International Journal of Economics and Finance; Vol. 15, No. 5; 2023
ISSN 1916-971X E-ISSN 1916-9728
Published by Canadian Center of Science and Education

The Use of Information Technology in Environmental Management: The Case of Brazilian Amazon Forest

Rodrigo M. Pereira[1], Celso Vila Nova de S. Júnior[2] & Tito Belchior S. Moreira[3]

[1] IPEA - Institute of Research and Applied Economics - Directorate of Macroeconomic, DF, Brazil

[2] Coordinator of the Graduate Program in Public Management – PPGP-UnB, DF, Brazil

[3] Economics Department, Catholic University of Brasília, D.F., Brazil

Corresponding author: Tito B. S. Moreira, Universidade Católica de Brasília, Brasilia, DF, Brazil. Tel: 55-999-763-111. E-mail: titoeco@yahoo.com.br

Received: February 21, 2023 Accepted: April 9, 2023 Online Published: April 15, 2023

doi:10.5539/ijef.v15n5p54 URL: https://doi.org/10.5539/ijef.v15n5p54

Abstract

In the mid 2000´s the Brazilian Government introduced a new environmental policy to reduce deforestation in the "Plan for Prevention and Control of Legal Amazon Deforestation", (PPCDAM). With 14 years of track record, heavily relying on technological innovation, the policy is nowadays considered a major example of success in the overall war waged against the deforestation of tropical rainforests. In this paper we quantify this success. The results suggest that the policy not only had a direct effect of reducing deforestation, but also rendered deforestation less sensitive to fluctuations in the Amazon commodity production, which can be considered our academic contribution to this paper. We also perform a counterfactual exercise, estimating the levels of deforestation that would have been registered, had the policy not existed. We estimate that the plan saved a total of 196 thousand square kilometers of forest between 2005 and 2015, corresponding to almost twice the total amount of deforestation observed during this period, and 4.9% of the entire Brazilian Amazon Forest.

Keywords: deforestation, legal Amazon, PPCDAM, tropical rainforests, technological innovation

1. Introduction

Unprecedented global technological changes in the last three decades have significantly altered the process of economic transformation as well as its impacts on the environment. In recent years it has been observed the ever-increasing use of information technology as a tool for governmental action and public policy management. The Amazon Forest encompasses more than 6 million square kilometers, in 9 countries, and 60% of it is in Brazilian territory. With its notoriously complex and diverse environments, the Amazon has close to 10% of the planet's biodiversity. The Brazilian Amazon has gone through a historical pattern of occupation and unsustainable use if its natural resources, mainly in the 70's and 80's. That is when military governments adopted certain standards of economic development, integrating the territorial occupation policies. Around 20% of the Brazilian Amazon has already been deforested. This is a result of territorial occupation, deliberate forest burnings, agribusiness (Note 1), use of the soil to produce other commodities, grabbing of public lands, and infrastructure expansion, based on L'Roe, Rausch, Munger, and Gibbs (2016). According to Azevedo-Ramos and Moutinho (2018), 70 million hectares of Brazilian Amazon public forests have no formal legal designation, increasing the risk of continued land grabbing and predatory use. L'Roe, Rausch, Munger, and Gibbs (2016) present an evaluation of deforestation and registration programs to date — the Rural Environmental Registry (CAR) in the Amazonian state of Pará. The authors find that for smallholder properties the environmental registries may have potential to reduce deforestation if combined with a favorable set of incentives.

In this paper we investigate the determinants of deforestation in the Brazilian Amazon, with particular emphasis given to the role played by this specific environmental policy of 2004, the PPCDAM. We estimate a panel of 760 Amazon municipalities and 15 years. The results suggest that municipal population growth, cattle grazing, total areas of permanent and temporary crops, as well as soybean crops significantly affect deforestation. Moreover, the new environmental policy significantly reduced deforestation in the Brazilian Amazon. The policy also rendered deforestation less sensitive to fluctuations in crop areas and cattle herds in the Amazon. The estimation of a deforestation equation allows us to perform an interesting exercise of policy evaluation. We address the question of how effective PPCDAM has been to reduce deforestation in the Brazilian Amazon. The model predicts that a much higher level of deforestation would have taken place from 2005 to 2015 had the PPCDAM not been implemented. Our results indicate that the policy avoided 196 thousand square kilometers of accumulated deforestation through these 11 years, which is almost twice the amount of actual deforestation that occurred in the period, and approximately 4.9% of the remaining forested areas in the Brazilian Amazon.

In order to promote a continuous and consistent deforestation reduction, the PPCDAM has been updated for the periods 2012-2015 and 2016-2020. Nonetheless, there is still a long way to go to make the remaining forest more economically and socially attractive than deforesting for cattle-raising and farming purposes. The more the deforestation rates are reduced, the more costly the new and successive reductions thereafter. Thus, it becomes increasingly important to define a model of development for the Amazon Forest, valuing and protecting its assets, while simultaneously fostering social and ethnic diversity and improving the population’s standard of living. Such new improvements will demand more sophisticated efforts from the federal, state, and municipal governments as well as from Brazilian society.

2. Literature Review

The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAM), launched in 2004, aims to reduce deforestation rates continuously and to bring about the conditions for a transition towards a sustainable development model in the region. A major challenge faced by the plan early on was that of internalizing the concern with deforestation in a diverse set of sectoral policies. The perception that the environmental institutions could not fight deforestation in isolation, due its complexity and crosscutting nature, lead to the coordinated approach chosen, with the engagement of several bodies and actors within the federal government and beyond, according to the Ministry of the Environment, 2018.

According to Ellwanger et al. (2020) Amazonian biodiversity is increasingly threatened due to the weakening of policies for combating deforestation, especially in Brazil. Loss of animal and plant species, many not yet known to science, is just one among many negative consequences of Amazon deforestation. Deforestation affects indigenous communities, riverside as well as urban populations, and even planetary health. Amazonia has a prominent role in regulating the Earth’s climate, with forest loss contributing to rising regional and global temperatures and intensification of extreme weather events. These climatic conditions are important drivers of emerging infectious diseases, and activities associated with deforestation contribute to the spread of disease vectors.

In the first decade of the century there was a large worldwide expansion in the demand for all kinds of commodities. With prices going up, commodity exporters strongly benefited from those market conditions, unleashing an intense run for minerals, oil, pasture, cattle, and agricultural land. Despite the positive consequences for economies largely relying on primary goods, such as Brazil, this event raised environmental concerns due to the increase in the pressure on tropical forests like the Amazon. This relationship between commodity expansion and deforestation is in the forefront of empirical research on the Brazilian Amazon. Specifically, cattle ranching, and soybean crops have been pointed out by several studies as the key driving forces behind the Amazon deforestation according to Barona, Ramankutty, Hyman, and Coomes (2010); Fearnside (2005); Margulis (2004); Ferraz (2001); Andersen (1996).

One of the most important questions today to understand the deforestation process in the Brazilian Amazon is what drove deforestation down after 2004. What explains a fivefold reduction of deforestation in the Brazilian Amazon, notwithstanding a simultaneous expansion of worldwide commodity markets? In addition, when commodity markets sunk, and prices collapsed after 2012, deforestation slightly increased in the Brazilian Amazon. Was there a reversal in a relationship that has been well stablished by evidence and common sense? Was the new policy so effective that it overwhelmed the effect of the commodity boom? Or did it change the way the forest structurally relates to fluctuations in the commodity markets?

After this brief introduction, we present in section 2 a description of data and information on deforestation in the Brazilian Amazon, as well as a theoretical framework on which the empirical models are based. Section 3 discusses the empirical results and, finally, in section 4 we present the final considerations.

3. Data, Technology in Environmental Management and Methodology

Deforestation in the Brazilian Amazon has been monitored with satellite data since the late 1980's by INPE (*Instituto Nacional de Pesquisas Espaciais*), a National Institute for Space Research, funded by the Federal Government. The institute monitors cleared forested areas in what is defined as the Legal Amazon (Amazonia Legal). The area comprises the whole northern region (states of Amazonas, Para, Acre, Rondônia, Roraima, Tocantins and Amapá) plus the center-western state of Mato Grosso, and around two thirds of the territory of the northeastern state of Maranhão. There are a total of 760 municipalities in the Legal Amazon. INPE provides aggregate deforestation data, in deforested square kilometers, since 1988. In 2000 the institute also began providing municipal data on deforestation. Unlike the aggregate data, the local data is presented by INPE as the total cumulative cleared areas in square kilometers for all the 760 municipalities. Deforestation that took place in a particular year would then be the difference between the total cleared areas in that year and the year before. Deforested areas are forever considered as such in INPE's methodology, no matter if the forest is eventually regenerated in those areas (Note 2).

Aggregate deforestation is relatively volatile from the late 1980's up to 2004. From then on, a steady decline begins, with current annual aggregate deforestation corresponding to approximately 20% of its peak value. The big boom in commodity prices occurred between 2004 and 2012. Beef prices in 2014, for example, doubled if compared to the 2005 value. Soybeans were 2.5 times more expensive in 2012 as compared to 2004.

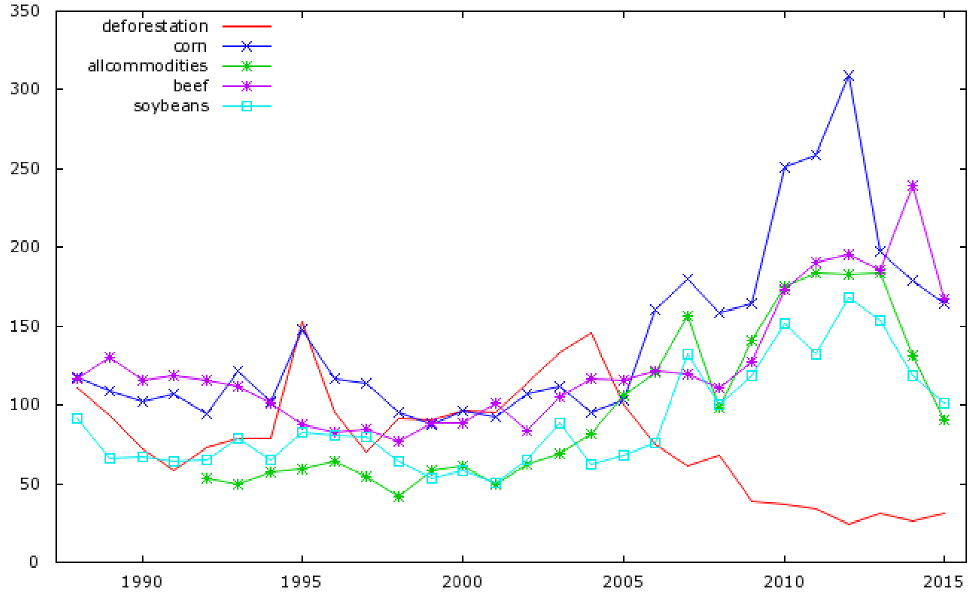

Figure 1. Amazon Deforestation and Commodity Prices (Note 3)

Figure 1 depicts those trajectories, where the index of annual deforestation in the Brazilian Amazon is plotted against some IMF's commodity price indexes, namely maize, soybean, beef, and a bundle for all commodities (fuel and non-fuel) (Note 4). Besides, it suggests that after 2004 the relationship between commodity prices and deforestation has changed. It seems that the early positive correlations gave way to negative correlations. This fact can be confirmed by splitting the sample in two segments: one that goes until 2004, and another that begins in 2005.

Figure 2 presents the same aggregate deforestation series, along with cattle herd and the total of crop areas in the Legal Amazon allocated to permanent crops, temporary crops (including soybean), and soybean crops. Areas for soybeans and other temporary crops had substantial increases from 2005 to 2015 (around 50%), the cattle herd had a moderate increase (around 12%), and there was a reduction of roughly 12% in the areas aimed for permanent crops. Those trajectories by themselves cannot explain the almost fivefold reduction in deforestation observed through the period. If nothing else, they would be consistent with increases in deforestation.

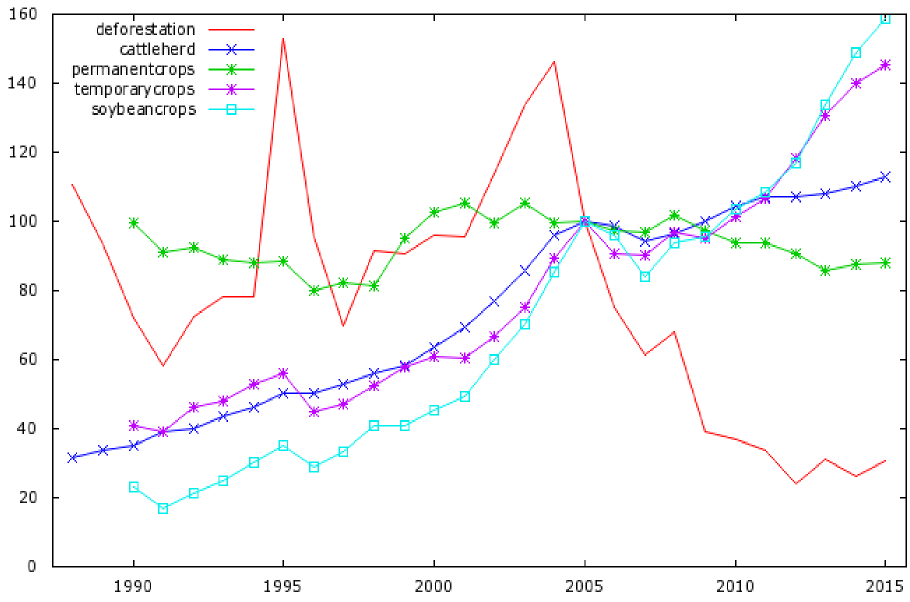

Figure 2. Aggregate Deforestation, Crop Areas and Cattle Herd at the Legal Amazon (Note 5)

But how can increases in soybean crops and cattle ranching in the Legal Amazon coexist with sharp reductions in deforestation? One possibility is to think of two alternative technologies available for the farmer, one that requires deforestation and another that does not. In the absence of monitoring and punishment for bad behavior, the first, forest unfriendly technology is preferred. When authorities start monitoring deforestation as well as enforcing the law, there is a migration of farmers from the bad to the good technology. So even with a booming market, with prices and profits increasing, raises in production are compatible with reductions in deforestation, as long as there are farmers changing their technologies.

Another possibility is to consider a technology in which land is an input with substitutes. So, if the markets for the commodities produced by the farm are booming, the farmer would naturally increase production, hiring more inputs. That includes more land, which may increase deforestation. However, if there is a simultaneous increase of environmental sanctions, the expected cost of land would increase for the farmer. That could be either because he faces harsher penalties if caught illegally deforesting, or because the probability of being caught becomes higher. In any case, the substitution of land for other inputs may be profit maximizing. Therefore, the combination of booming commodity markets and a lower level of deforestation may not be as unfamiliar as it seems.

We can then calculate Pearson correlation coefficients between the Amazon deforestation and the prices of several commodities, for the two consecutive time spans. The results are presented in Table 1. Again, we use IMF commodity price indexes, based on nominal US dollars. The changes in the correlation coefficients are quite remarkable. Most of them were positive until 2004, and became negative thereafter, suggesting a substantial change in the way fluctuations in commodity markets would affect the deforestation of the Amazon Forest.

The local level of deforestation for every municipality within the Legal Amazon can be seen with the help of quantile maps. Because there is a wide variation on the size of Amazon municipalities, using raw deforestation as the variable to be represented on the map would not be a very accurate procedure. In fact, gigantic municipalities would tend to have more deforested areas than the tiny ones. So, we will rather divide deforestation by the municipal area, which gives us an idea of the intensity of deforestation in a particular location.

Besides INPE's deforestation data described on the previous section, we use here several other economic data of the Legal Amazon municipalities. Brazil's IBGE (Instituto Brasileiro de Geografia e Estatística) provides annual data on municipal GDP in thousand reais of 2014, municipal cattle herd in heads, municipal permanent and temporary crops in hectares, and municipal soybean crops in hectares. Soybean is a temporary crop and is included in the aggregation of all temporary crops.

Table 1. Pearson correlation coefficients between amazon deforestation and commodity prices**

	Correlation Coefficients	
	1998/2004 *	2005/2015
deforestation	1	1
corn	0,3748	-0,689
metals	0,4727	-0,4225
all commodities	0,6591	-0,5248
food	0,1429	-0,837
agric raw mat	0,0391	-0,677
oil	0,492	-0,4205
beef	-0,1244	-0,7963
coal	0,3657	-0,5266
coffee	-0,1357	-0,5979
tim	0,0382	-0,6401
logs	-0,0718	-0,4237
swine	0,0668	-0,5881
poultry	0,6285	-0,7837
rice	0,024	-0,56
rubber	0,5515	-0,3887
salmon	-0,4144	-0,653
hardwood	0,0207	-0,7979
softwood	0,228	0,5793
soyb meal	0,2576	-0,791
soyb oil	0,1295	-0,5983
soybean	0,2878	-0,7688
aluminum	0,4368	0,3873
cocoa	0,3189	-0,7453

* Commodity Price Index starts in 1992; Food Price Index starts in 1991.

The data consists of areas that were planted (but not necessarily harvested). So we have a panel of 15 years, from 2001 to 2015, and 760 municipalities6. Population data might also be useful to explain deforestation. It is available in two points of time, the 2000 and the 2010 censuses.

Based on these observations we can construct cross section variables to be used in a panel data estimation. So, we take population growth observed in every municipality within these ten years, and the share of rural population in the total population for every municipality. The idea is to investigate if municipalities with a higher share of rural settlements tend to be more forest unfriendly than the more urbanized ones.

Since 1988 Brazil's Environmental Ministry (MMA) teams up with (INPE, 2017) to monitor the Amazon deforestation with the use of satellite images. The mapping of deforested areas is traditionally made with the images of the satellite Landasat. From 1998 until 2002 these mappings used low quality images, in the form of colored compositions in the scale 1:250.000. With these maps it was possible to compare the images of each year and detect the new deforested areas. The updates of the deforested areas usually had a lag of two or more years, mostly due to budget and organizational limitations. The number of observations done by the satellite would depend on the weather, basically the occurrence of clouds, and the rate at which the satellite would "revisit" each area.

Furthermore, we introduce a simple model of deforestation. We assume a representative farm that produces a single output Y, using two inputs: labor N, and land L. The government imposes a limit of land use of $\bar{L}$. Deforestation is allowed only within the limits of $\bar{L}$. Labor and land have unitary costs of w and x, respectively, and the product is sold at the price of q per unit. We assume that markets are competitive. If the farmer abides by the law, his total cost is wN + xL. The farmer can, however, choose to use more land than $\bar{L}$, in which case he enters a lottery. If the extra forest clearing is not detected by the authorities, then every unit of extra land simply costs x. But, if the illegal deforestation is detected, sanctions are imposed on the farmer. They can be environmental fines, seizure of property, machines, or even jail time. To make things simple, we just assume an extra cost of z per unit of deforested land above the legal limit $\bar{L}$ (Note 7). So, if detected, the farmer pays x for the first $\bar{L}$ units of land, and $x + z$ on every unit thereafter. If p is the probability of detection when the farmer decides to extend his farming area beyond $\bar{L}$, his expected profit is given by

$$\pi(q,w,x,y,p) = qY - wN - xL - Max\{0, pz(L-\bar{L})\}, \text{ s.t } F(N,L) \geq Y \quad (1)$$

Where $F(N,L)$ is a standard technology with positive and decreasing marginal productivities. The farmer's objective is to maximize his expected profit. The first order optimality conditions are given by equations 2, 3 and 4:

$$q(N, L) = w \quad (2),$$

$$qFL\,(N, L) = x \text{ if } L \leq \bar{L} \quad (3)$$

and

$$qFL\,(N, L) = x + pz \text{ if } L > \bar{L} \quad (4)$$

So, the value of labor's marginal productivity is equal to the wage, and the value of land's marginal productivity is equal to the expected marginal cost of land. If the farmer decides to use more than $\bar{L}$ of land, that cost includes the regular price of land, x, plus what could be defined as policy stringency, which is based in two measures: the probability p of being caught deforesting more than the legal threshold $\bar{L}$, and the associated penalty cost per unit of land, z.

When the market for the commodity produced by this farmer is booming, there are increases in the price q. The profit maximizing response is to increase labor and land, reducing their marginal productivity in such a way that the left-hand side of equations (2), (3) and (4) remain constant.

A policy designed to reduce deforestation amidst a commodity boom would naturally target the policy stringency pz in such a way that increases in the commodity price q (and consequently in the labor force N) would be matched by an increase in the expected cost of land *x + pz,* keeping land use L constant, or even reducing it. That's exactly what PPCDAM did in 2004. The plan comprised a series of actions designed to reduce deforestation. The war against deforestation would no longer be waged only by environmental agencies, but rather it would be in the forefront of Brazil's top policy priorities. Among other things, PPCDAM created subsidies to sustainable activities within the forest, and land use planning, with the creation of several conservation units. Most importantly, the plan relied on new technologies to launch a system called DETER, allowing almost real time detection of new deforested areas, streamlining the enforcement of the existing environmental laws. That changed the pattern of deforestation. Ranchers begun cutting small pockets of forest, enough to be below DETER's detection threshold (although detected by the regular annual monitoring). Overall, deforestation rates fell sharply. In fact, the data suggests that the plan was so effective in raising policy stringency that even with the steep rise in commodity prices there was a remarkable, never seen, reduction in the deforestation of the Brazilian Amazon.

4. Empirical Results

We want to evaluate the quantitative effects of variables that are commonly listed as determinants of the Amazon deforestation, such as cattle herd, crop areas, population, municipal GDP, etc. We also want to investigate if the policies adopted in 2004 in the form of the PPCDAM can explain the massive reduction of deforestation observed afterwards. The empirical strategy is to use a panel of 760 municipalities and 15 years, totaling 11400 observations, to estimate the following deforestation equation.

$$\begin{aligned} Def_{it} = \beta_0 + \beta_1.GDP_{it-1} + \beta_2.Cattle_{it} + \beta_3.PCrop_{it} + \beta_4.Tcrop_{it} + \beta_5.Soy_{it} + \beta_6.Area_{it} \\ + \beta_7.PopG_i + \beta_8.RuPop_i + \gamma_{1.}D_t + \gamma_{2.}D_tCattle_{it} + \gamma_{3.}D_tPCrop_{it} + \gamma_{4.}D_tTCrop_{it} \\ + \gamma_5 D_tSoy_{it} + \alpha_i + \varepsilon_{it} \end{aligned} \quad (5)$$

The variable Def_{it} here is raw deforestation, rather than deforestation as a share of municipal area. The reason is that we can control for the municipal area, by adding that variable in the regression equation. It would be a cross-sectional variable, time invariant, hence the absence of the sub-index *t* in Areai. Based on the 2000 and 2010 censuses, two other cross-sectional variables are created, namely, municipal population growth, and rural population as a share of total population on every municipality. The population growth calculates the percentual growth in the population of every municipality in the legal Amazon between the years 2010 and 2000. The rural population ratio is calculated with the data of the latest census of 2010. The term α_i captures unobserved variables that are time invariant, not included in the model. When we perform fixed effects estimation all these time invariant variables disappear from the model. We also perform a random effects estimation, along with a standard pooled OLS. In these cases, the observed time invariant variables are present, while the unobserved ones in α_i mingle with the error term, and there is a well-known possibility of inconsistencies.

There are five explanatory variables with a panel structure, namely, municipal GDP (GDP_{it}), cattle herd ($Cattle_{it}$), total areas of permanent crops ($PCrop_{it}$), total areas of temporary crops ($TCrop_{it}$), and total areas of soybean crops (Soy_{it}) (Note 8). These agricultural areas are measured in hectares, while deforestation is measured in square kilometers (100 hectares = 1 km^2). Cattle herd is measured in heads, and municipal GDP in thousands of reais of 2014. The reason we use the lag of GDP rather than current GDP is that the most recent available data on GDP is usually one year behind all the others. So, instead of losing 2015 and all of its 760 observations, we use lagged GDP, which is usually highly correlated and a very good proxy for current GDP.

To assess the effect of policy we introduce a dummy variable D_t, that has a value of 0 up to 2004, when the policy was implemented, and a value of 1 from 2005 on. This dummy is also interacted with cattle herd, permanent and temporary crops, and soybean crops. The idea is to analyze whether the PPCDAM plan changed the way these economic activities affect deforestation.

Table 2 presents the results of three different panel data estimations of equation (2): pooled ordinary least squares, fixed effects (without time dummies), and random effects. The three variables in the model that are time-invariant disappear when fixed effects are used. We also exclude lagged GDP in the fixed effects estimation due to lack of statistical significance. For both pooled OLS and random effects estimations, the lagged municipal GDP and the share of rural population do not significantly affect deforestation. Population growth, however, is highly significant. The pooled OLS coefficient of 0,33 (0.34 with random effects) states that on average every 3% of population growth accounts for an extra deforested square kilometer every year in that particular municipality. Municipal area is also highly significant, and here it controls for the fact that larger municipalities tend to be more deforested. So, every extra thousand square kilometers of municipal area imply 1.1 extra square kilometer of deforestation on average (1.2 with random effects).

Overall, the results of the three estimations are similar. The estimated coefficient signals are roughly the same on all models, the exception being the reversal of the cattle herd coefficient when fixed effects are used. Cattle herd having a negative effect on deforestation is not so strange as it seems. Indeed, the typical frontier deforestation has loggers extracting the most valuable timber before farmers burn the remaining vegetation to get agricultural land.

Within a few years of crops the soil becomes so poor that the land has to be converted to pasture according to Andersen (1996). So, if large cattle herds tend to be in places where deforestation has long occurred, and there is nothing left to deforest, that negative coefficient is perfectly reasonable. The same argument holds true for the negative coefficients of soybean crops. They simply mean that larger areas of soybean crops are located in municipalities that have long been deforested, so that current deforestation might be low.

The coefficient for the PPCDAM dummy is highly significant in all models, with values ranging from -10 to -12. So, after the policy is implemented, the annual deforestation is reduced on average in 11 square kilometers per municipality (fixed effects), controlling for other attributes.

Table 2. Estimation of the deforestation equation

Variable	*Pooled OLS*	*Fixed Effects*	*Random Effects*
Constant	-3.187	68.0534 ***	46763
	(-1.457)	(29.60)	(1.382)
Municipal GDP (-1)	0.000000129		-0.000000301
	(0.527)		(-0.7131)
Cattle Herd	0.000233941***	0.000341682***	0.000175460***
	(21.85)	(-15.81)	(14.28)
Perm Crops	0.00572287***	0.00117298	0.00585836***
	(10.33)	(1.284)	(9.363)
Temp Crops	0.00142011***	0.000569326***	0.00116923***
	(8.602)	(3.420)	(7.131)
Soybean Area	-0.00153351***	-0.000558516**	-0.00222621***
	{-6.984)	(-2.468)	(-5.611)
Municipal Area	0.00110229 ***		0.00122673***
	(24.31)		(14.61)
Pop Growth	0.328893***		0.344911***
	(13.57)		(7.715)
Rural Pop Ratio	6.13533*		-1.12941
	(1.827)		(-0,1827)

Dppcdam	-12.1402***	-11.0060***	-10.1828***
	(-6.766)	(-7214)	(-6.320)
Dcattle	-0.00014758***	-0.0000823197***	-0.000161665***
	(-12.61)	(-7.667)	(-15.27)
Dperm	-0.00432997***	-0.00183936***	-0.00404661***
	(-6.7864)	(-3.324)	(-7.080)
Dtemp	-0.00128222***	-0.000782371***	-0.00122763***
	(-7.175)	{-4.867)	(-7-441)
Dsoy	0.00134607***	0.000768355***	0.00132887***
	(5.551)	(3.527)	(5.984)
Observations	11400	11400	11400
Municipalities	760	760	760
Fit	R^2 = 0,2268	Whithin R^2 = 0,1587	

Note. t-ratio statistics are presented within brackets, and the usual symbols ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

That means a total of 8.36 thousand square kilometers per year for the 760 municipalities, and a total of 92 thousand square kilometers for the whole period of 2005 up to 2015. But this is only a partial effect because we interact the dummy with four other variables. The highly significant coefficients of all four interactions suggest that PPCDAM did change the way cattle grazing and agriculture affect deforestation. Before the plan was introduced every extra square kilometer of permanent crops and temporary crops accounted for an extra 0.57 and 0.14 extra annual square kilometer of deforestation, respectively, for every municipality (using the pooled OLS results). After the plan these numbers change to 0.14 and 0.01, respectively. Those numbers are obtained by adding the coefficients of the interactions to the original coefficients of the respective variables. These results suggest that the plan forced farmers to find ways to increase crop areas without cutting down the forest. By the same token, every additional 10 thousand cows would increase annual municipal deforestation by 2.3 square kilometers, on average, before the plan. That number shrunk to 0.86 after the plan, still using the pooled OLS regression. Besides, we perform a counterfactual exercise that measures the overall effect of the PPCDAM. The idea is to find out the numbers for the Amazon deforestation if the PPCDAM was not implemented. Based on the three estimation procedures presented in Table 3, we calculate the predicted value for deforestation, with the dummy for the PPCDAM having a value of zero throughout the whole period. Then we sum for all 760 municipalities and all 11 years since 2005, the first full year in which the policy is effective, up to 2015, the last year of the dataset. The result is an estimate of the amount of forest that was saved as a direct result of the policy. The estimates are 338194, 229187 and 324841, with the pooled OLS, fixed effects, and random effects models, respectively. Those are quite large numbers when compared with the 100425 square kilometers of deforestation that was observed for the period. From now on we will work with the most conservative of these numbers, which is the one obtained with the fixed effects estimation. So, based on the estimates in Table 3, we get:

$$\widehat{Def}_{it} = 68.06 - 0.00034Cattle_{it} + 0.0012PCrop_{it} + 0.00057TCrop_{it} - 0.00056Soy_{it} \quad (6)$$

Equation (6) gives the predicted deforestation of every municipality, for every year from 2005 to 2015, had the government not implemented the PPCDAM plan. These numbers can be aggregated on the time and/or cross-sectional dimensions. There is no upper bound on the levels of deforestation predicted. Therefore, the values predicted by equation (6) for municipalities with critical levels of deforestation are sometimes higher than the total municipal area, which obviously makes no sense. If we correct for that and establish that the maximum value for prediction is the correspondent municipal area, we find lower values than the ones listed above. Specifically, with fixed effects, the total saved forest in square kilometers becomes 196512, around 14.4% lower than the original estimate.

Putting this number in perspective, 196 thousand square kilometers corresponds to almost twice the amount of actual deforestation observed in the period. The total predicted cumulative deforestation without the policy is 297 thousand square kilometers. So, according to this result, the amount of forest that was saved by the policy corresponds to 66% of the total deforestation that would have occurred in the period from 2005 to 2015, had the PPCDAM not been implemented. The only other similar number for the PPCDAM ́s effectiveness found in the literature, to the best of our knowledge, was provided by Assunção, Gandour, and Rocha (2012). They found a slightly smaller figure of 52.1%, but their time span is also smaller, from 2005 to 20099. So, notwithstanding the fact that the reduction in aggregate deforestation flattened out after 2011, our results suggest that the share of deforestation avoided by the policy on the total predicted deforestation kept rising.

Figure 3 presents these series. The graph presents the original estimate with fixed effects, and the estimates corrected to the fact that municipalities cannot deforest more than 100% of their own area.

If we aggregate the data in the cross-section dimension, we can compare the two time series that together capture the effect of the policy, namely, the observed aggregate deforestation, and the predicted deforestation without the policy.

Another interesting exercise is to aggregate the data on the time series dimension. So, for every municipality we calculate the difference between the observed deforestation, and the deforestation without policy, predicted with equation (6).

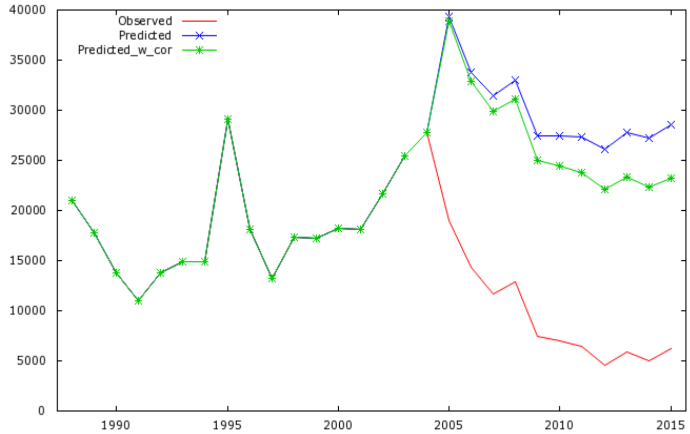

Figure 3. Observed and Predicted Deforestation without PPCDAM (Note 10)

We then sum those numbers for the whole time for which the plan has been operational, from 2005 to 2015. The result is the predicted cumulative area of forest saved by the policy, for each municipality. In order to present those numbers on a map, we take them as a share of the municipality area. These results are shown in Figure 4. Most of the forested areas saved by the PPCDAM are on the deforestation arch. There is also a visible projection of darker areas following the course of the Amazon River. The predictions of non-deforested areas south and southeast of the deforestation arch are certainly an overshoot. Those are areas in which the Amazon Forest meets the Cerrado (Central Savannas), and there is a high proportion of municipal areas that are originally non-forested. So, the fact that observed deforestation was low does not necessarily mean that the PPCDAM plan was effective, but rather that there is not much forest to be deforested.

That suggests that the actual number of square kilometers saved by the plan for the entire Amazon might be slightly lower than the number we have been working with. We can also use the predictions of the forested areas saved by the plan and compare the 2015 picture of cumulative deforestation with the cumulative deforestation that would exist had the plan not been enacted.

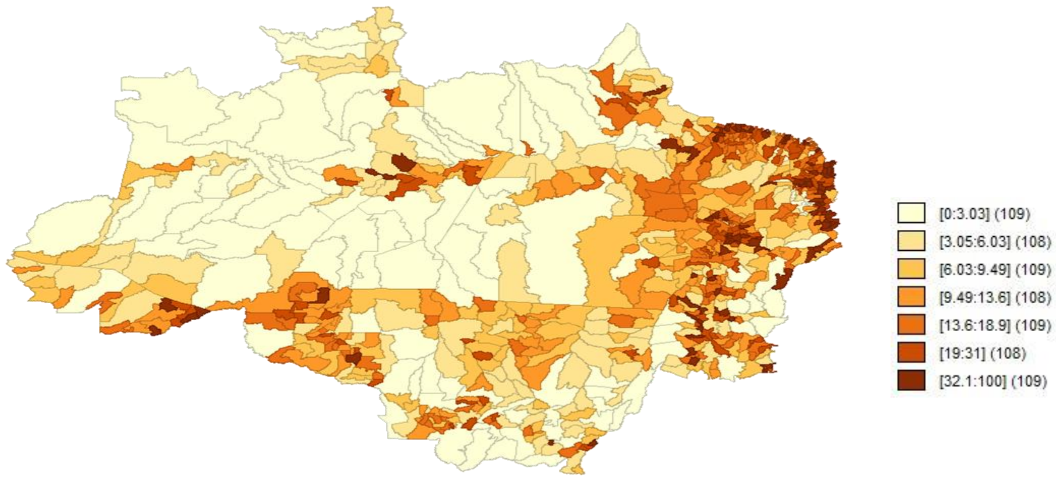

Figure 4. Forested Areas Saved by PPCDAM as a Share of Municipal Area (Note 11)

Figures 5 and 6 depict the results, in which the figure 5 shows the actual cumulative deforestation in the Amazon in 2015 and the figure 6 shows the counterfactual cumulative deforestation. Hence, these figures show how Amazon would look like by 2015 if the PPCDAM was never implemented.

A previous discussion should be made to show how we validate the model presented in this article. At first, we use a theoretical model, according to equations 1, 2, 3, and 4, showing that if deforestation exceeds a pre-established limit by law, those responsible for illegal deforestation will be punished. In this case, there is an incentive system to reduce deforestation.

Based on Figures 5 and 6 below, it is worth noting that, the high deforestation rates of the Brazilian Amazon in the years 2001 and 2002 provided the reasoning behind a new presidential decree signed in July 2003 that would create a permanent group of inter-ministerial work, whose objective was to draw up a new set of joint actions to fight the deforestation of the Amazon, ultimately giving rise to PPCDAM. After its implementation in April 2004, there was a noticeable reversal in the trends, with sharp reductions in the deforestation rates of the Amazon. Over the years, new guidelines and strategies have been added to PPCDAM to adjust it to the new dynamics of deforestation.

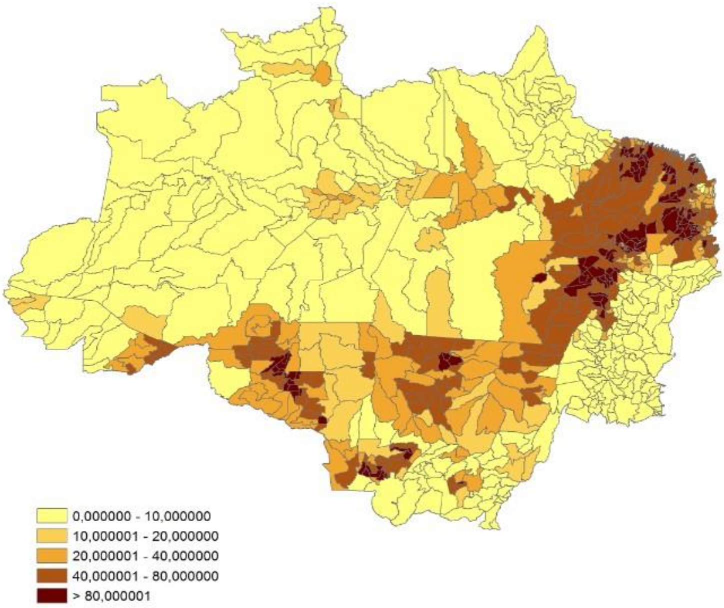

Figure 5. Actual cumulative Deforestation

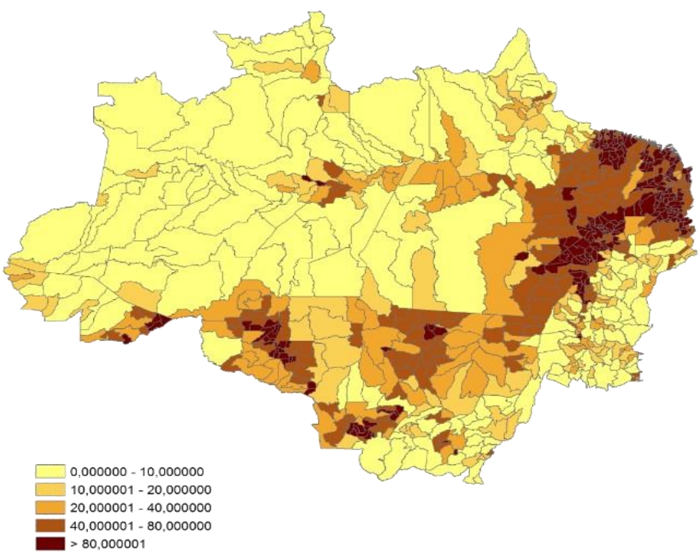

Figure 6. Counter factual cumulative Deforestation (Note 12)

In this context, deforestation in the Amazon rainforest began to be monitored based on new satellite technologies. Thus, with the help of these new technologies, the deforestation process is reduced as a result of the punishments resulting from the new environmental policy, due to this new regulation that was implemented in the mid-2000s by the Brazilian Government, based on the "Plan for Prevention and Control of Legal Amazon Deforestation", (PPCDAM).

Besides, according to empirical results, we perform a counterfactual exercise that measures the overall effect of the PPCDAM. The idea is to find out the numbers for the Amazon deforestation if the PPCDAM was not implemented. In this case, in a counterfactual exercise, the results suggest that the policy prevented 196 thousand square kilometers of Amazon Forest from being wiped out between 2005 and 2015. That number is 4.9% of the entire Brazilian Amazon Forest. It is almost twice the amount of actual deforestation that occurred in the same period.

In other words, considering the dimension and complexity of the Amazon, new efforts to curb deforestation have always faced some skepticism. No matter how officials tried to enforce the environmental laws, ranchers and loggers performing illegal cuttings were always one step ahead. However, the introduction of new monitoring technologies this time around seems to have been the real game changer when we look at the recent Amazon deforestation numbers.

5. Conclusions

This paper analyses the determinants of deforestation in the Brazilian Amazon, with particular focus on the role played by this bold conservation policy introduced by the federal government in 2004, the PPCDAM. To do so, it relies on a panel of 760 Amazon municipalities and 15 years that is used to estimate the effects of traditional deforestation drivers, like cattle herd and soybean crops, as well as the effect of the conservation policy. The main findings are that population growth, cattle herd, permanent and temporary crops, and soybean crops significantly affect deforestation. Moreover, the conservation policy significantly reduced deforestation. It changed the way the forest structurally relates to fluctuations in the commodity markets. With PPCDAM, deforestation became less sensitive to fluctuations in crop areas and cattle herds in the Amazon. In a counterfactual exercise the results suggest that the policy prevented 196 thousand square kilometers of Amazon Forest from being wiped out between 2005 and 2015. That number is 4.9% of the entire Brazilian Amazon Forest. It is almost twice the amount of actual deforestation that occurred in the same period.

The results obtained here suggest that a well-designed conservation policy can be very effective in curbing the deforestation process of rain forests. In fact, the Brazilian Amazon experience should be investigated, improved, and perhaps the main structure of a plan such as PPCDAM could be replicated in other rain forests that are going through deforestation processes. After all, 4.9% of the Amazon, along with all the biodiversity that has been preserved, in just 11 years is a formidable gift to the future generations.

References

Andersen, L. (1996). The Causes of Deforestation in the Brazilian Amazon. *The Journal of Environment & Development, 5*(3), 309-328. https://doi.org/10.1177/107049659600500304

Azevedo-Ramos, C., & Moutinho, P. (2018). No man's land in the Brazilian Amazon: Could undesignated public forests slow Amazon deforestation? *Land Use Policy*, (73), 125-127. https://doi.org/10.1016/j.landusepol.2018.01.005

Barona, E., Ramankutty, N., Hyman, G., & Coomes, O. (2010). The role of pasture and soybean. *Environmental Research Letters, 5*, 1-9. Retrieved from https://doi.org/10.1088/1748-9326/5/2/024002

Ellwanger, J. H., kulmann-leal, B., kaminski, V. L., Valverde-Villegas, J. M., … & Chies, J. A. B. (2020). Beyond diversity loss and climate change: Impacts of Amazon deforestation on infectious diseases and public health. *Biological Sciences, An. Acad. Bras. Ciênc., 92*(1). https://doi.org/10.1590/0001-3765202020191375

Fearnside, P. (2005). Deforestation in Brazilian Amazonia: History, rates and consequences. *Conservation Biology, 19*, 680-688. https://doi.org/10.1111/j.1523-1739.2005.00697.x

Ferraz, C. (2001). Explaining agriculture expansion and deforestation: Evidence from the 1980/98. *Texto para Discussão 828*, IPEA, 1-42. https://doi.org/10.2139/ssrn.294307

L'Roe, J., Rausch, L., Munger, J., & Gibbs, H. (2016). Mapping properties to monitor forests: Landholder response to a large enviromental registration program in the Brazilian Amazon. *Land Use Policy, 57*, 193-203. https://doi.org/10.1016/j.landusepol.2016.05.029

Margulis, S. (2004). Causes of Deforestation of the Brazilian Amazon. *World Bank Working Paper, No. 22*. Retrieved from https://openknowledge.worldbank.org/handle/10986/15060

Notes

Note 1. IBGE reports that around 80% of all the deforestation in the Brazilian Amazon originates from cattle ranching.

Note 2. It is a conventional wisdom for forest engineers that it would take more than 100 years for a full restoration of biodiversity in regenerated rain forests such as the Amazon. Even though, they might have their canopy layers very close to an untouched forest in a matter of a few years, with both types of forest looking identical from a satellite perspective.

Note 3. The graphs were generated by the Gretl software.

Note 4. Nominal prices, in US dollars.

Note 5. The graphs were generated by the Gretl software.

Note 6. INPE's municipal data starts in 2000, but the first observation in the time series is lost because deforestation is defined as the first difference of the total cleared areas.

Note 7. The idea is that any type of cost, no matter how prohibitive, has its equivalent in monetary terms.

Note 8. Soybean is a temporary crop. So, when we aggregate all the temporary crops, we can either include or exclude the soybean crop areas from this number. We decide to include it. So, our measure of temporary crops does include soybean crops. That would be a problem if soybean crops were a major component of temporary crops in most Amazon municipalities, which could be a source of multicollinearity. It is definitely not the case. We also did all the regressions with a measure of permanent crops that excluded soybeans, and the results were very similar.

Note 9. According to these authors the environmental policies saved 62 thousand square kilometers of forest between 2005 and 2009.

Note 10. The graphs were generated by the Gretl software.

Note 11. The map was generated by the GeoDa software.

Note 12. The maps were generated by the ArcGIS software.

Copyrights