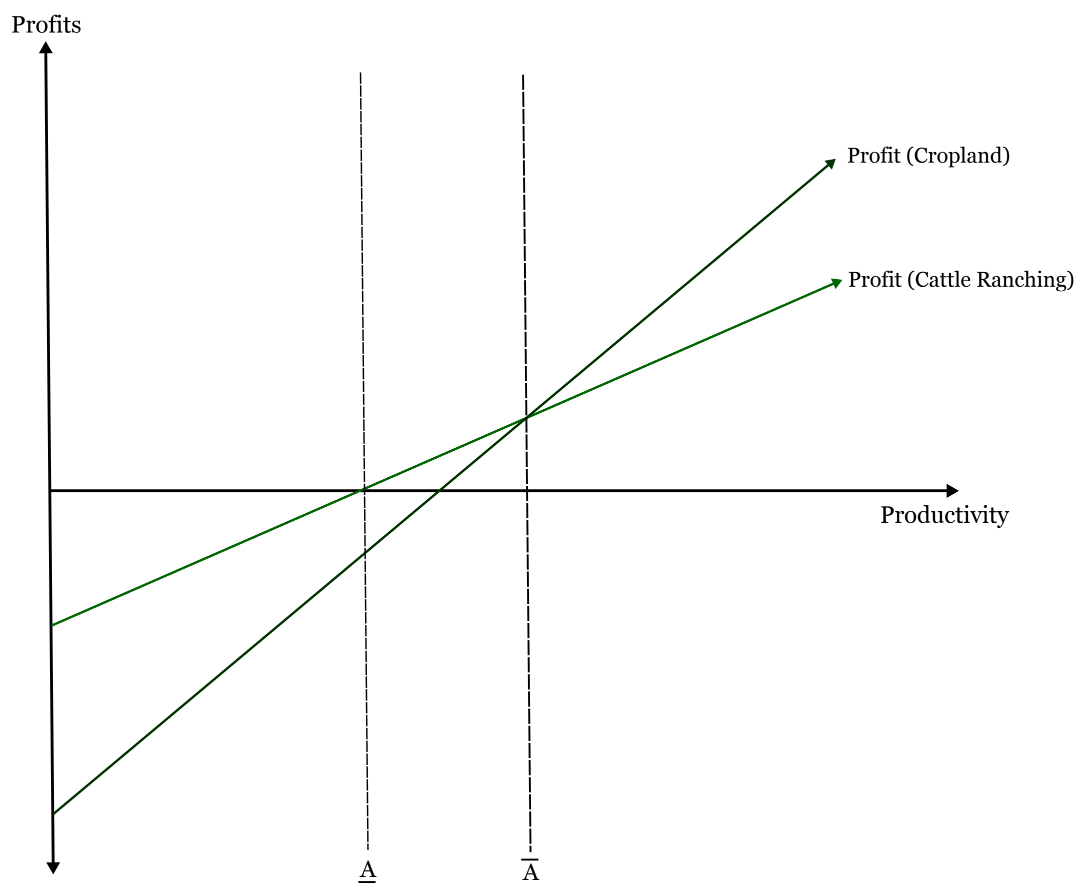

Figure 2: Land Use Choices

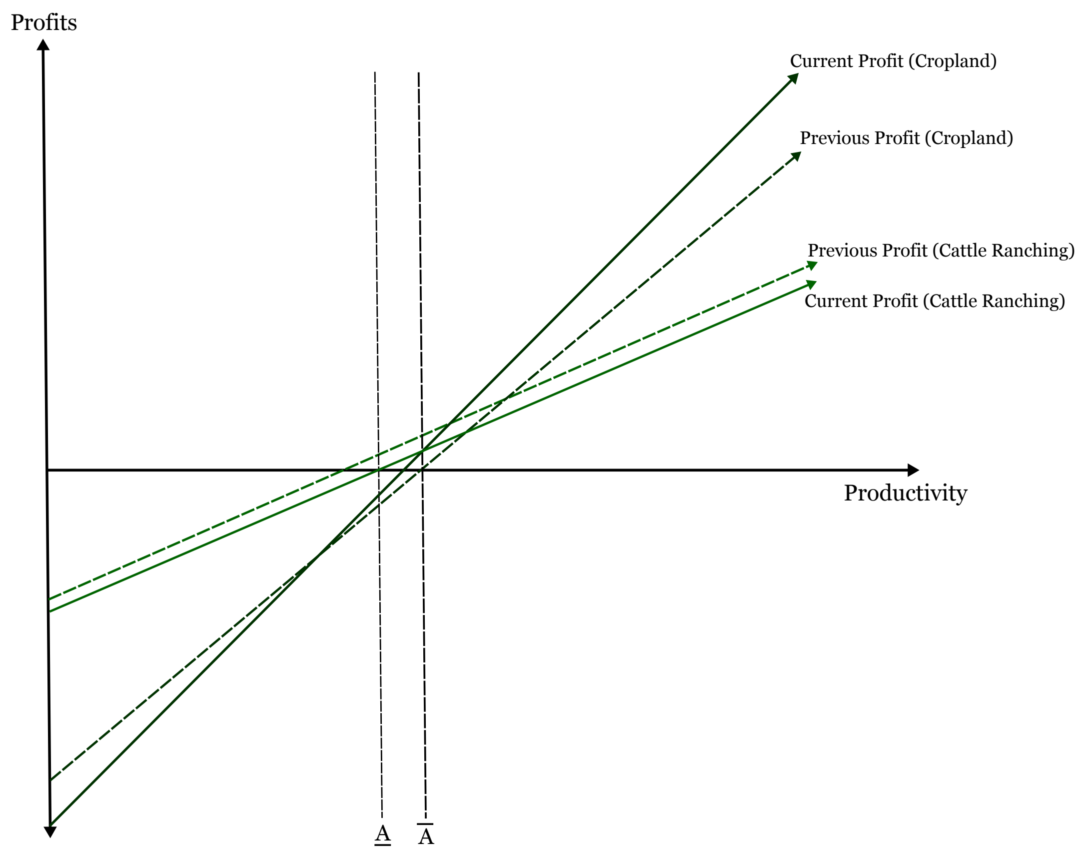

Figure 3: Effects of an Increase in Relative Prices

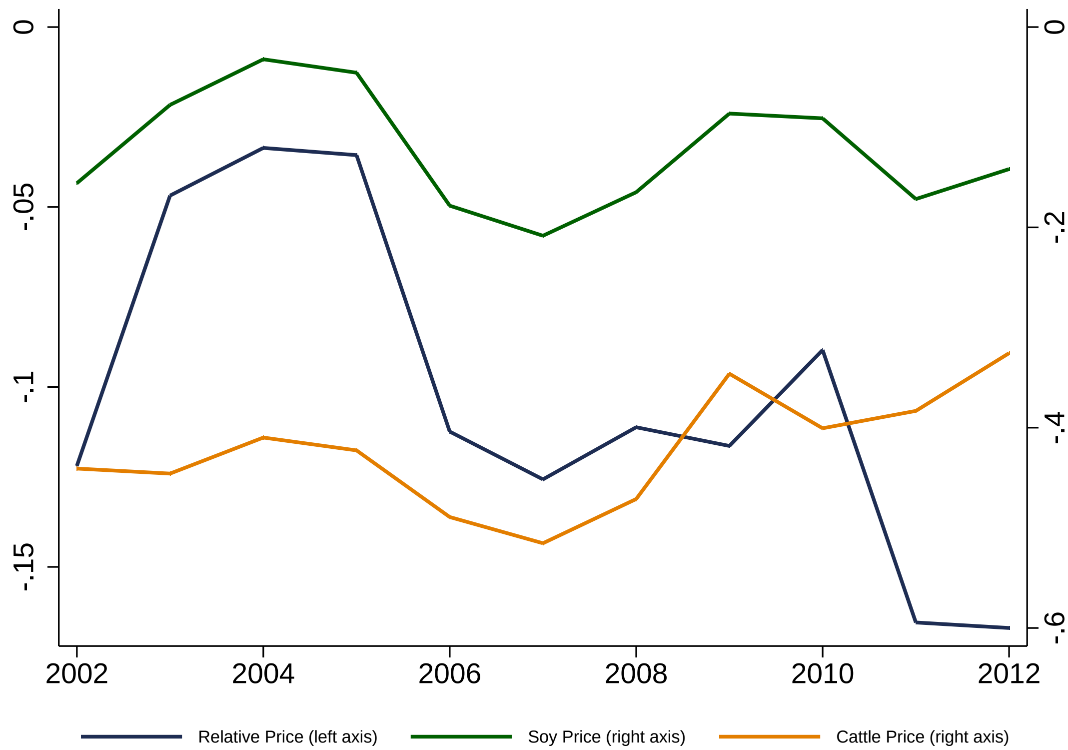

Figure 4: Price Variation

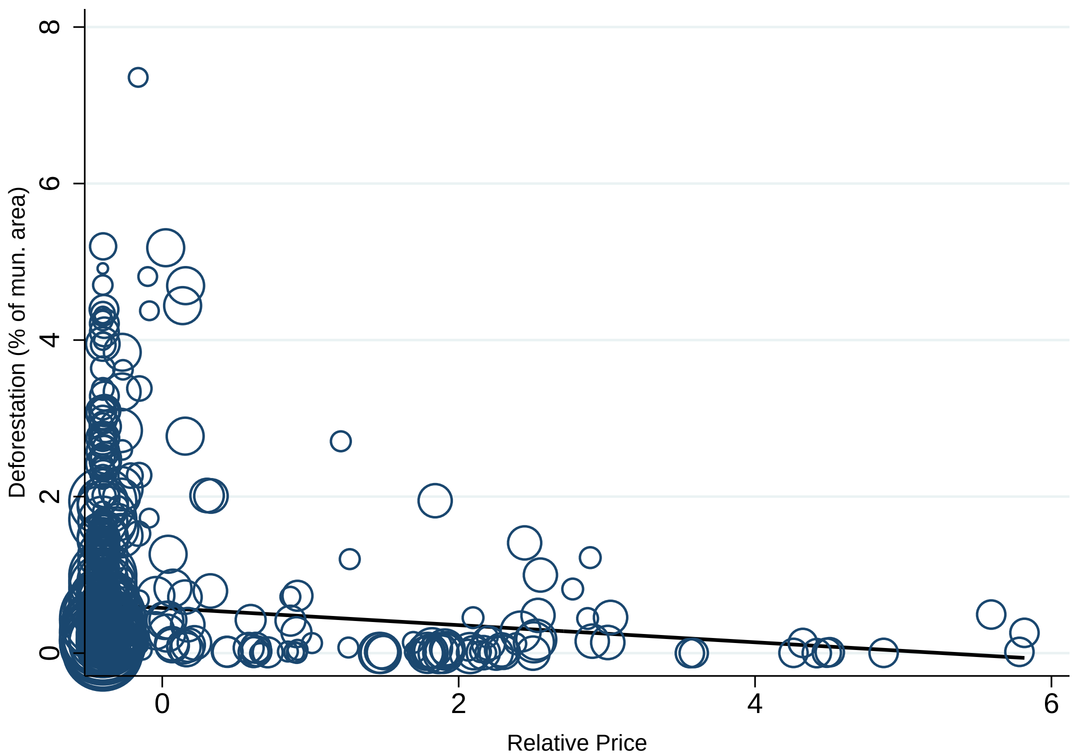

Figure 5: Relative Prices and Deforestation

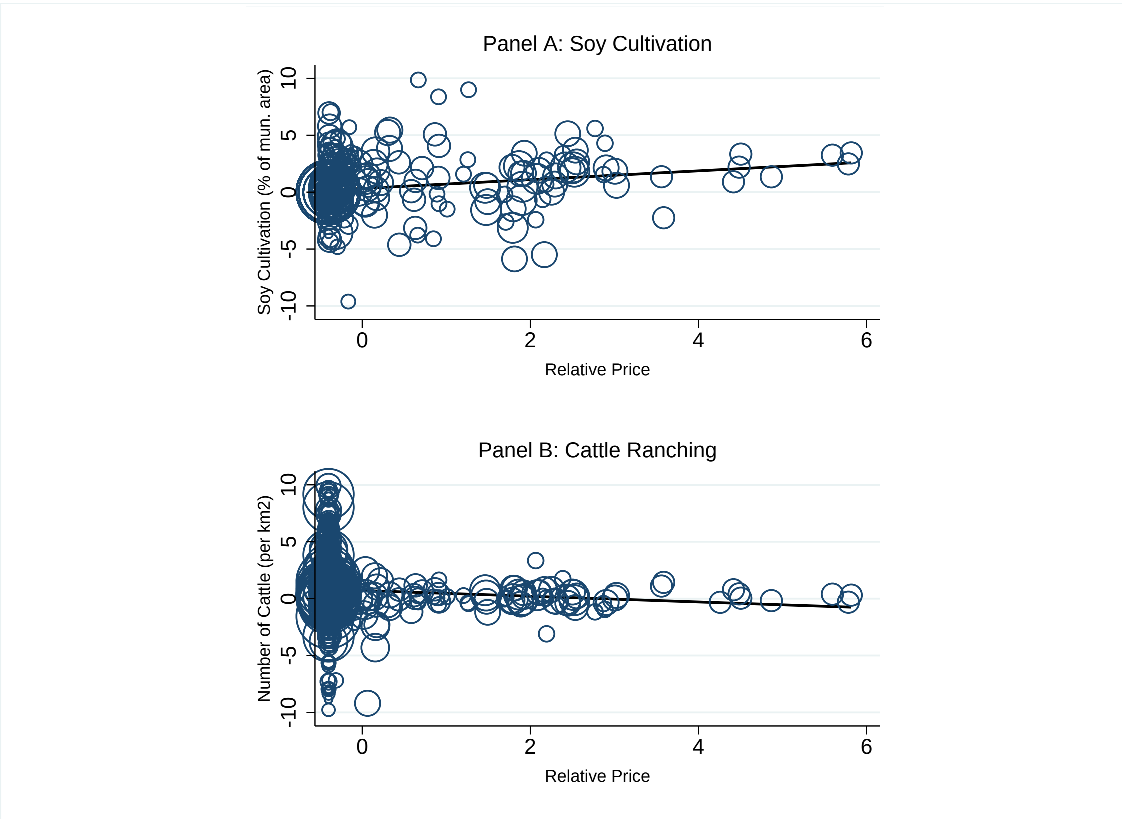

Figure 6: Relative Prices and Agricultural Activities

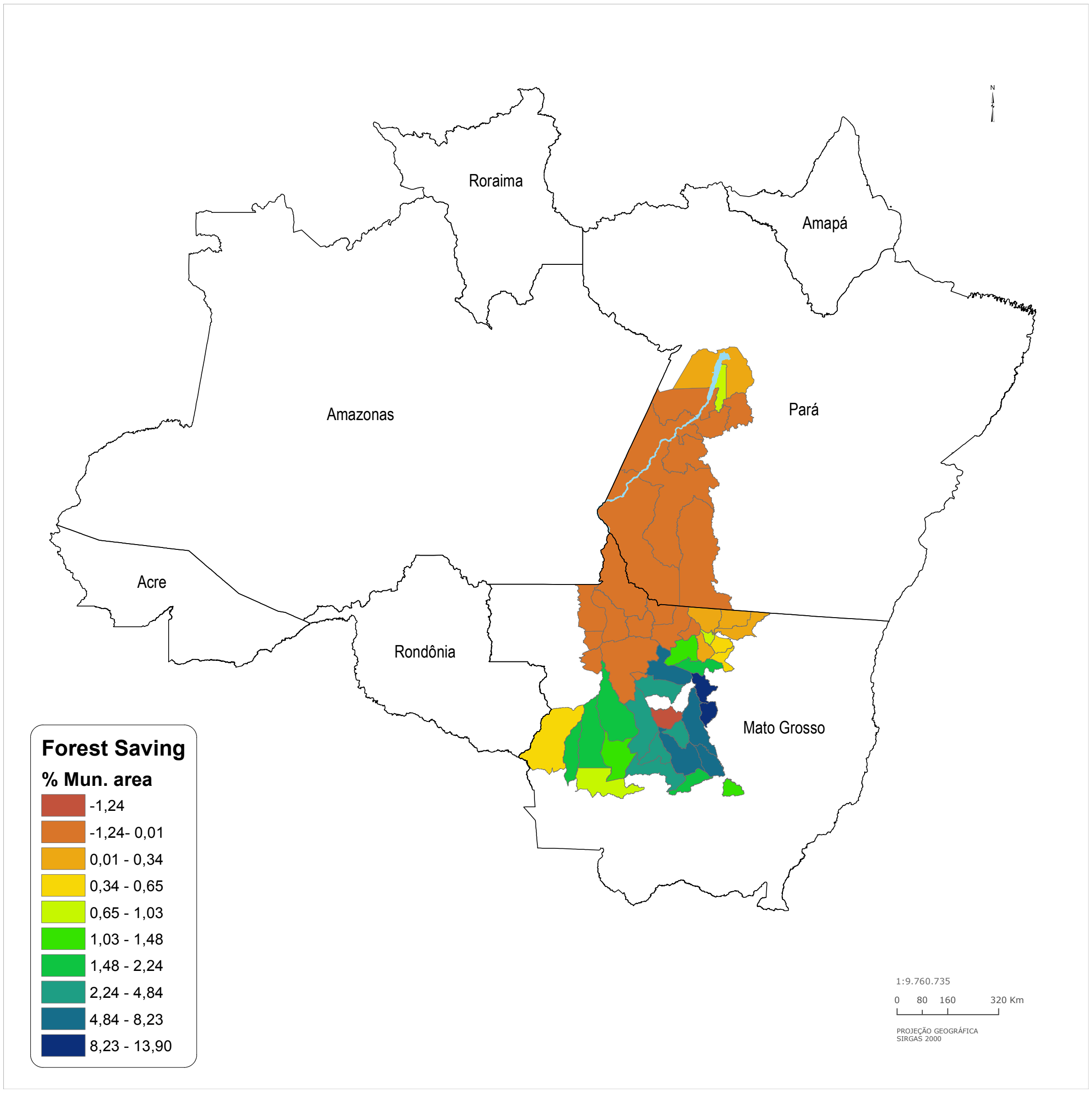

Figure 7: Forest Saving (% of municipal area)

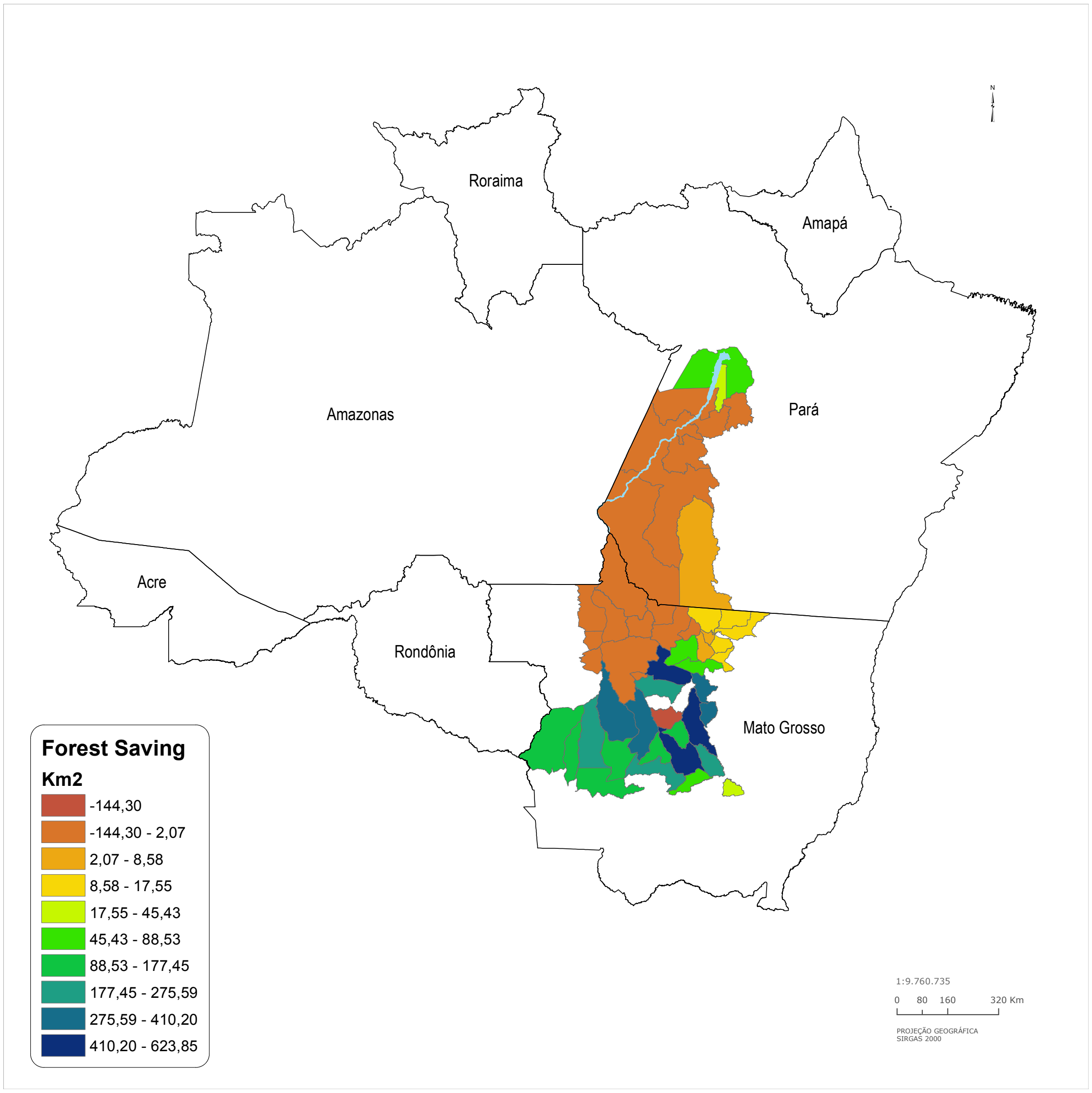

Figure 8: Forest Saving (square kilometers)

Table 1: Descriptive Statistics

	2002	2012	Difference
	(1)	(2)	(3)
Deforestation (% of municipal area)	16.334	21.598	5.264
	[2.653]	[3.237]	[0.771]
Cropland (% of municipal area)	6.499	11.888	5.388
	[2.070]	[3.552]	[1.636]
Soy (% of municipal area)	4.588	7.223	2.636
	[1.585]	[2.163]	[0.755]
Maize (% of municipal area)	0.923	3.038	2.114
	[0.352]	[1.006]	[0.734]
Other (% of municipal area)	0.989	1.627	0.638
	[0.229]	[0.482]	[0.319]
Number of Cattle (per km2)	14.000	20.912	6.911
	[2.906]	[3.977]	[1.546]
Soy Price Index	-0.156	-0.142	0.014
	[0.110]	[0.115]	[0.005]
Beef Price Index	-0.441	-0.326	0.115
	[0.097]	[0.121]	[0.024]
Relative Price	-0.122	-0.167	-0.045
	[0.114]	[0.096]	[0.018]
Number of Observations	49	49	49

Notes: Standard deviations are reported in brackets. Observations are computed using data from all 49 municipalities in the Tapajós basin and are weighted by municipal area.

Table 2: Relative Prices and Agriculture

	Dep. Var.: Change in Soy Cultivation			Dep. Var.: Change in the Number of Cattle		
	(1)	(2)	(3)	(4)	(5)	(6)
Soy to Beef Relative Price (t-1)	0.946*	1.095*	1.071*	-1.092**	-2.331***	-2.191**
	(0.545)	(0.602)	(0.593)	(0.445)	(0.859)	(0.834)
Price Controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Initial Forest Area	No	Yes	Yes	No	Yes	Yes
State-Specific Trends	No	No	Yes	No	No	Yes
R-Squared	0.17	0.20	0.20	0.19	0.24	0.24
Number of Municipalities	49	49	49	49	49	49
Number of Observations	539	539	539	539	539	539

Notes: Each column reports the results of regressing the dependent variable on the soy to beef relative price index conditional on soy and cattle price indexes and a set of additional covariates. The soy price index is obtained combining initial soy cultivation with aggregate price variation while the beef price index is obtained combining initial number of cattle with aggregate price variation. All estimates use data from the 49 municipalities in the Tapajós basin during the period 2002 to 2012. Observations are weighted by the square root of municipal area. Standard errors clustered at the municipality level are reported in parentheses. *** p<0.01 ** p<0.05 * p<0.1

Table 3: Relative Prices and Deforestation

	Dependent Variable: Deforestation (% of mun. area)			
	(1)	(2)	(3)	(4)
Soy to Beef Relative Price (t-1)	-0.656***	-0.618**	-0.437*	-0.441*
	(0.198)	(0.274)	(0.228)	(0.231)
Price Controls	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Initial Forest Area	No	Yes	Yes	Yes
State-Specific Trends	No	No	Yes	Yes
Coverage Variables	No	No	No	Yes
R-Squared	0.55	0.55	0.66	0.66
Number of Municipalities	49	49	49	49
Number of Observations	539	539	539	539

Notes: Each column reports the results regressing annual deforestation on the soy to beef relative price index conditional on soy and beef price indexes and a set of additional covariates. The soy price index is obtained combining initial soy cultivation with aggregate price variation while the beef price index is obtained combining initial number of cattle with aggregate price variation. All estimates use data from the 49 municipalities in the Tapajós basin during the period 2002 to 2012. Observations are weighted by the square root of municipal area. Standard errors clustered at the municipality level are reported in parentheses. *** p<0.01 ** p<0.05 * p<0.1

Table 4: Relative Prices and Deforestation - Alternative Price Measure

	Dependent Variable: Deforestation (% of mun. area)			
	(1)	(2)	(3)	(4)
Alter. Soy to Beef Relative Price (t-1)	-0.669***	-0.625**	-0.421*	-0.424*
	(0.203)	(0.282)	(0.229)	(0.232)
Price Controls	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Initial Forest Area	No	Yes	Yes	Yes
State-Specific Trends	No	No	Yes	Yes
Coverage Variables	No	No	No	Yes
R-Squared	0.55	0.55	0.66	0.67
Number of Municipalities	49	49	49	49
Number of Observations	539	539	539	539

Notes: Each column reports the results regressing annual deforestation on the soy to beef relative price index conditional on soy and beef price indexes and a set of additional covariates. The soy price index is obtained combining initial crop cultivation with aggregate price variation while the beef price index is obtained combining initial number of cattle with aggregate price variation. All estimates use data from the 49 municipalities in the Tapajós basin during the period 2002 to 2012. Observations are weighted by the square root of municipal area. Standard errors clustered at the municipality level are reported in parentheses. *** $p<0.01$ ** $p<0.05$ * $p<0.1$

Table 5: Crop to Beef Prices and Deforestation in the Tapajós Basin

	Annual Deforestation (% of municipal area)			
	(1)	(2)	(3)	(4)
Crop to Cattle Relative Price Index (t-1)	-0.661***	-0.626**	-0.429*	-0.436*
	(0.176)	(0.274)	(0.222)	(0.226)
Price Controls	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Initial Forest Area	No	Yes	Yes	Yes
State-Specific Trends	No	No	Yes	Yes
Coverage Variables	No	No	No	Yes
R-Squared	0.55	0.55	0.66	0.66
Number of Municipalities	49	49	49	49
Number of Observations	539	539	539	539

Notes: Each column reports the results regressing annual deforestation on the crop to cattle relative price index conditional on crop and cattle price indexes and a set of additional covariates. The crop price index is obtained combining initial soy and maize cultivation with aggregate price variation while the beef price index is obtained combining initial number of cattle with aggregate price variation. All estimates use data from the 49 municipalities in the Tapajós basin during the period 2002 to 2012. Observations are weighted by the square root of municipal area. Standard errors clustered at the municipality level are reported in parentheses. *** p<0.01 ** p<0.05 * p<0.1

Table 6: Relative Prices and Deforestation - Alternative Weighting Procedures

	Dependent Variable: Deforestation (% of mun. area)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Soy to Beef Relative Price (t-1)	-0.536***	-0.750**	-0.545*	-0.556*	-0.739***	-0.474**	-0.336*	-0.336*
	(0.197)	(0.347)	(0.288)	(0.296)	(0.201)	(0.217)	(0.182)	(0.184)
Price Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial Forest Area	No	Yes	Yes	Yes	No	Yes	Yes	Yes
State-Specific Trends	No	No	Yes	Yes	No	No	Yes	Yes
Coverage Variables	No	No	No	Yes	No	No	No	Yes
Weights	*Area*	*Area*	*Area*	*Area*	*None*	*None*	*None*	*None*
R-Squared	0.54	0.54	0.66	0.66	0.56	0.55	0.66	0.66
Number of Municipalities	49	49	49	49	49	49	49	49
Number of Observations	539	539	539	539	539	539	539	539

Notes: Each column reports the results regressing annual deforestation on the soy to beef relative price index conditional on soy and beef price indexes and a set of additional covariates. The soy price index is obtained combining initial soy cultivation with aggregate price variation while the beef price index is obtained combining initial number of cattle with aggregate price variation. All estimates use data from the 49 municipalities in the Tapajós basin during the period 2002 to 2012. Columns 1-4 weight observations using the municipal area and Columns 5-8 do not weight observations. Standard errors clustered at the municipality level are reported in parentheses. *** $p<0.01$ ** $p<0.05$ * $p<0.1$

Table 7: Relative Prices and Deforestation - Spatial Correlation in the Error Term

	Dependent Variable: Deforestation (% of mun. area)			
	(1)	(2)	(3)	(4)
Soy to Beef Relative Price (t-1)	-0.656	-0.618	-0.437	-0.441
	(0.117)***	(0.154)***	(0.131)***	(0.133)***
	[0.148]***	[0.171]***	[0.135]***	[0.135]***
	{0.169}***	{0.169}***	{0.136}***	{0.136}***
Price Controls	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Initial Forest Area	No	Yes	Yes	Yes
State-Specific Trends	No	No	Yes	Yes
Coverage Variables	No	No	No	Yes
R-Squared	0.55	0.55	0.66	0.66
Number of Municipalities	49	49	49	49
Number of Observations	539	539	539	539

Notes: Each column reports the results regressing annual deforestation on the soy to beef relative price index conditional on soy and beef price indexes and a set of additional covariates. The soy price index is obtained combining initial soy cultivation with aggregate price variation while the beef price index is obtained combining initial number of cattle with aggregate price variation. All estimates use data from the 49 municipalities in the Tapajós basin during the period 2002 to 2012. Observations are weighted by the square root of municipal area. Conley (1999) standard errors allowing for spatial correlation up to 100, 300 and 500 kilometers are reported in parentheses, brackets and curly brackets, respectively. *** p<0.01 ** p<0.05 * p<0.1

A Appendix

Proof of Proposition 1

Land allocation can be described using the following inequalities:

- Forest $\iff$ $\pi_b(A_i) < 0$ and $\pi_s(A_i) < 0$
- Pasture $\iff$ $\pi_b(A_i) > 0$ and $\pi_b(A_i) > \pi_s(A_i)$
- Cropland $\iff$ $\pi_s(A_i) > 0$ and $\pi_s(A_i) \geq \pi_b(A_i)$

The assumption $1 < \Delta(P_s/P_b) < (wl_s - rk_s)/(wl_b - rk_b)$ ensures that $\pi_s(A_i) < 0$ whenever $\pi_b(A_i) < 0$. It also ensures that $\pi_s(A_i) > 0$ whenever $\pi_s(A_i) \geq \pi_b(A_i)$. Hence, the inequalities above can be reduced to:

- Forest $\iff$ $\pi_b(A_i) < 0$
- Pasture $\iff$ $\pi_b(A_i) > 0$ and $\pi_b(A_i) > \pi_s(A_i)$
- Cropland $\iff$ $\pi_s(A_i) \geq \pi_b(A_i)$

I can express the inequalities above as a function of A_i. The first expression can be written as:

$$A_i < \underline{A} = \frac{wl_b + rk_b}{P_b} \tag{A.1}$$

The third expression can be written as:

$$A_i < \overline{A} = \frac{w(l_s - l_b) + r(k_s - k_b)}{\Delta P_s - P_b} \tag{A.2}$$

Notice that the thresholds above can also be used to re-write the second expression. Therefore, these limits determine the land allocation as stated in proposition 1. Land remains as forest when $A_i < \underline{A}$ and is used as pasture when $\underline{A} \leq A_i < \overline{A}$ and as cropland when $A_i \geq \overline{A}$.

Proof of Proposition 2

Let the relative price be $P = P_s/P_b$. Define the price of beef as the numeraire and write the cost function having a composite input called I with price θ. The input intensities continue to differ across activities with $I_s > I_b$. The thresholds $\underline{A}$ and $\overline{A}$ can be re-written as:

$$\underline{A} = \theta I_b \tag{A.3}$$

$$\overline{A} = \frac{\theta(I_s - I_b)}{\Delta P - 1} \tag{A.4}$$

The effect of an increase in relative prices on land allocation is:

$$\frac{d\underline{A}}{dP} = I_b \frac{d\theta}{dP} \tag{A.5}$$

$$\frac{d\overline{A}}{dP} = -\Delta \frac{\theta(I_s - I_b)}{(\Delta P - 1)^2} + \frac{d\theta}{dP} \frac{I_s - I_b}{\Delta P - 1} \tag{A.6}$$

The equations above make clear that the effect of relative prices on land use depends on its effect on input prices. Let $D(\theta)$ and $S(\theta)$ be the demand and supply of the composite input. Notice that $D(\theta) = I_s A_s + I_b A_b$ and that $S'(\theta) > 0$. Market clearing implies that $D(\theta) = S(\theta)$. Using the implicit function theorem on this equilibrium it is possible to determine the impact of relative prices on input prices:

$$\frac{d\theta}{dP} = \frac{\Delta g(\overline{A})\theta \left(\frac{I_s - I_b}{\Delta P - 1}\right)^2}{S'(\theta) + I_s g(\overline{A}) \left(\frac{I_s - I_b}{\Delta P - 1}\right) - I_b g(\overline{A} - \underline{A}) \left(\frac{I_s - I_b \Delta P}{\Delta P - 1}\right)} > 0 \tag{A.7}$$

Both the numerator and denominator are greater than zero in the expression above. This result comes from the problem's assumption $1 < \Delta P < I_s/I_b$.

The effect of relative prices on $\overline{A}$ will be negative whenever $d\overline{A}/dP < \Delta\theta/(\Delta P - 1)$. Notice that:

$$\frac{d\theta}{dP} < \frac{\Delta g(\overline{A})\theta((I_s - I_b)/(\Delta P - 1))^2}{I_s g(\overline{A})((I_s - I_b)/(\Delta P - 1))} = \frac{\Delta\theta}{(\Delta P - 1)}(1 - I_b/I_s) < \frac{\Delta\theta}{(\Delta P - 1)} \tag{A.8}$$

Equations A.7 and A.8 ensure that $\overline{A}$ will fall as relative prices increase while equation A.7 proves that $\underline{A}$ will increase as these prices increase. These results prove that an increase in relative prices increases cropland and forest area and reduces pasture area, i.e., it establishes the result in Proposition 2.