Protected Areas' Deforestation Spillovers and Two Critical Underlying Mechanisms:

An Empirical Exploration for the Brazilian Amazon

by

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Duke University

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Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University Program in Environmental Policy in the Graduate School of Duke University

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ABSTRACT

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Abstract

To date, the creation of protected areas (PAs) has been the dominant policy in the efforts to protect forests. Yet there is still somewhat limited rigorous evidence about the impacts of PAs on rates of deforestation. Further, most of the existing evidence concerns the impacts of protection within the boundaries of PAs. Much of that existing evidence does not use the characteristics of the protected lands when generating the baselines to which outcomes on protected lands are compared in order to infer the PAs' impacts. Yet even when impact within a PA has been estimated as rigorously as possible, since the total impact of protection involves impact not only inside the PA but also outside the PA even the best possible estimates of impacts within PAs could mis-state total PA impacts. Overstatements occur if there is "leakage" from PAs, i.e., spillovers of activities to forests outside PAs, so deforestation outside is higher than it would have been without the PAs.

My dissertation starts with a reduced form examination of net local spillovers. We follow this with an evaluation of two mechanisms through which PAs could affect forest nearby. In particular we explore two novel angles by considering both migration choices and road building decisions. PA creation could affect the development equilibrium by shifting private and public expectations to lower migration and road building where the PA is established, beyond the PA's boundaries. My dissertation

explores implications of such thinking and provides novel empirical evidence for the Brazilian Legal Amazon.

Chapter 1 estimates deforestation spillovers around Brazilian Amazon PAs. Given PA location bias towards regions with low deforestation pressure, we use matching methods to control for observable land characteristics that may confound PAs' impacts. Specifically, we compare 2000-2004 and 2004-2008 deforestation on the land nearby to PAs with clearing of untreated forests similar in key deforestation determinants. We find that some PAs reduce deforestation rates nearby and, consistent with deforestation impacts inside PAs, those local spillovers vary across the landscape. Reductions are significant near roads and cities – not expected if the result is due to insufficient empirical controls but unsurprising if real impacts are arising due to PAs – and around an understandable subset of PAs. This result contrast sharply with most existing analyses of PAs' spillovers where, if anything, 'leakage' (higher nearby clearing) is discussed and observed. Yet we affirm a more general point that local spillovers depend on local development dynamics.

Chapter 2 examines one mechanism for the prior result that PAs lowered rates of deforestation nearby. Given migration's importance throughout the history of this forest frontier, we ask whether dissuading migration could be a mechanism for protection's local conservation spillovers. Examining individual migration decisions among the Amazon municipalities, we find that Federal PAs – previously seen to reduce rates of deforestation near PAs – seem to encourage outmigration from and discourage migration to PA areas.

Chapter 3 examines another mechanism for the result in my Chapter 1. We consider a recent expansion of the unofficial roads networks in the Brazilian Amazon to provide initial evidence concerning whether PAs may affect such investments in development. Specifically, controlling for prior roads – both official and unofficial – we test whether the growth in unofficial roads between 2008 and 2010 is reduced by establishments of PAs. Thus, we examine road growth as another potential mechanism for forest spillovers from PAs. Controlling for relevant observable factors, and using both matching and OLS, we find that having a large fraction of municipal area in PAs – in particular Federal PAs – reduces the growth of unofficial roads. Such impacts can significantly influence regional development patterns.

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1. 'Spillover Conservation' around Protected Areas in the Brazilian Amazon

The creation of PAs has been the dominant policy in global efforts to protect forests, yet the body of rigorous evidence concerning their causal impacts on rates of deforestation remains limited. The vast majority of existing PA-impact analyses address deforestation impacts within PAs' borders and most do not use the sites' characteristics to generate the baselines to which to PA outcomes are compared. Yet it is known that a bias in PA sites toward lower deforestation pressure (Joppa and Pfaff 2009) creates bias in estimates of PAs' impacts (see Andam et al. 2008 for Costa Rica, Joppa and Pfaff 2010 for global). To reduce such biases, we apply matching's explicit approach to making 'apples-to-apples' comparisons.

Yet even if impacts in PAs were estimated rigorously, we could misunderstand PAs' total impacts because the total impact of protection involves its impacts not only inside of PAs but also outside of them. Even perfect estimates of impacts inside PAs overstate net impact when deforestation "leakage" occurred, i.e., spillovers to local land uses raised nearby deforestation above what it would have been without a PA. Spillovers may be only local – e.g., deforestation nearby – but could be global if increasing market prices for timber or crops, due to local supply reductions, increase both production and deforestation elsewhere. We extend a limited empirical literature on PA spillovers by examining the deforestation on nearby lands.

Such local forest spillovers could, in theory, go in either direction, i.e., increase or decrease the clearing of nearby forest. Robalino and Pfaff 2012 discuss varied spillover mechanisms and directions for private land-use decisions taken near each other, some of which apply to spillovers from public land uses (though creating a PA might affect more area than most private land-use decisions and be longer lasting). They note that multiple mechanisms can apply to a single place and time, implying that any net spillovers could be positive or negative in aggregate, and could vary across a landscape if effects vary in magnitude (Robalino and Pfaff 2012, as well as Robalino and Pfaff 2014, show variations in spillovers' magnitudes).

We contribute with new hypotheses about spillovers that reduce nearby deforestation, plus tests of the deforestation impacts of being near a PA, using matching and regression to control for site characteristics. We examine 2000-2004-2008 deforestation in the Brazilian Amazon, an important forest frontier. Thus, my hypotheses derive from consideration of how economic development can unfold on the frontier.

Responses to PAs must be expected to vary according to development setting. For example, Robalino (2012) predicts leakage for Costa Rica, which could be expected in a mature land with existing infrastructure and labor markets. Developing frontiers can display significant endogenous responses not found in mature landscapes, though.

Within a still developing frontier like the Brazilian Amazon, that could generate a very different set of PA responses from those considered to date in the spillovers literature.

For instance, PA creation on a frontier could affect not only private migration but also public acts, such as road building, by signaling that on balance the state has determined that the region with a new PA is not a future focus for economic development (defined as, e.g., increased production and employment). Since migration and land speculation respond to expected income from production and employment, PAs could affect them by signaling that 'conservation was chosen', i.e., lower future economic development. Then, in turn, road building and maintenance by agencies that allocate resources over space may respond to development benefits, e.g., expected migration, as well as political costs of infrastructure investments. In sum, creating PAs could affect development equilibria by shifting both private and public expectations. We hypothesize that such responses to PAs could function to push development further away from PAs, i.e., to generate local 'blockage', or lower deforestation nearby, with distant 'leakage', or higher clearing. Further, who created a PA and what type of PA was created may affect such a signal and thus its impacts.

Following this line of thought, we compare lands near PAs with unprotected forest lands that are observationally most similar to 'PA buffers' forest, using matching for best apples-to-apples comparisons. We find net local blockage, i.e., lower deforestation than otherwise would be expected, around some PAs. In particular, we find this for the Federal and the Sustainable Use conservation units. Further, in looking at these spatially impactful subsets of PAs in settings of higher and lower pressure, we find that our tests present patterns that are the opposite of what is expected for spurious results (representing poor controls): false low-clearing 'halos' would be expected in distant areas but ours are significant for higher pressures.

The rest of the chapter is as follows. Section 1.1 discusses literature on deforestation spillovers from protected areas as well as other land uses and policies. Section 1.2 presents the data and matching methods. Section 1.3 then provides results, while Section 1.4 discusses both interpretations and extensions.

1.1 Spillovers Literature

1.1.1 Measured Deforestation Spillovers

As highlighted by Pattanayak et al (2010), one of the fundamental issues confounding evaluations of PA impacts is that PAs generate forest spillovers, so that total impacts differ from impacts in the boundaries of those PAs. In principle, this is well known. Yet, in practice, it is not considered in most evaluations.

Robalino and Pfaff (2012) consider causal spatial interactions in private deforestation decisions in Costa Rica by using neighboring lands' exogenously varying slopes to instrument for neighbor land uses. They highlight the fact that there are many possible sources of interaction between neighboring land uses – and much of that logic applies to interactions between private land use and neighboring public land use, e.g., between farmers' land-use choices and the establishment of a PA, which affects private incentives. For instance, establishing a PA can attract tourism. That could increase private relative returns to forest, e.g., selling forest visits to tourists versus deforesting, or lower them by raising the returns to new hotels. For private neighbors, Robalino and Pfaff (2010) find a positive interaction, i.e., deforestation will spread.

Robalino et al. 2014 extend empirical evidence by considering spillovers from Costa Rican PAs, following a prior result (within Andam et al. 2008) that the rings of forest around PAs bear no spillovers. Robalino et al. 2014 confirm this for a different time period but then they use theories about mechanisms to delineate subsets of lands near PAs where it is more or less likely to see forest spillovers. In particular, they find that land near PAs and near roads but far from park entrances (where tourism supports forests) display 'leakage', i.e., have higher deforestation rates near PAs than would be expected without protection. Near PAs and roads but also near park entrances, leakage is not found − given the influence of tourism. Yet moving further away from the entrances along the roads, tourism's effect falls and leakage reemerges.

PAs, though, are not the only conservation policies that could be expected to generate spillovers. Alix-Garcia et al. 2012 consider a significant payments for ecosystem services (PES) program in Mexico. Examining locations with significant numbers of landholders receiving such payments − raising income that loosens household constraints − they find that especially in locations that are less well connected to other markets, the additional income and demand for local production can increase deforestation nearby.

Other related literature takes a different, more market-oriented approach to modeling spillovers. For instance, modeling timber markets suggests that forest protection can have wide-ranging effects at the regional, national and even the global scale as timber is tradable and markets for the many types of timber (hardwood versus softwood, pulpwood versus sawtimber, tropical versus temperate/boreal) are connected.

Sohngen, Mendelsohn and Sedjo (1999) developed a forward-looking dynamic global model of timber markets to try to capture how timber supply is likely to react to future rises in demands for timber. In their model, timber suppliers anticipate such future shifts in demand and make efficient investments in future timber supplies (which can rely on long-term growth). Besides analyzing impacts of higher future demand on prices, investments in regeneration, establishments of plantations and output using this model, the authors study the effects of two forest-conservation strategies that generate system-wide predictions. They conclude that set-asides, e.g., could increase forest harvest elsewhere, particularly in natural forests.

Sohngen and Brown (2004) estimate the leakage from forest-based carbon projects which seek to reduce carbon emissions from timber harvesting in tropical forests – treating Bolivia as a timber supplier. They measure leakage as a difference in net national carbon emissions from timber harvesting when comparing a baseline with a scenario where part of the forested land is removed from the concession base. Leakage is measured over 30 to 50 years. Under different assumptions on global sequestration policy, capital constraints, demand elasticity and rate of wood decomposition, leakage ranges from 2% to 42% (to get a further sense, it is lower when demand is more elastic and wood decomposition rates are faster).

Using this approach, Sun and Sohngen (2009) study set-asides within global carbon sequestration using a global mode of land use and forestry to test three possible schemes for awarding set-aside credits. They show that while such forest-set-asides policies could generate significant leakage in the near term, in the longer run carbon is removed from the atmosphere on net. Leakage is estimated to be 47-52% depending on the crediting scheme. They argue in particular that set asides yield leakage when utilized in the absence of credits for other carbon-sequestering actions. Such analyses provides a very useful global perspective on leakage, one relevant for comparing local and total leakage even within a nation or region, although one not designed as a direct substitute for the kind of empirical local assessment we apply here.

1.1.2 Potential Spillover Mechanisms: Empirics & Models

Other than timber-market models, few empirical studies try to show through what mechanisms policies could be affecting environmental and socioeconomic outcomes of interest outside the policy boundaries. Ferraro and Hanauer (2014) present a framework to explore how PAs might affect poverty in Costa Rica that focuses on three mechanism: changes in tourism and recreational services; changes in infrastructure such as roads, health clinics and schools; and changes in regulating and provisioning ecosystem services. They find most of the poverty reduction associated with the creation of PAs in Costa Rica is attributable to tourism. Robalino and Villalobos (2014) also provide evidence that such impacts of PAs in Costa Rica are due to tourism, including by using park entrances, while Sims (2010) provides evidence for Thailand.

Various hypotheses exist for how PAs might affect nearby deforestation. Some authors argue that conservation policy (which could mean PAs or PES or other acts) can increase environmental awareness (Scheldas 2005) and may promote tourism, which requires forest protection on private land (Stern 2003). Those types of conceptual models would tend to suggest that PAs might reduce the deforestation nearby. Others argue that land restrictions for PAs surely will displace development toward unprotected lands (Wu 2000, Wu 2005, Robalino 2006, Armsworth et al. 2006). Further, facing a threat of 'takings' for PAs, landowners could choose to preemptively deforest to avoid any land restrictions (Newmark 1994, Fiallo and Jacobson 1995). These latter conceptual models suggest PAs could increase the deforestation nearby.

Clearly it matters which conceptual models are relevant and, critically, that varies a lot by setting. In the case of a mature land and labor markets, such as the U.S. or for a developing country in Costa Rica, some responses to PA creation like tourism employment are more likely than on the developing frontier. Further, it can be hard to disentangle effects as there may be more regulatory capacity than on a frontier. When development processes are ongoing out on a frontier, however, additional reactions can be in play. Entire regions or sub-regions will be entirely changed, or not, depending on public and private decisions that are interlinked, e.g., choices to invest in infrastructure that affect but also are motivated by migration. Thus, the set of large-scale private and public responses to conservation may be larger − in number and in magnitude or consequence − as development plays out. Those could imply quite significant spillovers.

For the Brazilian Amazon in recent decades, we hypothesize that the creation of a PA can signal a change in a regional development path that could affect both private migration and public road building − which also will affect each other. In a frontier setting such as the Brazilian Amazon, where most PAs do not feature much tourism, the establishment of a PA may signal less development to a number of parties. That may discourage migration which, in turn, may help to discourage road building and maintenance. While few if any studies to date provide clear evidence on migration underlying forest impacts from PAs, the importance of studying population dynamics and its links to conservation was noted by Joppa (2012). As human populations have grown exponentially, increased numbers of people must live close to PAs, creating greater anthropogenic pressure. Yet it is less clear how the PAs influence nearby human activity.

Private migration choices are thought to respond in part to changes in individuals' expectations of potential employment and income in each candidate migration destination, including the current location. Creation of a PA may signal that in the relevant political economy, forces in favor of conservation have gained traction relative to those for economic development. If so, one might well lower one's expectations of standard frontier development investments (e.g., schools or health posts) and migrants may stay away.

Moving to potential public development responses to conservation − likely both public actions − creating new roads or maintaining existing roads are ways to pursue the goal of economic development. However, an allocation of scarce resources to maintain a road may not seem worthwhile if other factors limit the migration and thereby the development response to that investment: if nobody will use the road, then the resources should go elsewhere. Indeed, in the Brazilian Amazon roads have gone to ruin when initial investments yielded little use − lowering development expectations and so lowering maintenance.

Such private and public responses to the creation of a PA could magnify the PA's local impacts, while likely also creating non-local leakage. That could significantly shift optimal PA locations and types. A complete assessment of PAs' potential spillovers, then, would involve empirical assessment of which of many potential consequential responses actually occur (e.g., shifts in migration, infrastructure and more). This paper starts with a reduced-form test of forest spillovers, to see whether any appear to be present, with the caveat that just as in Robalino et al. 2014 the right theory of spillovers could guide better testing.

1.2 Data and Empirical Strategy

1.2.1 Dependent & Independent Variables

Deforestation

We study 2000-2004 and 2004-2008 deforestation using PRODES data for 2000, 2004 and 2008 from the Brazilian space agency, INPE (*Instituto Nacional de Pesquisas Espaciais*). For a single pixel in the data, the data set indicates a single land-cover class. Thus, deforestation is measured here as a change from the forested to the non-forested land cover. For each forest pixel in 2000, our deforestation variable is binary (= 1 when forest in 2000 but not in 2004, and = 0 when forest in both years) and for each forest pixel in 2004, again deforestation is binary (= 1 when forest in 2004 but not 2008, = 0 when forest in both years).

The original PRODES dataset was downloaded, in a raster format, from the INPE web site in Geographic Coordinate System, South American Datum of 1969. The cell resolution of the raster data was 0.000808 decimal degrees, which is equivalent to 2.9088 s, or 90 m around the equator once it is projected. INPE's own analyses, since the year 2001, in fact have been conducted at a finer scale, then results have been resampled to 90x90m, in order to create the downloadable version of these data sets.

Protected Areas

The Brazilian Legal Amazon is a region of 521,742,300 hectares (that is approximately 5 million km^2). About 30 percent of the Legal Amazon currently is under one of the following forms of protection, within one of 532 protected areas in total: 7% (within 104 areas) is within all of the Federal Conservation Units; 4% (114 areas) is within the State Conservation Units; while 19 % (314 areas) is in the Indigenous Lands. Taken on aggregate, which is the scale we work at here, that is a very large fraction of an immense area.

Figure 1 presents the number of protected hectares for each of these categories during 1959-2008. We can see that most of protected areas were established during 1990-1999, especially in the cases of the State Conservation Units and the Indigenous Lands. However, most of the land that has been protected within the Federal Conservation Units so far was protected during the 1980-1989 and 2000-2008 periods. Again considering all of this protection on the whole, most of the PAs were created before our 2000-2004 period of deforestation while, of the rest, a large fraction were created before our 2004-2008 time period.

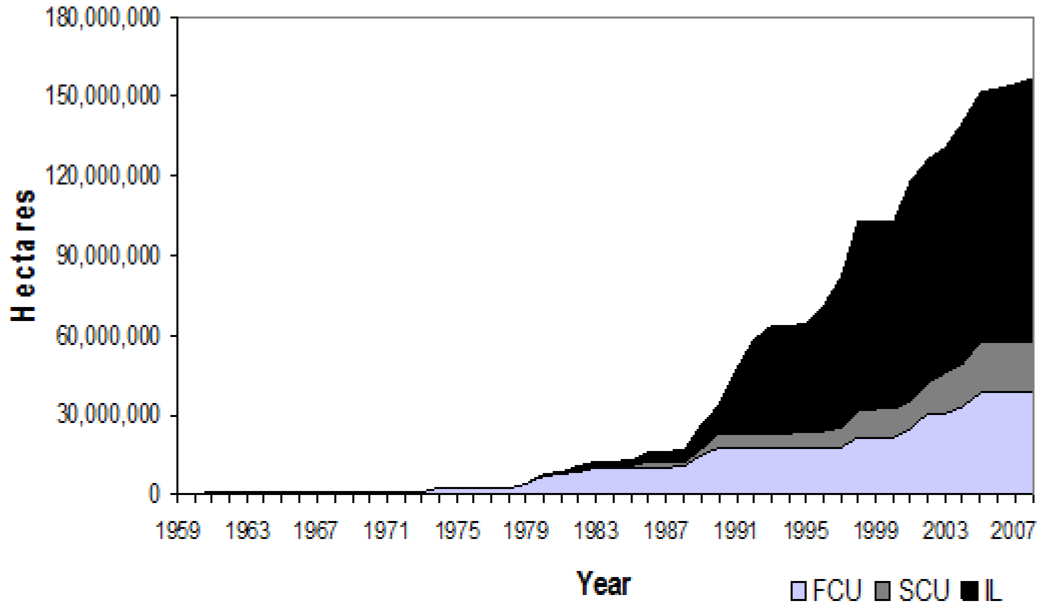

Figure 1: Hectares of PA created by year (cumulative), Federal (FCU), State (SCU) and Indigenous Lands (IL)

Land & Site Characteristics

Many factors that affect the benefits and (direct or opportunity) costs of clearing forests have influence on deforestation. Since relative profitability can lead local stakeholders to resist creation of protected areas – which limit productive activities – many of those same factors can be expected to influence siting of PAs. Any factors that affects both types of decisions are liable to bias empirical estimation of PAs' impacts.

To better estimate the impacts of protected areas on deforestation rates within or nearby to PAs, we need to control for the influences of the factors we observe that affect the profitability of deforestation. That includes various relevant characteristics of a location that are not physical features of the land itself, such as the distance to the nearest road in 1985 (a date that is chosen because it is before most protection) as well as the distances to the nearest city in 1991 (the date again was chosen to be before the protection). Another relevant distance is that to the forest's edge because it is harder to access land deep in the forest. For analyses of 2000–04 deforestation, we use distance to forest edge in 2000; for 2004–08 deforestation, we use that distance in 2004, in both cases employing the same data for deforestation that we have just discussed. Digital road maps were from the Department of Geography at Michigan State University, based on paper maps by DNER (*Departamento Nacional de Estradas de Rodagem*), an agency in the Transport Ministry in Brazil. The information on 1991 cities comes from the Demographic Census.

We also use maps of various relevant biophysical conditions. We employ an index of soil quality, a continuous measure of rainfall (from Laurance et al., 2002), a binary indicator of slope (distinguishing, e.g., "steeply sloped" from "rolling hills") from the 'Diagnostico' data of IBGE (*Instituto Brasileiro de Geografia e Estatistica*) and and indicator of cerrado vegetation. Table 1 confirms the relevance of such factors concerning deforestation, while Table 2's descriptive statistics suggest they affect PA siting too.

Table 1: Factors Affecting the Probability of Deforestation in Non-Protected Areas

Logit Regression	*Deforestation 2000-2004*	*Deforestation 2004-2008*
log (Road Distance)	-0.1849***	-0.0973***
	[0.007]	[0.015]
log (City Distance)	-0.7181***	-0.1868***
	[0.012]	[0.015]
log (Edge Distance)	-0.1002***	-0.684***
	[0.007]	[0.010]
Flatter Slopes	0.3125***	0.0207
	[0.020]	[0.020]
Soil Fertility	-0.0572***	0.0663***
	[0.008]	[0.010]
Rainfall Amount	-0.0000***	-0.0000***
	[0.000]	[0.000]
Vegetation Type	-0.4933***	-0.0859***
	[0.008]	[0.039]
Rondonia & Acre	1.9253***	2.000***
	[0.047]	[0.053]
Maranhao & Tocantins	4.0857***	2.2051***
	[0.045]	[0.067]
Pará & Amapa	2.4271***	1.8175***
	[0.039]	[0.045]
Mato Grosso	2.6651***	2.5040***
	[0.041]	[0.047]
constant	5.2850***	2.222***
	[0.125]	[0.162]
# obs	322,932	281,996

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table 2: Factors Affecting the Probability of Protection Overall

	All Protected Areas Before 2004
log (Road Distance)	0.2826***
	[0.003]
log (City Distance)	0.8418***
	[0.005]
log (Edge Distance)	0.0674***
	[0.002]
Flatter Slopes	-0.1146***
	[0.009]
Soil Fertility	-0.0235***
	[0.003]
Rainfall Amount	-0.0000***
	[0.000]
Vegetation Type	-0.0149
	[0.018]
Rondonia & Acre	1.3251***
	[0.012]
Maranhao & Tocantins	1.1445***
	[0.031]
Pará & Amapa	-0.1225***
	[0.008]
Mato Grosso	0.0996***
	[0.012]
constant	-13.6862***
	[0.070]
# obs	453,254

Observations & Our Sample

We start with a sample of 800,000 pixels. If the land-cover information available (which is 16 categories) does not clearly indicate that the point was in forest cover, then we simply drop the observation (that would include all of the categories *No Data, Non Forest, Water, Clouds,* and *Residual*). That leaves us with a sample of ~ 450,000 pixels in forest in 2000 (and in 2004) that can be examined for deforestation.

1.2.2 Matching Approach

If protection in the Brazilian Amazon had been implemented randomly across all forest lands, its impacts would be easy to estimate. We would only need to look at the difference between deforestation rates on treated land (inside or near PAs) versus untreated. The latter would provide an unbiased estimate of what would have been the treated deforestation rate had there been no PAs, as other factors would cancel out.

However, PAs do not appear to have been located in a 'random-like' fashion. PAs' sites are biased in terms of deforestation-relevant land and site characteristics, including the distances to roads and cities (Figure 2). Thus observed differences in deforestation between treated and unprotected lands reflect not only impacts of protection but also the influences of characteristics. To remove those influences, we use matching. The principle of this technique is to find an improved and acceptable control group by matching each treated observation to the most similar untreated observations, for more of an 'apples to apples' comparison.

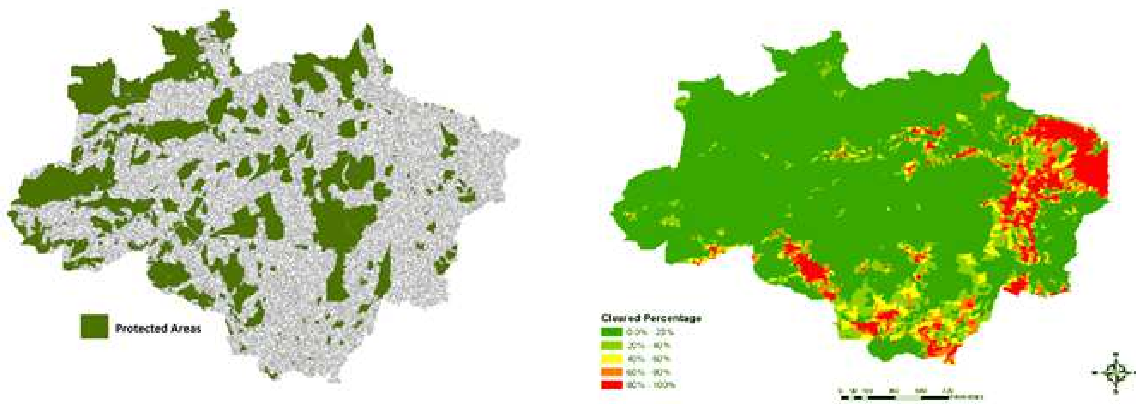

Figure 2: Protected Areas (Left) and Cleared Percentage by 1991 (Right)

For example, PAs and their 'buffers' may be in relatively low-productivity areas for agriculture. If so, to test for net spillovers we should compare deforestation near to PAs to that low-productivity areas far from PAs. Matching does so using multiple observed characteristics. To the extent observed factors we have on hand to identify differences in the profitabilities of different locations do capture important relevant differences, matching should reduce potential impact-estimation bias caused by PAs' locations.

To define similarity, we used propensity scores. This matches treated (PA buffer) and untreated observations based on probability being treated. Thus, PA-buffer outcomes are compared to deforestation also not in PAs but further away, with similar characteristics yielding similar treatment probabilities. The probabilities in question, i.e., of being within a PA buffer, are generated by a probit model for PA buffers. The regressors are variables we think could affect where the PAs, and thus buffers, are located (following Rosenbaum and Rubin 1983). We implement the estimator developed by Abadie and Imbens (2012) that adjusts for the 1st-step estimation of propensity scores and incorporates a large sample variance estimate.

With similarity defined, we choose how many untreated observations to compare to each treated. As that increases, the variance of the estimator will decrease because it will be based on more data. However, the bias increases, as we have gone beyond the most similar unprotected pixels to less similar.

1.3 Results

1.3.1 Where Are Deforestation & Protection?

To motivate the use of empirical controls for the factors in deforestation that are present within our data, Table 1 presents a regression of factors that affect deforestation rates on unprotected land. This confirms that the variables we have in the data set, since in principle they are relevant, do seem to be relevant.

Table 2 then considers where protection is located, which compared to Table 1 can suggest biases in the estimation of PA impacts on deforestation if the locations of PAs are high or low in deforestation. Table 2 confirms (as in Joppa and Pfaff 2009's global analysis) that PAs are far from roads and cities, as well as the forest edge. They are also less likely to be on flatter slopes that have higher agricultural profit. Juxtaposing this with Table 1's impacts of the same variables on deforestation suggest that without control for the characteristics of protected sites analyses will tend to overestimate the deforestation impacts of PAs because the locations with more PAs are also the locations that tend, all else equal, to lower deforestation.

Table 3 then shows the average land characteristics for the different categories of protection that we consider here in examining the local deforestation spillovers from protection and how they may vary. Clearly, these characteristics vary across PA types and actors, motivating attention to variation in impacts. Some differences are expected, e.g., state PAs are farther from roads compared to the federal PA average. Others are not. State integral PAs are closer to roads than state sustainable use, though enforcement also matters, yet federal sustainable use are closer to roads than federal integral. The latter is more expected.

Table 3: Different Subsets of Protected Areas' Observable Characteristics

	FCU	SCU	IL	IP	SU	FCU-IP	FCU-SU	SCU-IP	SCU-SU
Distance To Road 1985	107	159	111	111	132	120	94	63	183
Distance To City 1991	84	78	132	97	72	97	72	96	74
Fertility Index	3.17	2.94	2.91	2.90	3.23	2.92	3.42	2.76	2.99
Rain Index	2,339	2,488	2,265	2,444	2,351	2,511	2,174	2,089	2,585
Slope	0.49	0.76	0.57	0.54	0.60	0.49	0.50	0.78	0.75
Vegetation Index	0.00	0.03	0.05	0.02	0.01	0.00	0.01	0.12	0.01
Rondonia-Acre	0.18	0.36	0.10	0.15	0.29	0.12	0.24	0.36	0.36
Maranhao-Tocantins	0.01	0.00	0.01	0.02	0.00	0.02	0.00	0.03	0.00
Pará-Amapá	0.34	0.08	0.31	0.16	0.32	0.19	0.49	0.01	0.10
Mato Grosso	0.00	0.04	0.09	0.03	0.00	0.00	0.00	0.2	0.00
Amazonas-Roraima	0.47	0.52	0.49	0.64	0.59	0.67	0.27	0.40	0.54
# obs	3,156	1,512	9,568	1,842	2,826	1,547	1,609	295	1,217

1.3.2 Matching Methods for Controls

Given some statistically significant characteristics differences before matching, both between protected and unprotected and between subsets of protected areas, we would like to use matching to find subsets of treated and untreated points that are quite comparable in terms of all of their non-treatment characteristics. Table 4 shows that across many comparisons we would like to make to evaluate a suite of PA impacts, the matching that we have tried overall seems to be doing a pretty good job in reducing the potential for bias. Putting that another way, the matching seems to reduce most characteristics differences to insignificance. However, it is notable that for state PAs, in particular state integral, some significant differences remain.

Table 4: Matching Balances (treated - untreated differences in characteristics)

		FEDERAL			STATE			INDIG
		ALL FED	FED INTEG	FED SUST	ALL STATE	STATE INTEG	STATE SUST	ALL INDIG
Distance To Road 1985	*Before*	0.09**	-0.6***	0.19***	-0.19***	-0.16	0.58***	0.25***
	After	0.01**	0.2	0.06	0.00	0.29**	0.17*	0.02
Distance To City 1991	*Before*	-0.0**	0.18**	-0.1***	-0.9***	0.01	-0.2***	0.05**
	After	0.02	-0.02	0.1**	0.9**	0.1**	0.04	-0.03
Fertility Index	*Before*	0.29***	0.39***	0.26***	-0.19***	-0.23***	-0.14**	-0.09***
	After	-0.08	-0.07	-0.01	0.00	0.19	-0.04	-0.07
Rain Index	*Before*	-2.5	84.9**	-22.2	41.8**	-95***	5.1	59.6***
	After	21.27	54.3	-11.6	6.22	104	34.1*	-15.5
Slope	*Before*	-0.18***	-0.2***	-0.1***	0.08***	0.13***	0.12***	0.00
	After	0.03	0.04	-0.01	0.02	-0.04	-0.02	0.00
Vegetation Index	*Before*	0.00	0.09***	-0.00	0.04***	0.30***	-	-0.02***
	After	0.00	0.03	-0.00	-0.01	-0.03	-	-0.00
	# treated	772	103	680	477	133	344	1,100
	# untreated	11,849	11,569	11,849	14,064	14,064	10,937	14,344

*** p < 0.01, ** p < 0.05, * p < 0.10

1.3.3 Spillovers On Average & By Actor And Type

We find that, on average across all PAs, the spillovers results are not statistically significant (similar to a finding by Andam et al. 2008, while Robalino et al. 2012 find effects when breaking into subsets for Costa Rica). Given the immensity of the Brazilian Amazon, and the varied dynamics into which protection intervenes, perhaps this is not surprising. For this complicated subject, averaging might simply bury varied impacts.

Table 5 shows the results of our propensity-score matching to estimate the 2000-2004 and the 2004-2008 deforestation spillovers for three PA subsets: Federal PAs; State PAs; and Indigenous Lands. We present the results for the three buffers (concentric rings). The significant impacts clearly are Federal, consistent with the federal government being the significant exogenous intervening actor in this region. We note that those dependably significant Federal impacts are negative terms. This contradicts concerns with local leakage – although not broader leakage since pressure deflected locally can go elsewhere – i.e., there appears to have been statistically significantly lowering of deforestation near the Federal PAs.

Table 5: Spillovers By Actor

2000-2004 Deforestation			
PROPENSITY SCORE MATCHING	*Pre-2000 PAs*		
	Federal	**State**	**Indigenous**
0 - 10 km	-1.34%***	0.76%	-0.10%
0 - 20 km	-1.11%***	0.32%	-0.00%
0 - 30 km	-0.93%***	-0.74%**	0.43%***
2004-2008 Deforestation			
PROPENSITY SCORE MATCHING	*Pre-2004 PAs*		
	Federal	**State**	**Indigenous**
0 - 10 km	-0.77%***	-0.03%	-0.27%
0 - 20 km	-0.63%***	-0.10%	0.17%
0 - 30 km	-1.34%***	-0.13%	-0.13%

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Table 6 then asks which Federal actions appear to most drive such effects, as we split the Federal and State PA groups (split by actor) both down into Integral Protection and Sustainable Use (by type too). For the earlier period of deforestation, whatever deforestation-reducing interactions drive these spillovers appear to be larger for the Federal Sustainable Use PAs.[1] Sustainable Use PAs permit local smallholders some

[1] We note in Table 6 that for the second period of deforestation, the complete lack of negative significance is simply consistent with the great preponderance of the results by actor within Table 5. However, we must also note that for the

rights to produce within the PAs, seemingly helping PAs to be located in higher-pressure locations (although the difference between impacts by type does not appear to be strong for the later deforestation).

At least the clear differences by actors surely could matter for international funders considering through whom they should run their funds for carbon storage, as within REDD+, or habitat for species, as is one objective for the GEF's focus upon biodiversity. Also it could matter for domestic decisions about how to do forest protection, as it could easily be that political costs of PAs are lower for Sustainable Use.

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first deforestation period, the state integral protection PAs appear in Table 6 to be generating negative spillovers. That seems potentially surprising and worth better understanding (recalling that those PAs are close to roads as well) but we also sound a note of caution based on Table 4. It could easily be that the failure to have excellent balances on distances to roads and cities for the matching evaluation of state integral PAs taints our ability to draw conclusions.

Table 6: Spillovers by Actor and Type

2000-2004 Deforestation				
PROPENSITY SCORE MATCHING	***FEDERAL** PAs (pre-2000)*		***STATE** PAs (pre-2000)*	
	Integral Protection	**Sustainable Use**	**Integral Protection**	**Sustainable Use**
0 - 10 km	-1.32%***	-2.33%***	-0.39%	-0.76%
0 - 20 km	-0.73%***	-2.63%***	-2.01***	-0.60%
0 - 30 km	-0.36%**	-2.76%***	-2.46%***	-0.02%
2004-2008 Deforestation				
PROPENSITY SCORE MATCHING	***FEDERAL** PAs (pre-2004)*		***STATE** PAs (pre-2004)*	
	Integral Protection	**Sustainable Use**	**Integral Protection**	**Sustainable Use**
0 - 10 km	-1.41%***	-1.24%***	-0.53%	0.78%*
0 - 20 km	-0.93%***	-1.23%***	-0.04%	0.03%
0 - 30 km	-0.86%***	-1.15%***	-0.01%	0.79**

*** p < 0.01, ** p < 0.05, * p < 0.10

1.3.4 Robustness Checks Using Pressure

Stepping back to consider the nature of the evidence provided in the, say, Tables 5 and 6, we must concede that despite their significance in Tables 1 and 2, the number of observable controls is small. Thus, especially a finding of relatively low deforestation rates nearby to PAs seems not obviously clean, since PAs are known to have relatively distant sites and observables factors may not sufficiently control. Unobservable characteristics that make the sites bad for profits could easily be the reason PAs went there.

Perhaps, though, we may use proxies from the past for unobservable factors in clearing pressure. Should we be able to identify locations where we think that unobservable rises in deforestation pressures were likely to be higher, at least compares with others places they were likely to be lower, that could help within this inference. We suspect that spurious negative effects are less likely where the pressure is high.

Thus, in Tables 7 and 8 we have split the sample of buffers around the subsets of PAs found to be impactful above in terms of local deforestation spillovers, i.e., Federal and Federal-Sustainable Use PAs, by the distances to prior roads (distance in 1985) and to cities (small, medium and large cities in 1991). Both of them are likely to proxy for decades of upward evolution in deforestation pressure, given the likelihood that new development often tends to follow upon older or prior development within a region. Should our spillovers estimates actually be spurious negatives that are due to a weakness of our controls, then we would expect to see even larger such "effects" for the PA-buffer points far from development. If on the other hand our results really represent some local blockage of development to reduce deforestation, then we would expect to see larger and more significant such blockage effects close to prior development, i.e., for the PA-buffer points closer to prior roads and cities where new unobserved roads and more arose.

Using that logic, Tables 7 and 8 clearly support that we are finding actual local forest spillovers. Within both of these impactful subsets of PAs – again talking in terms of local spillovers shown here – most of the statistically significant reductions in deforestation happen in the PA-buffer locations that are closer to prior roads and cities. The effects for the more distant buffer points are generally not significant. Thus, it would appear within these results as though the PAs may be having local spillover effects that benefit local forests – possibly because they are dissuading investments in migration and infrastructure.

Table 7: Federal Spillovers by Pressure Subsets

Propensity Score Matching	*2000-2004 Deforestation & Federal PAs (pre-2000)*			
	LOW Road Distance	**HIGH Road Distance**	**LOW City Distance**	**HIGH City Distance**
0 - 10 km	-3.64%***	-0.37%	-2.67%***	0.01%
0 - 20 km	-2.81%***	-0.42%	-1.74%***	0.10%
0 - 30 km	-2.00%***	-0.74%**	-1.35%***	0.24%
Propensity Score Matching	*2004-2008 Deforestation & Federal PAs (pre-2004)*			
	LOW Road Distance	**HIGH Road Distance**	**LOW City Distance**	**HIGH City Distance**
0 - 10 km	-2.07%***	-0.31%	-1.27%***	0.46%**
0 - 20 km	-2.30%***	-0.27%	-3.80%**	0.30%**
0 - 30 km	-1.82%***	0.27**	-0.97%***	0.39%***

*** p < 0.01, ** p < 0.05, * p < 0.10

Table 8: Federal Sustainable Spillovers by Pressure Subsets

PROPENSITY SCORE MATCHING	*2000-2004 Deforestation & Federal Sustainable PAs (pre-2000)*			
	LOW Road Distance	**HIGH Road Distance**	**LOW City Distance**	**HIGH City Distance**
0 - 10 km	-3.66%***	-1.01%	-2.91%***	-0.48%
0 - 20 km	-3.66%***	-1.85%*	-2.35%***	0.41%*
0 - 30 km	-3.59%***	-1.84%***	-2.06%***	0.37%*

PROPENSITY SCORE MATCHING	*2004-2008 Deforestation & Federal Sustainable PAs (pre-2004)*			
	LOW Road Distance	**HIGH Road Distance**	**LOW City Distance**	**HIGH City Distance**
0 - 10 km	-2.39%***	-0.09%	-2.04%***	-0.32%
0 - 20 km	-1.11%***	0.10%	-2.27%***	0.03%
0 - 30 km	-1.45%***	0.08%	-2.23%***	-0.19%

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

1.4 Discussion

We find local blockage of deforestation around Brazilian Amazon PAs, with interesting variation as well. This motivates study of mechanisms behind forest spillovers within development and land-use dynamics. We speculate that the establishment of a PA could discourage private migration and public road building nearby. Job opportunities are affected by the roads, so roads affect migration, while decisions on creating and maintaining roads are affected by migration since agencies will build and maintain where people go. All of this is based on expectations. One must speculate whether people and goods will use a new road. For a dynamic analysis, empirically, we want to start by studying decisions to migrate and to build roads.

Creating a new PA may signal lower future development in that region, which might dissuade migrants. As noted, in principle that could, in turn, divert deforestation by shifting new road building as well.

We have emphasized that PAs are pushed into locations more distant from clearing pressure than is average unprotected forestland. Thus, we believe that at least some local actors perceive consequences of PAs distinct from impacts on deforestation. As Robalino 2007 lays out, land restrictions implied by PAs could negatively impact local actors, reducing profits and the demands for local labor. On the other hand, PAs can generate tourism, which may provide gains in terms of consumption, employment and income.

In the next chapters we explore the mechanisms behind these PA results starting with migration. For this we use Microdata from Brazil's 2010 Census. This consists of a detailed questionnaire administered to a sample of the population (about 10%) on household and individual characteristics, which considers migration. We also consider subsamples from the 1991 and 2000 Census, available from IPUMS and data from the 2006 Agricultural Census. We will explain migration decisions as a function of differences in characteristics between spatial units.

Another way to describe the motivation for this analysis is moving from static baselines to a dynamic baseline. Considering links between PAs and roads – the canonical policies for conservation and development – illustrates why this matters. As noted, much existing protection has been located far from roads, for example. If the baseline is 'static', i.e., if we take the development as given and independent of policy for conservation, then this distance from roads suggests low PA impact because the baseline deforestation tends to be low when far from roads. Such PA locations thereby would be estimated to have had low impact on avoided deforestation. Within dynamic baselines, though, if roads are far away from a PA because of the influence of the PA upon roads' locations, then in fact the local impact of the creation of the PA could be very high, since conservation then has diverted pressures on the forest to other regions farther away.

2. Impacts of Brazilian Amazon Protected Areas on Human Migration

As both standard and novel efforts to conserve forests increase, including within climate policy[1], understanding their impacts is increasingly important. Many will occur in developing countries and thus conservation's multiple interactions with development processes are critical for thinking about not only what is optimal, locally or globally, but also how desired change can come about. Here we focus upon one particular way in which development may respond to conservation, and influence its impact, in examining whether protection in the Brazilian Amazon affects migration.

Within climate policy, global actors may wish to reward forested countries for lowering deforestation given credible evidence that the emissions from forests fell below agreed baselines. Such calculations should consider all of the impacts from a policy, including spatial spillovers, and net outcomes from carbon-market investments are likely to be scrutinized relatively closely. A lack of convincing evidence concerning net impacts could be grounds to ignore tropical forest as a source of emissions reductions. Alternatively, a sense of how forest spillovers might unfold could lead to an agreed basis for adjusting transfers, e.g., ex-post after spillovers are quantified. We examine how Amazonian migration responds to different types of protected areas (PA), the

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[1] PA initiatives for species also will continue. The Convention on Biological Diversity's Work Program on Protected Areas or "2010 targets" (www.cbd.int/protected/targets.shtml), e.g., suggests ongoing expansion of protected areas.

dominant conservation policies. Rigorous evidence on their deforestation impact is limited, with even less linking development to impact variations. Very little evidence exists on spillovers – forest or socioeconomic – from PAs. To my knowledge chapter 1 is the first empirical evaluation of spillover effects for PAs in the Brazilian Amazon. Given such limited empirical evidence, and its value for conservation planning, here we aim to provide novel empirical evidence concerning whether the migratory responses of individuals to conservation is an issue actors should consider in planning. My results ideally could help to inform planning and contractual discussions for climate policies.

For the current reduced-form exploration of migration due to PAs, below we examine empirically the linkage to frontier migration from PAs in the Brazilian Amazon. We combine geographic (pixel) data on spatially specific land characteristics, and forests over time, with socioeconomic (micro) data from the 1991, 2000 and 2010 Brazilian Census as well as the 2006 Agricultural Census, including individuals' characteristics and recent migration decisions. Merging such data permits me to examine determinants, including PAs, of individuals' 2005-10 (non-) migration across locations in the Brazilian Amazon. To test the impacts of recent changes, we examine effects of PAs created during 2000-04, prior to the period of migration that we consider.

First we study the outmigration in a binary logit model using characteristics of individuals and their current locations. Education, employment sector and gender, e.g., are known to be significant factors in outmigration. Critically, PA locations are known to often be biased along such dimensions. As that can affect outcomes of interest, to at least partially address endogeneity we employ not only multivariate regressions but also matching, as a pre-processing of my sample, before redoing my logit regressions. This step forces greater similarity across sites with high and low PA fractions. To examine how the characteristics of both origin and destination locations affect the choice of MCA during 2005-2010, we also implement a multinomial (conditional) logit.

The logit suggests PA impacts on outmigration consistent with deforestation spillovers. Most specifically, Federal PAs, previously found to reduce nearby clearing, appear to encourage individual outmigration. Moreover, the multinomial logit shows that they reduce the likelihood of immigration. Federal actions appear to have greater ability to affect the relevant expectations.

2.1 Protected Areas, Spillovers & Migration

2.1.1 Protected Areas' Forest Impacts

As highlighted by Pattanayak et al (2010) and Joppa and Pfaff (2010), at least two fundamental issues often confound evaluation of PA impacts. One – a central motivation here – is that PAs can generate forest spillovers, such that total impacts differ from impacts within the boundaries of those PAs. In principle, this is widely acknowledged. In practice, in most evaluations it is not.

Robalino and Pfaff (2012), in considering spatial interactions within private deforestation decisions through the use of neighbors' slopes to instrument for neighbors' land-use decisions, note there are many possible sources of interactions between neighboring land uses. That applies to interactions between public neighboring land uses, e.g., between PAs and forested land-use decisions nearby that might respond to public land use. For instance, reduced crop production on protected lands could deflect demand to lands nearby and, as a result, increase production and clearing in the nearby forests. Alternatively, establishing a PA can attract tourism, increasing the private returns to retaining forest to engage in the tourism sector (instead of clearing to produce).

Empirical evaluations of interactions can be confounded by a second fundamental issue, that the locations of PAs often are not distributed randomly across the landscape but have a bias. Relevant for my study of local forest spillovers, that means lands near PAs also are not random, i.e., they might be expected to differ from unprotected lands in ways relevant for deforestation. The effects of this can be seen in evidence on the impacts of protection upon forests within PAs. Most evaluations have not explicitly measured the characteristics of protected lands in generating the baselines to which PAs are compared in order to infer PAs' impacts. As a consequence, since PAs are biased towards low pressure (Joppa and Pfaff 2009), PA impacts often are overestimated (see, for instance, Andam et al. 2008 for Costa Rica or Joppa and Pfaff 2010 for a global study).

My previous work (with others) concerning PAs in the Brazilian Amazon also considers impacts on deforestation within PA boundaries, for Acre State (Pfaff et al 2014b) and the region (Pfaff et al. 2014c, d). Using randomly selected pixels with detailed geographic data, two main categories of protection are compared, Integral Protection areas and Sustainable Use areas, either of which could be implemented at the Federal or at the State level. As we do here, that work aims to reduce potential estimation biases using matching methods (Rosenbaum and Rubin 1983), i.e., by explicitly seeking to compare treated (protected) areas to untreated locations that are similar in terms of the characteristics that are expected, and are shown, to be relevant for deforestation. This approach halves estimated impacts versus 'apples to oranges' comparisons, while revealing considerable variation in PA impact (taking as a given that most of these PAs are well enforced). Further, it appears as though the political economy of PA location permits Sustainable Use areas, whose governance allows some local deforestation, to be closer to clearing threat and thus block more deforestation than Integral areas that ban clearing but seem feasible only far from threats. The same is true of Federal PAs, which are higher in pressure, and thus impact, than State PAs.

Previously we evaluated local forest spillovers from PAs in the Brazilian Amazon, using matching as land near PAs is likely to have location biases PAs do (see Figure 2). Comparing the deforestation nearby to PAs to that on unprotected lands that are observationally similar but far from PAs suggests lower-deforestation 'halos' around some PAs. That is, there was less deforestation around those PAs than expected if the PA were not to exist. Further, and consistent with the impacts within these PAs, these spillover effects were larger and more significant around Federal and Sustainable Use PAs than around the other types of PAs. Such a 'halo' contrasts with 'leakage', i.e., more deforestation, near Costa Rican PAs (Robalino et al 2012) near roads but far from PA entrances − which follows from different land-use dynamics.

2.1.2 Potential Spillover Mechanisms

To my knowledge, no study provides evidence on migration underlying forest impacts from PAs outside of their boundaries, which could have environmental and socioeconomic implications even quite far from where protection is implemented. The importance of studying population dynamics, including migration, and their relationships to conservation is noted by Joppa (2012). As human populations around the world have also grown exponentially, increased numbers live close to PAs, generating greater anthropogenic pressure on them. However, it is less clear how the existence of the PAs has influenced human activity near PA borders. Understanding such interactions between development patterns and conservation is important for guiding not only the most effective conservation but also ways to address concern for rural development and welfare.

Few empirical studies attempt to show mechanisms through which conservation policies affect social and environmental outcomes outside their boundaries. Ferraro and

Hanauer (2014) present a framework to explore how PAs might affect poverty in Costa Rica. They focus on three mechanism: changes in tourism and recreational services; changes in infrastructure such as road networks, health clinics and schools; and changes in regulating and provisioning ecosystem services and forgone production activities that arise from land use restrictions. They find that the major part of the poverty reduction associated with the creation of PAs in Costa Rica is causally attributable to tourism activities. Robalino and Villalobos (2014) also provide evidence that such impacts of PAs in Costa Rica are due to tourism, including through the idea of tracking the location of PA entrances, while Sims (2010) provides some related evidence for Thailand.

For the case of the Brazilian Amazon in recent decades, we hypothesize that the creation of a PA could serve as a signal of a change in the local/regional development path that could affect both private migration and public road building – which also will affect each other. In a frontier setting such as the Brazilian Amazon, where most of the PAs have not featured a lot of tourism development, the establishment of PAs by a public authority may signal to a number of parties that there will be fewer subsidies to local economic development than previously were expected. Such a signal could discourage migration, as well as building and maintenance of roads nearby.

Taking each of these potential responses in turn, private migration choices are thought to respond at least in part to changes in individual expectations of employment and income in each candidate migration destination (including the current location, i.e., should one just not migrate). The establishment of a PA may well signal that within the relevant political economy, forces in favor of conservation have gained traction relative to the forces of economic development. If so, then one might well lower one's expectations of standard frontier development investments (e.g., schools or health posts). That provides a rationale for a migrant to lean away from the PA's area.

Moving to potential public responses, creating a new road or maintaining an existing road or improving (e.g., paving) it are ways to pursue the general goal of economic development. Consider, for instance, the decision to maintain a road. That may not seem worthwhile if other factors have limited migration since, if nobody will use the road, resources should go elsewhere. Indeed, in the Brazilian Amazon roads have gone to ruin when initial investments did not lead to a high usage – seemingly lowering development expectations and clearly lowering maintenance.

Such responses to PA creation could magnify local PA impact (while likely also creating non-local leakage) and that could significantly shift the optimal locations and types of new PAs. A natural step toward complete assessment of PAs' potential spillovers, then, is to empirically assess whether PAs do generate such potential responses. In this paper, we begin with an analysis of individual migration decisions within the Brazilian Amazon region and, controlling for other potential drivers, examine how these are affected by an intensification of the creation of PAs.

2.1.3 Models of Human Migration

A neoclassical economic perspective on migration is in Sjaasted (1962) and Todaro (1969)'s seminal studies. Migration is viewed as an income-augmenting investment, in which costs are incurred initially while the returns accrue over time. Any individual will compare the direct costs of migration with the discounted present value of income gains from each potential destination, searching for the maximum net gain from a set of potential migration gains. Under this view, younger people will obtain returns over a longer period, have larger gains, and be more mobile. Therefore, age helps to determine migration. The more educated are more likely to be migrants. Migrants also tend not to be from the poorest families, suggesting this is constrained by income.

Another literature addresses migrant selectivity by combining theories on individuals' migration decisions with human capital theory starting with Mincer (1974) and Becker (1975). Income at different locations is defined as a function of individuals' skills, which affect their productivity at each location. The human capital perspective implies that those who migrate have high differentials in discounted income (which could be expected income net of migration costs) between migrating and not migrating. Most recent microeconomic studies are based on this view, considering the income differential across origin versus potential destination locations as a key determinant of migration, while including other possible drivers such as characteristics of labor markets, transport networks and urbanization, plus other geographic characteristics that influence the location decisions of economic actors (see for instance Krugman 1990 and Fujita et al 1999).

New Economics of Labor Migration (NELM) sees the household as the unit of interest, with diverse preferences. Migration can provide capital and reduce risk by diversifying income. Family members are assumed to act collectively to maximize expected income and also to loosen the constraints associated with missing credit, insurance, and other markets (e.g. Taylor 1986).

Within the field of human geography, Lee (1966) has been highly influential. In his model, often referred to as the 'push-pull' model, the decision to migrate is determined by factors associated with the area of origin and area of destination, intervening obstacles such as distance, physical barriers, immigration laws, as well personal factors. Lee states that migration is selective with respect to the individual characteristics of migrants because people respond differently to 'positive' and 'negative' factors at different locations and have different abilities to cope with the intervening variables. This framework is more general than but not inconsistent with migration neoclassical models. Van Wey et al (2012) argue that in the push-pull model, one can think of 'push factors' as limited opportunities for employment in the origin. 'Pull factors' can be the opportunities in potential migration destinations, including urban employment, higher urban wages, available uncleared land, and amenities like health and education infrastructure.

Concerning PAs' migration impacts, Ogelthorpe et al (2007) say PAs can attract (pull) or repel (push) people. To 'pull', PAs provide benefits for local actors in the environs of the PA, for instance ecosystem services themselves or income if employment opportunities are available, e.g. in eco-tourism. PAs could then retain or attract human settlement. On the other hand, PAs may be seen as a 'push' force in that they constrain expansion or even continuation of economic activities, such as crop production or resource extraction, and/or deny access to traditional lands.

My empirical analysis of migration to follow is based directly upon the neoclassical view of migration. Individuals make choices about staying in a particular location, versus migrating to another of many potential other locations, based on which generates higher expected benefits. Applying that perspective, empirically we will explore how decisions to out-migrate from a given location are affected both by individuals' employment-relevant characteristics and characteristics of the locations themselves in order to provide a test of the impact of PA creation on migration.

2.2 Study Area, Data & Empirical Strategy

2.2.1 The Brazilian Amazon

The Brazilian Legal Amazon is a region of 521,742,300 hectares (about 5 million km2), which is close to 60% of Brazil's area. It contains the largest tropical forest in the world and one of the most important species hotspots, the Amazon Biome. About 44% of the Legal Amazon is protected, with 8% in Integral areas, 14% in Sustainable Use, and 22% in Indigenous Lands. Integral protection does not allow consumption, extraction or destruction of natural resources and restricts the presence of humans. Sustainable Use areas allow for the extraction of natural resources in attempting to make protection compatible with local socioeconomic development. In that vein, settlements are allowed in Sustainable Use PAs – and indeed in some cases that seems to be a prerequisite for creating this type of PA, focused on livelihoods (D'Antona et al 2013). The half of the PA network that is Indigenous Lands recognizes traditional communities' rights and is not officially designated as "conservation units" (Fearnside 2003). Most PAs were created after 1990 and, as noted above, on average PAs have had some impact in reducing deforestation.

According to the Brazilian Institute of Geography and Statistics (IBGE), by 2010 this region's population was near 24 million. Recent decades have seen urbanization plus population growth. At 20% for 2000 - 2010, the latter's rate is above the average for the rest of the country. Most of the population resides in urban areas and is distributed in 775 municipalities in the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins, Maranhão and Goiás (only 0.8% of this state). D'Antona et al (2013) look at PAs created up to 2006 in the entire Brazilian Legal Amazon and estimate populations of 297,693 in Sustainable Use areas and 27,705 in Integral

Protection areas, with 1,020,237 in areas around PAs. Overall, Amazon PAs were established in sites with relatively low population density and prior development (Figure 2).

2.2.2 Data

Brazil Demographic Census 2010

This dataset consists of 6,192,332 households and 20,625,472 individuals, equivalent to a 10.7% sample of all households. It is generated by a detailed questionnaire on household and individual characteristics, which considers migration. There are 2,903,042 person records for the Amazon, with municipality as the smallest unit, and variables include the municipalities where the person lived in 2005 and lived in 2010. We focus here on people who moved within the Amazon region. That is, currently we exclude those individuals who migrated out of the region or migrated into it.

We consider household heads older than 18 years of age in the analysis. We use information on the education level of each individual and created a dummy variable for completion of *ensino medio*, i.e., the last phase of basic education. There is information on the economic sector in which an individual works and we create a dummy variable for whether the person works in agricultural or extractive activities (versus in others sectors, such as manufacturing or services). Measures of income in 2010 exist but initially we have focused on prior conditions as determinants though the theories of migration discussed above certainly involve forward-looking expectations. Other relevant variables that we extracted from this census are the age and gender of individuals.

Subsamples of Microdata from Brazil Demographic Census 1991 and 2000

These subsamples were generated by IPUMS from the original records and were used to obtain some average characteristics of the municipalities from which the individuals were outmigrating. Only the 2000 Census was used for this purpose in this study. The 1991 dataset has 8.5 million observations (5.8% sample of the population), while the 2000 data has 10 million (6% sample). They provide similar information as is in the 2010 Census. The average income, unemployment rate and population density of each municipality in 2000 were calculated to use as determinants of migration. IPUMS also generates a variable called Minimum Comparable Area (MCA) which is a geographic unit that combines more recent municipalities in order to achieve consistency across time (and censuses). That is important for Brazil given significant changes in municipality boundaries across time, in particular subdivisions of municipalities into multiple municipalities. We have used these MCAs as the units of observations for analyses to be able to compare over time. Figure 3 shows the 288 MCAs in the sample.

Brazil Agricultural Census 2006

These data result from interviews with agricultural producers in 5,175,489 units of production throughout Brazil. Information is aggregated at municipality level and includes characteristics of the producers, characteristics of the establishments, employees, finances, value of production and resources used in production. We aggregate to the MCA units used for the Demographic Censuses. Two relevant variables are the number of hectares in agriculture by MCA, as well as the hectares in settlements supported by the National Institute of Colonization and Agrarian Reform (INCRA) to promote agricultural production by and provide technical assistance to families in those sites.

Geographic Data

Geographic characteristics affecting the profitability of the land are extracted from an 800,000 random pixel sample used in prior analyses of deforestation. We extracted MCA averages for soil quality, slope, vegetation and rain, as well as road density for different years. There are data on deforestation cover for 2000-04 and 2000-08, although in my initial analyses we did not use them. Finally, of course a necessary element of geographic or spatial data for my analyses are maps of the PAs with dates of PA creation. Those include Federal PAs, State PAs and Indigenous Lands, with the Federal and the State PAs identified as in either Integral protection or Sustainable Use.

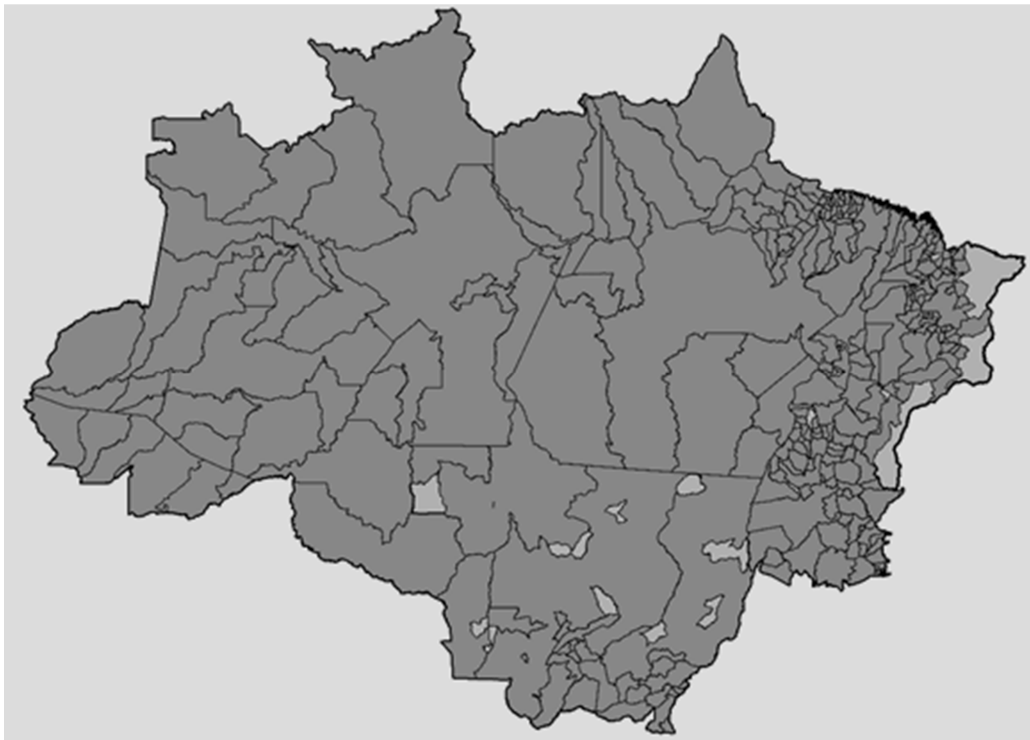

Figure 3: 288 MCAS in sample

2.2.3 Empirical Strategy

Migration often has been modeled as a discrete choice, a binary decision to move or to stay, in probit or logit models (e.g. Emerson 1989, Finnie 2004, Chi and Voss 2005). Yet sometimes it is conceived as a choice among many locations that empirically is implemented using multinomial logit, probit or other maximum-likelihood techniques for estimating discrete-continuous models (e.g., Taylor and Mora 2005). Such studies are based upon a random-utility theoretical model, in which all of the migration decisions are taken to maximize welfare.

More recently, within the economic valuation of locational amenities, 'horizontal sorting' models apply a conditional logit framework to study households’ choices across neighborhoods. Those choices are assumed to be responses to wealth and preferences for house characteristics, public goods, characteristics of neighbors, and commuting opportunities. This approach has been used to assess workers' choices across jobs, according to their qualifications and preferences for job attributes. Sorting models estimate structural parameters that characterize the heterogeneity of preferences (Kuminoff, Smith and Timmins 2012). Timmins (2007) develops an application of this framework for the entire Brazilian Amazon, one of few done for a developing country.

Given constraints on secondary data about individual migrations in the Brazilian Amazon, in particular on individuals' exact situations in their current locations plus all possible destinations, many studies of migration drivers focus on particular regions in the Amazon and rely on primary data instead (e.g., Caviglia-Harris et al. (2012), Parry et al. (2010), and VanWey et al. (2012)). Many lessons can be drawn from these detailed local case studies, yet we believe that these could be complemented with uses of secondary data for the entire region concerning individual moves across greater distances, even while controlling for individuals' specific economic opportunities. That can add to a bigger picture concerning migration's drivers and the development of regions.

To study PA impacts on migration, as in Timmins (2007), we use data for the entire region from the Brazilian Demographic Census at individual level. We study the drivers of the likelihood of household-head outmigration during 2005 and 2010 in a logit model with a binary dependent variable using individual characteristics and features of individuals' places of origin before 2005. Then we use multinomial (conditional) logit model to examine the individuals' MCA choices in that period, testing determinants from both origin and destination MCAs. We consider effects of:

- Individuals: age, education, gender, employment sector (agricultural/extractive or other)
- MCAs: Income per capita 2000, Population density 2000, Education HDI 2000
- MCAs: % in agriculture 2005, % in INCRA settlements 2005
- MCAs: dummies for above average % of area in Federal (Integral and Sustainable) PAs
- MCAs: dummies for above average % of area in State (Integral and Sustainable) PAs
- MCAs: dummies for above average % of area in Indigenous Lands
- States: dummies

In the multinomial logit model, we include dummies that proxy for moving costs across MCAs, based on distances between an individual's 2005 location and all potential destinations for 2010. One dummy is for zero distance, i.e., not changing MCA. The others are low, medium and high distance dummies.PA variables can represent total area within an MCA that was ever put into the given category of protection or a change (indeed both can be used in the same specification). We focus some on new PAs created during 2000 and 2004 that could generate new signals to others. Figure 4 shows that an important share of the total area in conservation was implemented then.

For the outmigration analysis, in order to partially address the endogeneity of PAs' locations, at least to the extent that is possible using the observable characteristics of locations, we employ propensity-score matching (Abadie and Imbens 2012) to find MCAs with low PA density that are otherwise similar to those with high PA density. They have similar relevant characteristics, e.g., similar population density, area in agriculture, education and state dummies, etc., we then run the logit for matched samples.

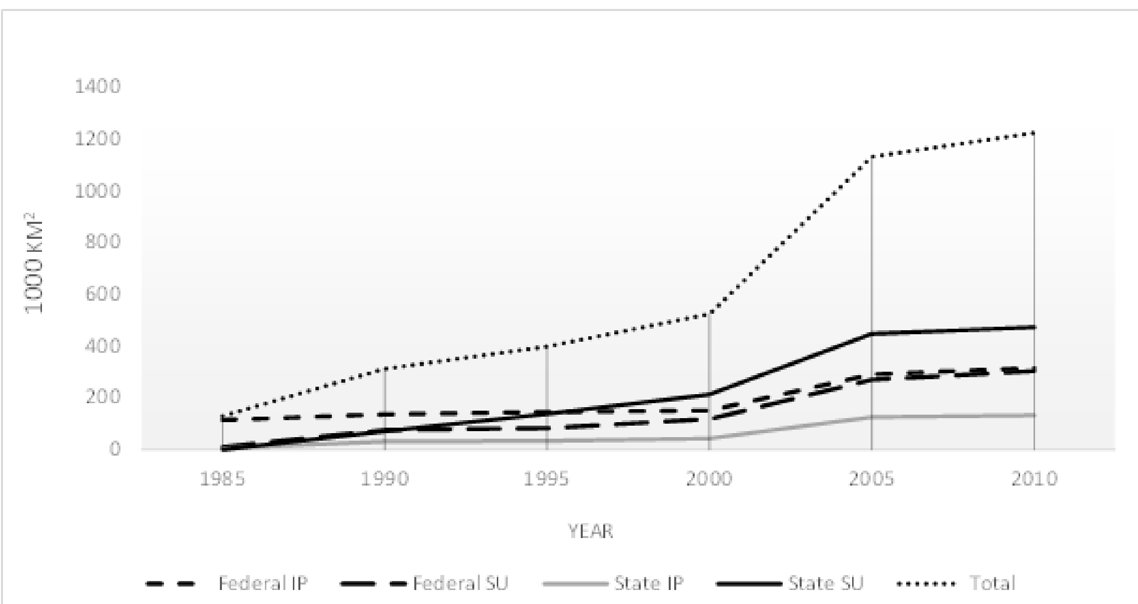

Figure 4: Cumulative area (1000 km2) in Federal and State PAs

2.3 Results

Our final sample contains 60,525 individuals, 31,548 migrants and 28,977 non migrants. Table 9 indicates less difference than one might suppose between the migrants and the non-migrants. Migrants have slightly higher levels of education and have achieved a higher income by 2010, i.e., after their recent migration, than non-migrants. More migrants are in urban centers by 2010. That is consistent with fewer migrants being employed in agriculture and extractive activities.

Table 9: Mean Characteristics of Individuals in Sample

	Migrants	Non-Migrants
Number of individuals	31,548	28,977
Percent with High Education	70%	68%
Average Individual income 2010	1298	1270
Percent working in Extractive or Agro sector	19%	22%
Percent living in Urban area by 2010	73%	71%
Percent of Male	69%	69%
Age	38	38

Table 10 presents average characteristics of the 288 MCAs in our sample. There are real differences across MCAs (and municipalities) in area, population density, and income per capita. Fractions of area in PA categories in 2005 (pre-migration) also vary significantly. Some MCAs have none of their area in PAs while others have more than half of it in some kind of protection.

Table 10: MCAs Characteristics

Variable	Mean	Std. Dev.	Median	Min	Max
Area of MCA in ha	1,764,381	4,618,917	256,432.00	15,066	36,100,000
Population Density 2000	33	159	5.81	0.13	2127
Income per capita 2000	327	988	117	39	12,786
Education HDI	0.74	0.09	0.75	0.47	0.93
% in Federal Integral PAs 04	0.02	0.08	0.00	0.00	0.96
% in Federal Sustainable PAs 04	0.02	0.09	0.00	0.00	0.95
% in State Integral PAs 04	0.00	0.04	0.00	0.00	0.63
% in State Sustainable PAs 04	0.01	0.05	0.00	0.00	0.63
% in Indigenous Lands 04	0.05	0.13	0.00	0.00	0.84
% in Agriculture	0.41	0.28	0.39	0.00	1.00
% in INCRA settlement	0.00	0.02	0.00	0.00	0.24
Roads density	0.11	0.21	0.00	0.00	0.93
Slope (plain)	0.47	0.30	0.46	0.00	1.00
Soil Fertility Index	2.59	1.02	2.59	0.00	5.00
Vegetation (cerrado)	0.32	0.41	0.02	0.00	1.00

Table 11 shows that using matching to preprocess the sample before running the analyses certainly helps to improve similarity between the treated and untreated MCAs. We define "treated" and "untreated" MCAs here in terms of a threshold for the density of protection. A treated MCA has a percentage above the average for MCAs, i.e., above 11%, for area that is under protection implemented during 2000-2004. Correspondingly, an untreated MCA has a fraction under 11%. Current work involves testing different protection thresholds to verify the robustness of these results, but as a starting point we will use this above/below average criteria.

Table 11: Matching To Preprocess Data Improved Treated-Untreated Covariate Balance

Variable	Sample	Treated	Controls	Difference	Std. Err.
Matching balance N=1					
Variable	**Sample**	**Treated**	**Controls**	**Difference**	**Std. Err.**
Education HDI	Before Matching	0.70	0.74	-0.04***	0.02
	After Matching	0.70	0.69	0.01	0.03
Population Density	Before Matching	5.21	37.62	-32.41	27.90
	After Matching	5.21	7.15	-1.93	2.50
Area in Agriculture	Before Matching	0.18	0.45	-0.27***	0.05
	After Matching	0.18	0.28	-0.10*	0.06
Acre	Before Matching	0.08	0.01	0.07***	0.02
	After Matching	0.08	0.08	0.00	0.06
Mato Groso	Before Matching	0.08	0.02	0.06**	0.03
	After Matching	0.08	0.05	0.02	0.06
Matching balance N=2					
Variable	**Sample**	**Treated**	**Controls**	**Difference**	**Std. Err.**
Education HDI	Before Matching	0.70	0.74	-0.04***	0.02
	After Matching	0.70	0.71	-0.00	0.02
Population Density	Before Matching	5.21	37.62	-32.41	27.90
	After Matching	5.21	6.58	-1.37	2.16
Area in Agriculture	Before Matching	0.18	0.45	-0.27***	0.05
	After Matching	0.18	0.31	-0.13**	0.06
Acre	Before Matching	0.08	0.01	0.07***	0.02
	After Matching	0.08	0.05	0.03	0.06
Mato Groso	Before Matching	0.08	0.02	0.06**	0.03
	After Matching	0.08	0.05	0.03	0.06
Matching balance N=3					
Variable	**Sample**	**Treated**	**Controls**	**Difference**	**Std. Err.**
Education HDI	Before Matching	0.70	0.74	-0.04***	0.02
	After Matching	0.70	0.71	-0.00	0.02
Population Density	Before Matching	5.21	37.62	-32.41	27.90
	After Matching	5.21	6.88	-1.66	2.18
Area in Agriculture	Before Matching	0.18	0.45	-0.27***	0.05
	After Matching	0.18	0.33	-0.15***	0.05
Acre	Before Matching	0.08	0.01	0.07***	0.02
	After Matching	0.08	0.07	0.01	0.06
Mato Groso	Before Matching	0.08	0.02	0.06**	0.03
	After Matching	0.08	0.08	0.00	0.06

Given this definition, 38 MCAs from the sample are considered "treated". The controls are found by matching each treated MCA to an untreated MCA with the nearest propensity score, using nearest-neighbor matching (N=1). Table 11 shows matching achieved considerably better balances in covariates such as education and population density, which reduces some concerns. Most site characteristics have significant differences when comparing all of the treated with all the untreated MCAs. However, after matching, there remain none of the statistically significant differences. This includes when we move from just one untreated MCA for each treated MCA to two or three. That is helpful to have sufficient data for analyses, given the limited pool of MCAs.

Table 12 presents the results of the binary logit model for (non-) outmigration decisions. Looking within the matched sample, we find individual characteristics like education and gender to be positively and significantly linked with the likelihood of outmigration during this period. Employment in agriculture or resource extraction activities is associated with less outmigration, as is greater age, all of which is understandable. Concerning MCAs' characteristics, Federal PAs (both Integral Protection and Sustainable Use) have a positive significant effect on outmigration. Yet State PAs (both Integral Protection and Sustainable Use) show a negative significant impact. The evidence for Federal PAs is consistent with a 'halo' local forest spillover. This PA category in prior literature (Pfaff et al. 2014a) showed the strongest evidence of reducing deforestation in areas outside of but near PAs. Here, consistent with that result, and thus the idea that migration could be an underlying mechanism, Federal PAs are associated with more individuals moving.

Table 12: Logit model after PSM matching for 2005-2010 Outmigration[1]

	N=1		N=2		N=3	
Variable	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Education	0.14***	0.03	0.14***	0.03	0.14***	0.03
Working in Agricultural Sector	-0.38***	0.03	-0.31***	0.04	-0.33***	0.03
Gender (male)	0.13***	0.03	0.12***	0.03	0.12***	0.03
Age	-0.00***	0.00	-0.00***	0.00	-0.00***	0.00
Low Population Density 2000	0.06***	0.01	0.07***	0.01	0.07***	0.01
Government settlement	-0.32***	0.10	-0.41***	0.08	-0.57***	0.09
Area in Agriculture	-0.09	0.20	-0.43***	0.14	-0.51**	0.13
Federal Integral PAs 0004 dummy	0.52***	0.06	0.52***	0.06	0.53***	0.06
Federal Sustainable PAs 0004 dummy	0.74***	0.14	0.80***	0.13	0.71***	0.12
State Integral PAs 0004 dummy	-0.17*	0.10	-0.38***	0.08	-0.36***	0.08
State Sustainable PAs 0004 dummy	-0.91***	0.11	-0.90***	0.10	-0.87***	0.10
Indigenous Lands 0004 dummy	-0.04	0.06	-0.01	0.06	0.00	0.05
Rondonia	-1.94***	0.08	-1.88***	0.07	-1.97***	0.07
Acre	-0.48***	0.14	-0.51***	0.11	-0.43***	0.11
Para	-0.21**	0.08	-0.25***	0.07	-0.37***	0.06
Tocantins	0.10	0.17	0.20**	0.11	0.21**	0.12
Maranhao	0.10	0.16	0.11	0.15	0.01	0.15
Mato Groso	-0.83***	0.13	-0.51***	0.09	-0.59***	0.09
Constant	0.43***	0.10	0.45***	0.10	0.53***	0.09
# individuals	26,714		30,115		31,846	

*** p < 0.01, ** p < 0.05, * p < 0.10

1/ Comparing MCAs with over 11% in PAs created in 2000-04 to similar MCAs with under 11%

Table 13 presents my conditional logit results using a 40% random sample of individuals (23,919). Each individual chooses among 288 alternative locations within the

Brazilian Amazon. Using both origin and destination MCA characteristics, this analysis confirms the patterns in the outmigration analysis. Factors like income per capita, area in agriculture and INCRA settlements increase the likelihood of an individual choosing to move to or stay in an MCA. The migration distance dummies (high migration distance excluded from the regression) show that not moving, or moving to lower distances, can be much more attractive than moving to location farther away.

Table 13: Multinomial (Conditional) Logit for MCA Choice

Dependant variable: Choice of 288 MCAs	Coef.	Std. Err.
Income per capita 2000	0.22***	0.00
Area in Agriculture dummy	0.06**	0.02
Government Settlement dummy	0.75***	0.02
Migration Distance dummy (zero)	7.26***	0.06
Migration Distance dummy (low)	3.68***	0.06
Migration Distance dummy (medium)	1.21***	0.06
Federal Integral PAs 0004 dummy	-1.19***	0.11
Federal Sustainable PAs 0004 dummy	-0.49***	0.04
State Integral PAs 0004 dummy	0.99***	0.03
State Sustainable PAs 0004 dummy	1.55***	0.05
Indigenous Lands 0004 dummy	-0.44***	0.04
Rondonia	3.75***	0.14
Acre	1.13***	0.09
Roraima	3.73***	0.09
Para	0.48***	0.06
Amapa	3.37***	0.14
Tocantins	-0.02	0.07
Maranhao	-0.04	0.06
Mato Grosso	0.40***	0.07
# observations	23,919	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Federal PAs − Integral and Sustainable Use − have significant negative effects on the likelihood of choosing an MCA. State PAs have a significant positive effect, which could link with differences in enforcement or differences in the type of protection chosen. That is consistent with evidence on local PA spillovers, plus that between 2000 and 2004, the federal government actively discouraged deforestation, signaling a regime change to all, at least at the federal level.

2.4 Discussion

My results for impacts upon outmigration given establishment of PAs are consistent with prior results for local forest-conserving spillovers from some Amazon Federal PAs. Evidence from my analysis suggests that greater Federal PA density raises individuals' propensity to out-migrate. When we examine in a multinomial framework the choice of location during 2005-2010, greater Federal PA density more generally reduces the likelihood of choosing a location. That holds for both the Integral and the Sustainable Use PAs. It could be interpreted as evidence of migration as a mechanism underlying forest spillovers and, perhaps, even of shifts within development paths.

If pursuing an interpretation of migration as a mechanism to further reduce local clearing, Sustainable Use areas in particular should be studied further. As highlighted in Pfaff et al. 2014 for Acre State, this type of PA allows for some resource uses within PA boundaries and, consistent with the political economic implications of that approach, it is located closer to roads and markets (close enough for total impact, or blocking of pressure, to be above Integral PAs). Thus in these sites there is economic activity to be diverted. That generates avoided deforestation while posing a question: whose migration is influenced to permit a nearby 'halo' of lowered deforestation instead of local leakage? One possibility is that larger producers exit from the area. Sustainable Use PAs in particular might send a signal that distinguishes across producer groups: they permit some extraction within their borders but that tends to be for less capitalized actors; while their presence may dissuade larger producers from operating at their desired larger scales.

Thus, my results are at least suggestive of specific potentially important dynamics in the interaction of conservation policies and development processes. Such interactions will continue to be important to conservation's forest impacts as well as their distribution of economic impacts, and increasingly so if the scale of interventions rises with efforts at climate change mitigation.

3. Protected Areas & Road Growth in the Brazilian Amazon

3.1 PAs' impact on Roads Dynamics

Expansion of roads networks in the Brazilian Amazon began in the early 1960s with efforts by the federal government to connect the region to the rest of Brazil as part of frontier development. These included important intraregional highways such as the Transamazon highway (BR-230), which runs east-west across the northern part of the region, and Cuiaba-Santarem highway (BR-163) linking the central Amazon to southern Brazil (Perz et al 2007). In 2000 the government proposed 'Avança Brasil', an initiative to pave 7500km of highways for development, including expanding mechanized soybean agriculture which was intended primarily for exports (Fearnside 2001). Such critical infrastructural investments have been led by public actors and affect deforestation rates (see Pfaff 1999 and Pfaff et al. 2007 concerning roads' impacts). Given roads' importance for deforestation, and thus for the outcome of efforts to generate REDD, here we examine whether the establishment of protected areas can affect the expansion of roads.

We distinguish official and unofficial roads. Local groups who entered the region via official roads often may have roles in the creation of unofficial roads. Private actors, for instance, actually build roads for access to land, timber and other natural resources (Perz et al 2007). Unofficial roads tend to grow from previous official roads and to form dense local networks tied to local communities. They have expanded rapidly of late, while the official network has not grown as much in the last decade. For example, according to Brandao and Souza (2006) within the western part of the eastern Amazon state of Para, unofficial roads grew by 300 percent in eleven years.

Roads are one way states pursue economic development goals, whether creating a new road or maintaining or improving an existing road. Thus, there are likely to be tradeoffs among roads' multiple outcomes. We do not comment here on any outcomes of roads – economic or environmental – although one motivation to consider whether PAs affect where roads are built is that all of roads' impacts could well vary with the roads' locations (Andersen et al. 2002 for economic impacts and Pfaff et al. 2015 for forest).

In the face of road-linked pressures for forest clearing and degradation as well as habitat fragmentation (for the Amazon see Bierregaard et al 2001, Laurance et al 2002), establishing PAs has been the main way to lower deforestation in the Brazilian Amazon. Multiple protection types (Federal and State, Integral and Sustainable Use, Indigenous) have significantly increased in recent years. In a developing frontier like the Brazilian Amazon, conservation and development actions often are occurring simultaneously.

To consider the impacts PAs in the Brazilian Amazon, adding to Soares-Filho et al. 2006, recent work shows variation in impacts across the landscape (Pfaff et al 2014a) and across PA types (Pfaff et al. 2014b). The latter results suggest quite regionally varied political economy influencing how PAs are sited as a function of development pressure. We also consider PAs' spillover effects, which greatly affect PAs' overall impacts.

Reduced form evidence from Chapter 1 on net forest spillovers suggests that PAs may influence behaviors and lower nearby deforestation. Instead of raising forest clearing near their boundaries ("leakage"), PAs may displace such activities to other regions ("blockage").

As seen in Chapter 2, a possible mechanism by which PAs could lower pressure on the forest in nearby areas could be that human migration decisions in the region are being affected by conservation policies. For instance, the establishment of a PA could signal lower future prospects for jobs or income, dissuading migration. To explore such potential effects, we controlled for factors that influence individuals' location decisions within the Amazon to show that migrants seem to be moving away from areas with a higher PA concentration – in particular protection of the Federal variety, which seems to send stronger signals to the relevant actors, possibly concerning better enforcement.

Another possible mechanism that may underlie forest-raising spatial spillovers from PAs within a frontier such as the Brazilian Amazon could be an influence of PAs on roads investments. Road-building decisions involve a calculus involving expected development impacts of such construction, e.g., more output or employment in regions receiving investments (recall, investment could be a new road, paving or maintenance). The creation of a PA in a developing frontier could signal that pro-environment forces in the government will limit investments in economic development in an area, which could in turn reduce another ministry's expectation for economic impacts of road investments.

Those expectations could include expectations of migration that occur along a new road; thus, if the ministry anticipated migrants' responses to a PA, that too could affect roads.

This chapter empirically analyzes roads dynamics in the Brazilian Amazon to provide what we believe is the first test of how conservation policy affects such dynamics. For greatest current relevance, we consider a recent expansion of unofficial roads in the region, controlling for the past presence of official roads because all local investments in transport both reflect unobserved conditions and will have their own natural dynamics, regardless of what conservation has occurred. Results from regression and matching analyses show that recent unofficial road growth is, in part, associated with the presence of previous official roads, as we expected. Controlling for that, and also consistent with recent evidence on Federal PAs' deforestation spillovers through impacts on migration, this category of PAs does seem to displace investments in unofficial roads. Thus, road investments may be a mechanism by which PAs can have impacts on nearby forests.

3.2 Relevant Literature

3.2.1 Roads' Impacts (by location, with varied impacts so location matters)

Deforestation Impacts

Rigorous evidence is slowly growing on road building's deforestation impacts in developing countries. Data has improved over time and additional perspectives both on rigor and on impact are being incorporated. Such literature started with global-scale regressions using country-year or country-decade observations. Not surprisingly, the literature has focused on average impacts of roads. However, as data has improved and the focus on informing policy choice as increased, some study impacts across space.

The literature began using smaller observations during the 1990s, units within countries from political units − permitting use of census data (e.g., states, counties) − down to pixels, which are more spatially precise as locations but lack the social data. Chomitz and Gray (1996), Pfaff 1999 and Cropper et al. (2001) are examples of studies based on profit maximization models in agriculture, linked to the von Thunen (1966) agricultural land use model. Such work found significant impacts of land characteristics- for example slopes, soils, distance to roads and markets- on land use choices.

An early previewing of "spatial zoning" perspectives supported by my work include Pfaff 1999's finding that the marginal impact of population on deforestation falls with the population density. This implies that for any given amount of total population, where those people are affects the population's impact on deforestation. Such thoughts also previewing concerns with endogeneity of policy, as Pfaff 1999 finds a challenge in separating the effects of mostly urban credit access from population focused in cities.

Most relevant for this chapter is that road impacts vary with location, making it important for PA spillover impacts to understand how PAs affect the locations of roads. Nelson and Hellerstein (1997) use pixel data in a multinomial logit framework and with correction for spatial dependence for one region in Mexico to suggest road impacts and that they vary. Andersen et al. (2002) use county data from the census for the Brazilian Amazon, investigating the effect of previous forest clearing with an interaction effect to suggest that higher prior rates of deforestation lower the marginal impact of new roads (though the spatial intensification model suggested to potentially explain such outcomes is rejected by Pfaff et al 2007 using census-tract data to observe changes within counties).

Pfaff et al (2015) provide an alternative, based on von Thunen, suggesting that new roads' impacts might be non-monotonic in prior development: not only with lower impacts where prior development and clearing are higher (consistent with the Andersen 2002 empirical gradient − if not with claims about average effects), but also where they are lower, i.e., in relatively pristine areas where development has not been profitable.

Unofficial roads – my empirical outcome in this chapter – have their own pattern without conservation but that is little known. Studies of unofficial road development are relatively limited to date. For the Brazilian Amazon, Brandao and Souza (2006) maps unofficial roads in the Central-West region of the state of Para between 1985 and 2001. An important finding is that the highest rates of deforestation occur in the areas with high densities of unofficial roads. Moreover, according to the authors, the presence of PAs has slowed, but has not halted, the development of further such unofficial roads.

More recently, Barber et al (2014) assess links between an evolving transportation network, including unofficial roads alongside roads and rivers, and deforestation. They consider PAs as a factor that mitigates effects of roads on deforestation. Using satellite data for the entire Amazon, they argue that the proximity to transportation networks is a major driver of deforestation, and that protected areas have a strong mitigation effect on that risk. However, while they claim that some types of protection experience less forest loss (without control for other factors that can confound impacts of roads or PAs) they do not consider whether one way PAs can have impact is to discourage unofficial roads.

Socioeconomic Impacts

Variation in road benefit may also be critical for where roads are sited. Variation across rural locations is the focus of van de Walle (2002). The authors suggest that rural roads generate less of the kinds of benefit that get counted and more of the benefits that often do not. Illustrating for Vietnam, they note the importance of identifying whether a new road improves access for a given group. Gibson and Rozelle (2003) stress the value of identifying where road benefits are highest − considering Papua New Guinea, where terrain and history yielded transport gaps. Their emphasis is where access is a factor in poverty. Their evidence suggests that roads reduce poverty if there was low prior access to infrastructure. Warr (2005) provides additional evidence for rural road benefit, noting the positive interaction between economic reforms and access to markets (distinguishing access only during dry seasons from year-round). This study finds adding wet-weather access was in part responsible for a fall in poverty. Methodologically, these authors very strongly advocate the use of data on changes in roads in order to address endogeneity.

Andersen et al (2002) note that for the Brazilian Amazon the gains in GDP from paved roads are higher when there is prior economic activity. Recalling that the clearing impacts of new roads in very highly cleared areas may be lower, these results may well suggest that the ratio of the GDP gain to the loss of forest could be maximized with a form of spatial zoning in which new roads intensify the development that has already been occurring instead of opening up relatively pristine areas for deforestation.

Duranton and Turner (2012) study links between transportation networks and economic growth in a developed setting. They estimate a structural model of urban growth and transportation which relies on an instrumental variable approach to evaluate the effect on interstate highways in the growth of US cities. They find that a 10 percent increase in a city stock of highways causes about 1.5 percent increase in its employment over 20 years.

3.2.2 Protected Areas' Spillovers

Protected Areas' Deforestation Spillovers

Identifying spatial interactions in deforestation is an empirical challenge. Since for PAs random assignment is unlikely, one empirical approach for good identification would be an instrument. Robalino and Pfaff (2012) present one candidate, the naturally varying slope of private land within Costa Rica. Specifically, slopes of neighboring lands are used to explain neighboring land uses. That variations is then in turn used to explain private deforestation. There are many possible mechanisms that could lead land use on a parcel to affect neighboring land use. Further, more than one can occur at the same time. As each could vary in magnitude across the landscape, net effects can vary in magnitude and sign. For this case, deforestation raises nearby deforestation and the magnitude of the effect is larger near parks and far from cities.

For PAs, it is more difficult to find a convincing instrument for where protection was implemented. That leaves empirical controls as an approach to identification, i.e., for separating the impacts of PAs from other relevant factors. Robalino (2012) consider local spatial deforestation spillovers from PAs in Costa Rica, building on a finding that entire rings around PAs show no spillovers (Andam et al. 2008). The paper emphasizes theory about the potential mechanisms underlying where any spillovers might occur, in this case emphasizing likely roles of both roads nearby and the location of PA entrances, which are almost surely the spatial focus of tourism's influence. Far from the entrances while near roads, they do find leakage. Near entrances, though, where tourism supports forest, there is no leakage from the PAs, even when nearby to roads. This evidence is generated using OLS and matching to control for factors influences in comparisons.

The stability of land use over time in Costa Rica, however, differs from frontier development such as in the Brazilian Amazon. Further, tourism is central for Costa Rica but minimal as a factor in most PAs in the Amazon. Thus, there is no reason to expect a local deforestation spillover in the Amazon would be like those in Costa Rica. In fact, in Chapter 1 of this dissertation we found that while in fact there are significant deforestation spillovers around some Amazon PAs, they are of the opposite sign, i.e., deforestation is lower than would otherwise be expected – not higher – within the areas nearby to PAs.

How could that be? One story is that PAs serve as a signal to both migrants and those who build roads in the Amazon that the area around the PA will not be a center for employment. Other public investments may be lower, given that the government has chosen new PAs. Such dynamics are perfectly possible in the Amazon, even if less likely in Costa Rica (or the opposite from Costa Rica if creating PAs means local tourism jobs). Chapter 2 explored this mechanism and found Federal PAs seem to dissuade migration.

Protected Areas' Socioeconomic Spillovers

Few empirical studies attempt to show mechanisms through which conservation policies affect socioeconomic outcomes outside their boundaries. Ferraro and Hanauer (2014) present a framework to explore how PAs might affect poverty in Costa Rica. They focus on: changes in tourism and recreational services; changes in infrastructure such as road networks, health clinics and schools; and changes in regulating and provisioning ecosystem services and foregone production that arise from land use restrictions. They find that the major part of the poverty reduction associated with the creation of PAs in Costa Rica is causally attributable to tourism activities.

Robalino and Villalobos (2014) also provide evidence that such impacts of PAs in Costa Rica are due to tourism, including by distinguishing PA entrances. They find that parks' effects on wages are on average positive and significant but the magnitudes vary. Wages close to parks are higher for local workers living near tourist entrances. However, there is no robust evidence of positive effects for those close to parks but far away from tourist entrances. Sims (2010) provides some related evidence for Thailand. The results indicate that protected areas increased average consumption and lowered poverty rates, gains that could be explained by increased tourism in and around protected areas.

3.3 Data & Empirical Approach

3.3.1 Data

We use municipalities as units of analysis, similar to previous studies of the Brazilian Amazon region (Pfaff 1999, Andersen et al. 2002, Weinhold and Reis 2008). My dataset consists of 547 municipalities covering most of the Amazon region (Figure 5). About 90 experienced changes in their boundaries greater than 100 km^2, which could add noise to our analysis. One way to address that is to use 'Minimum Comparable Areas' (MCAs) defined by aggregating municipalities into larger geographic units that are consistent across time (as was done in chapter 2). But there is a tradeoff in using MCAs for the roads analysis, given that MCAs significantly reduce the variability in road density across units, our key variable of study. Given that, it becomes difficult to test statistically for different factors' impacts on unofficial road building. Therefore in this chapter we use municipalities as units of analysis.

We decided to use the 2013 map of the municipalities as the basis upon which to calculate density of the different geographic variables. We linked this to socioeconomic information from different censuses – working by municipality. Given that most of the municipalities did not experience large changes in boundaries, we believe that this is a reasonable approximation to each municipality's prior socioeconomic conditions.

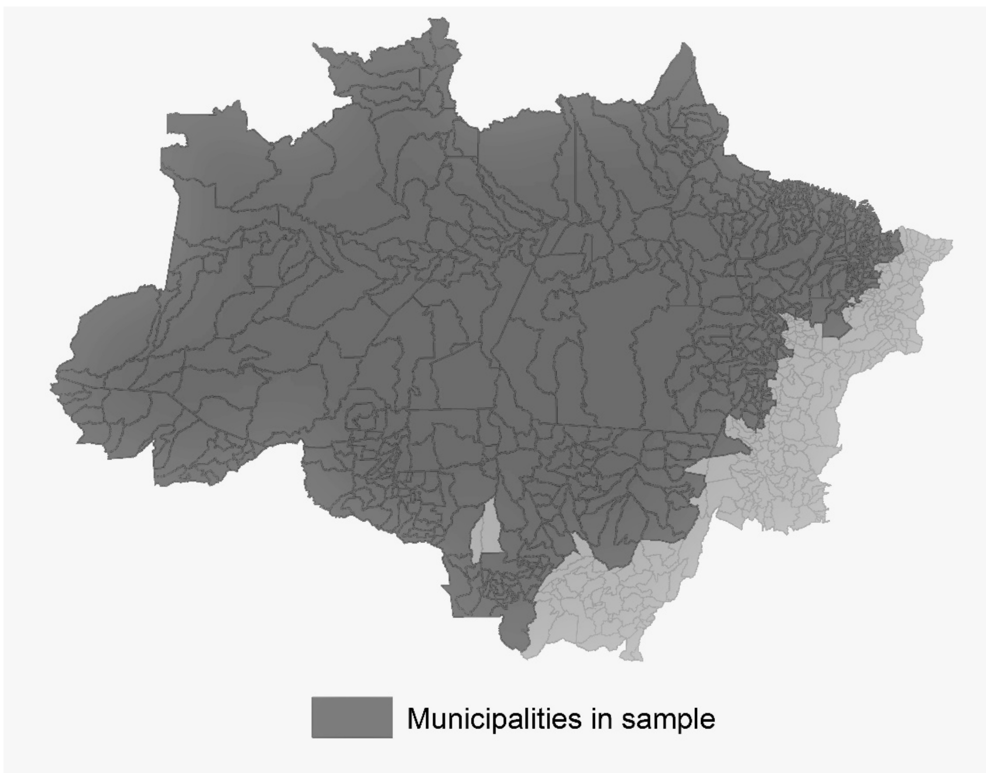

Figure 5: Municipalities in the sample

Roads: new (dependent variable) & prior (independent variables)

Official and unofficial roads maps are available for 2007, 2008 and 2010 from the

Instituto do Homem e Meio Ambiente da Amazonia (or Imazon). For each municipality, we calculated any given road density as the ratio of kilometers of those roads over the area of the municipality. As dependent variable for this paper, we use the increase in the unofficial road density during 2008 to 2010. Because road building has its own dynamics, though, we want to consider using as controls all prior road densities, including not only the unofficial roads but also the official roads. To represent past actions, which could correlate with unobserved factors, we use the 2007 densities.

Protected Areas (treatment)

Wanting to consider the conservation actions that had occurred before the roads expansion we study, we can make use of maps of all of the PAs created up through 2008. That includes both Federal and State PAs and specifically two types of PAs − Integral and Sustainable Use − for each actor. We can compare various aggregations of these four PA types in order to see whether the impacts of the types differ. Further, we could also consider whether the establishment of Indigenous Lands − a large category driven by rather different motivations − appear to send the same or different signals to others.

As we are looking for signals that could affect expectations of those creating recent roads, we are particularly interested in testing the effects of more recent PAs, i.e., created after 2000 (noting that after 2000 the PA network in Brazil's Amazon experienced some rapid expansion). We compare the impact from these later PAs to the impacts from all PAs created before 2008. Further comparisons of treatments over time could also be tried.

Other Explanatory Variables

We also consider other factors in order to explain the increase in unofficial roads densities. From the 2000 Demographic Census, the Imazon data set 'O Estado da Amazonia' and the 2006 Agricultural Census, respectively, we obtained measures of population density in 2000, GDP per capita in 2003 and the area in agriculture in 2005. Two relevant biophysical variables that we incorporate are the mean slope of the terrain and the percent of the municipality in forest cover in the year 2000. We also include a dummy indicating which of the municipalities are located in the Eastern region of the Amazon, which is closer to the agricultural frontiers and the larger population centers. As a robustness check (although not included in the analyses presented in this chapter), We have also included as explanatory variable the prior unofficial roads 2007,which could help control for unobservable factor that affect where new unofficial roads are built.

3.3.2 Empirical Approach

We use municipality data over time to assess links between new unofficial roads, and the PA creation that is our focus among all of the drivers, with controls for prior roads as well as other factors. We start with the following OLS regression:

$$
\begin{aligned}
\Delta \text{ Unofficial Roads Density } i\,;\, t_1 - t_0 = \; & \beta 0 \; + \\
& \beta 1 \text{ * Prior Official Roads Density } i\,;\, t_0 \; + \\
& \beta 2 \text{ * Federal Integral PA dummy } i\,;\, t_0 \; + \\
& \beta 3 \text{ * Federal Sustainable PA dummy } i\,;\, t_0 \; + \\
& \beta 4 \text{ * State Integral PA dummy } i\,;\, t_0 \; + \\
& \beta 5 \text{ * State Sustainable PA dummy } i\,;\, t_0 \; + \\
& \beta 6 \text{ * GDP per capita } i\,;\, t_0 \; + \\
& \beta 7 \text{ * Population Density } i\,;\, t_0 \; + \\
& \beta 8 \text{ * Population Density\^{}2 } i\,;\, t_0 \; + \\
& \beta 9 \text{ * Area in Agriculture } i\,;\, t_0 \; + \\
& \beta 10 \text{ * Mean Slope } i\,;\, t_0 \; + \\
& \beta 11 \text{ * Prior Forest Cover } i;\, t_0 \; + \\
& \beta 12 \text{ * East/West dummy} \; + \\
& \varepsilon i
\end{aligned}
$$

where i = municipality i, t_j = time j

However, PAs could be going to places with characteristics that, on their own, lower unofficial road building. That could generate a spurious estimate of PA impact, seeming to reduce roads. Above, in the OLS regression framework, the use of lagged road variables could help (as noted, perhaps reflecting differences that we do not observe as an analyst but local road builders could see when they made decisions). However, to perhaps also better control for the influences of all of the observed characteristics, we also implement matching methods. 'Treated' municipalities are those with an area protected that is above average for the aggregate of all PAs or considering a given type separately.

The idea of matching is to remove the influence of differences in characteristics between treated and untreated municipalities to isolate the effect of PAs. The goal is an improved control group with low protection by matching each treated (high protection) municipality to the most similar untreated municipality in terms of observed factors.

To that end, we have implemented two matching approaches to finding similar untreated parcels for treated parcels, propensity-score (Abadie and Imbens 2012) and covariate (Abadie and Imbens 2006). Propensity-score matching uses the probability of a municipality of being treated (in this case having higher levels of protection) in order to define 'similarity'. The predicted probability of treatment aggregates all the observables. For covariate matching, 'similarity' is defined using a distance in the multidimensions space of the observed factors that are believed to potentially affect both treatment and unofficial road growth.

3.4 Results

Table 14 presents descriptive statistics for treated and untreated municipalities. Statistics for the latter are in the first column. Each column after that presents statistics for the municipalities that qualify as treated under a different treatment, i.e., that have high PA density level for a particular type of protection. Untreated municipalities are generally much smaller than treated municipalities. Unofficial road densities tend to be higher in untreated municipalities than in those that are treated, as would be expected, since PAs are on average biased towards areas of low development. An exception is the group of municipalities with a State Integral treatment (in particular those with recently created PAs of this category) which has relatively high levels of development with high unofficial roads and population densities, GDP and area in agriculture, mostly located in the state of Mato Grosso. The density of official roads also appears to be slightly higher in untreated municipalities than in the treated groups. Relative to 2007 there does not seem to be much expansion in the official roads network during 2008-10. Untreated municipalities on average have flatter slopes and lower levels of forest cover that those that are treated (consistent with Joppa and Pfaff 2009). All of these differences could significantly bias estimates for PA impacts on the growth rate of unofficial roads.

Table 14: Descriptive Statistics: Mean Characteristics of Treated and Untreated Municipalities

		Treated Municipalities by type of PA				
Variable	**Untreated Municipalities**	**Federal Sustainable**	**Federal Integral**	**State Sustainable**	**State Integral**	**Indigenous Lands**
Area sq km	2,558.28	17,772.23	33,499.37	21,236.69	18,470.06	19,964.25
Density Unofficial Roads 2007	0.12	0.06	0.03	0.07	0.12	0.07
Density Unofficial Roads 08-10	0.02	0.01	0.00	0.02	0.02	0.01
Density Official Roads 2007	0.02	0.01	0.01	0.01	0.01	0.01
Density Official Roads 08-10	0.00	0.00	0.00	0.00	0.00	0.00
GDP per capita 2003	3,764.36	3,120.10	4,158.19	4,503.51	6,771.22	4,486.92
GDP agro 2003	19,557.52	19,510.47	20,990.18	15,584.10	29,507.76	22,258.37
Population density 2000	32.69	7.52	5.23	2.97	40.77	3.21
Area in agriculture sq km	1,161.25	1,343.48	1,640.24	1,301.24	3,632.65	2,364.46
Mean slope	0.55	0.55	0.68	0.51	0.63	0.73
Percent Forest Cover 2000	0.81	0.92	0.88	0.90	0.72	0.84
Acre	0.02	0.16	0.14	0.02	0.00	0.07
Amazonas	0.05	0.20	0.28	0.44	0.20	0.20
Amapa	0.02	0.07	0.16	0.07	0.00	0.02
Maranhao	0.27	0.08	0.07	0.00	0.03	0.09
Mato Grosso	0.16	0.00	0.02	0.02	0.43	0.21
Para	0.30	0.36	0.16	0.02	0.03	0.16
Rondonia	0.07	0.08	0.09	0.42	0.27	0.13
Roraima	0.01	0.03	0.05	0.00	0.00	0.10
Tocantins	0.11	0.01	0.02	0.00	0.03	0.02
# of municipalities	329	74	43	43	30	131

Starting with OLS regressions applied for different levels of aggregation of PAs, Tables 15 and 16 show the effect of the different covariates on the change in unofficial roads density 2008-10. Those covariates include PA densities and, specifically, Table 15 considers Federal and State PAs divided into Integral Protection and Sustainable Use, while Table 16 considers the more aggregated Federal and State categories. Each of these tables considers in one column the effect of all PAs created before 2008 and in a second column the effect only of PAs created in 2000-08. Overall, prior official roads density has a positive and significant effect on the rise in density for the unofficial roads as would be expected given previous evidence in the literature on roads dynamics. The first column of Table 15 shows that Federal PAs, both Integral Protection and Sustainable Use, have a negative effect on the change in roads density. But for Federal PAs created in 2000-2008, only those in the Sustainable Use category seem to have this negative significant effect. State Sustainable PAs created before 2008 show a positive though not highly significant effect on the change in unofficial roads density. However, for State PAs created in 2000-2008 neither of the subcategories of protection has a significant effect. Indigenous lands show a non-significant coefficient when all PAs created before 2008 are considered, but those recently created have a significant negative effects on the change in roads density.

Table 15: Impact of PAs created before 2008 and between 2000-08 on the Change in Unofficial Roads Density 2008-10, OLS regression

Variables	PAs created before 2008	PAs created between 2000-08
Density Official Roads 07	0.136***	0.145***
	(0.0335)	(0.0332)
Federal Sustainable PAs dummy	-0.00692***	-0.00609*
	(0.00260)	(0.00345)
Federal Integral PAs dummy	-0.0109***	-0.00922
	(0.00336)	(0.00592)
State Sustainable PAs dummy	0.00701*	-0.00436
	(0.00361)	(0.00542)
State Integral PAs dummy	-0.000864	-0.00121
	(0.00406)	(0.00635)
Indigenous Lands dummy	-0.00174	-0.00582**
	(0.00229)	(0.00296)
GDP per capita 2003	1.12e-06***	1.15e-06***
	(2.67e-07)	(2.69e-07)
Population Density 2000	-4.48e-05**	-4.57e-05**
	(2.03e-05)	(2.04e-05)
Population Density 2000^2	1.93e-08	1.98e-08
	(1.21e-08)	(1.21e-08)
Area in Agriculture	2.98e-06***	3.13e-06***
	(5.09e-07)	(5.17e-07)
Mean slope	-0.00372	-0.00538**
	(0.00226)	(0.00227)
Forest cover 2000	0.0249***	0.0240***
	(0.00388)	(0.00387)
Eastern region dummy	0.00395*	0.00273
	(0.00222)	(0.00212)
Constant	-0.0150***	-0.0132***
	(0.00408)	(0.00408)
Observations	547	547
R-squared	0.277	0.262

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 16: Impact of PAs created before 2008 and between 2000-08 on the Change in Unofficial Roads Density 2008-10 (aggregate categories), OLS regression

Variables	PAs created before 2008	PAs created between 2000-08
Density Official Roads 07	0.133***	0.146***
	(0.0336)	(0.0331)
Federal PAs dummy	-0.00920***	-0.00801***
	(0.00231)	(0.00308)
State PAs dummy	0.00240	-0.00253
	(0.00293)	(0.00420)
Indigenous Lands dummy	-0.00264	-0.00591**
	(0.00224)	(0.00294)
GDP per capita 2003	1.13e-06***	1.13e-06***
	(2.66e-07)	(2.67e-07)
Population Density 2000	-4.78e-05**	-4.61e-05**
	(2.03e-05)	(2.04e-05)
Population Density 2000^2	2.07e-08*	1.99e-08
	(1.20e-08)	(1.21e-08)
Area in Agriculture	2.89e-06***	3.12e-06***
	(5.02e-07)	(5.00e-07)
Mean slope	-0.00394*	-0.00550**
	(0.00226)	(0.00226)
Forest cover 2000	0.0254***	0.0240***
	(0.00385)	(0.00385)
Eastern region dummy	0.00294	0.00282
	(0.00220)	(0.00209)
Constant	-0.0140***	-0.0131***
	(0.00409)	(0.00406)
Observations	547	547
R-squared	0.271	0.262

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Higher levels of GDP per capita, population density, area in agriculture, and prior forest cover seem to generate a larger increment in the unofficial roads density. The effect of the forest variable is consistent with studies suggesting that roads are being built in densely forested areas for extractive purposes. The dummy variable for the

Eastern region that contains more active agricultural frontiers has a positive coefficient, while higher slopes have a negative effect on the change in roads density. Federal PAs -- both all created before 2008 and the recent ones created in 2000-2008 -- on average have a negative significant effect upon the outcome variable, as shown in Table 16, while State PAs have a non-significant average effect upon the change in unofficial roads density.

My next step in evaluating the impacts of the different treatments on the change in 2008-2010 unofficial roads uses propensity score matching and covariate matching. The pool of potential controls, i.e., municipalities that were never treated under any type of conservation, remains the same across these analyses. Tables 17 through 20 show the impact estimates for each category of protection as well as the balancing from matching. For impact estimates, the first columns of these tables show simply the differences in the outcome variable, i.e., the change in unofficial roads density during 2008-2010, between the treated and untreated groups before matching. Next the impacts from propensity score and covariate matching are provided. In order to get a sense of what matching has done for each estimation, these tables also show the initial imbalance and improvement in balance in terms of the observed characteristics -- using a standardized bias measure. This bias measure is simply the percent difference of the sample means in the treated and untreated subsamples expressed as a percentage of the square root of the average of the sample variances in the treated and untreated groups (Rosenbaum and Rubin 1985).

Tables 17 and 18 present the results for Federal and State respectively (as well as subcategories Integral and Sustainable) considering as treatments all of the PAs created before 2008. Federal PAs -- both of the Integral Protection and Sustainable Use types -- show significant negative impacts on the change in unofficial roads density. Propensity score and covariate matching seem to improve the balance in covariates by generating lower and mostly non-significant standardized bias measures. On the other hand, State PAs do not show a consistent significant effect on change in unofficial roads density, although the matching again seems to reduce the bias in most covariates employed.

Table 17: Impact of Federal PAs created before 2008, Matching Results and Balance in Characteristics

	Federal Sustainable created before 2008			**Federal Integral created before 2008**		
	Means Comparison	*PSM*	*CVM*	*Means Comparison*	*PSM*	*CVM*
Impact on Unofficial Roads density 08-10	-0.00802***	-0.00588*	-0.00478*	-0.0132***	-0.0195***	-0.0149***
	(0.00306)	(0.00312)	(0.00275)	(0.00393)	(0.00520)	(0.00412)
Standardized bias (%)	*Before Matching*	*After PSM*	*After CVM*	*Before Matching*	*After PSM*	*After CVM*
Density of Official Roads 2007	-53.9***	-14.5	-19.3	-74.7***	-2.1	-56**
GDP per capita 2003	-21.1	-11.3	1.7	12	-5.5	3.7
Population density 2000	-25	-3.6	-14.4	-27.1	-6.8	8.5
Population density 2000^2	-12	2.2	-4.3	-11.9	17.3	21.1
Area in agriculture	12.1	13.9	7.5	21**	11.7	9.1
Mean slope	1.1	16.8	6.4	32.5**	6.9	14.6
Forest cover 2000	60.6***	15.7	-4.2	32.5**	-15.4	-9.6
Eastern region	-73.7***	30*	0	-93.3***	4.6	0

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 18: Impact of State PAs created before 2008, Matching Results and Balance in Characteristics

	State Sustainable created before 2008			State Integral created before 2008		
	Means Comparison	*PSM*	*CVM*	*Means Comparison*	*PSM*	*CVM*
Impact on Unofficial Roads density 08-10	0.000185	-0.00290	-0.000348	0.00281	-0.00398	-0.0120**
	(0.00406)	(0.00492)	(0.00468)	(0.00481)	(0.00725)	(0.00550)
Standardized bias (%)	*Before Matching*	*After PSM*	*After CVM*	*Before Matching*	*After PSM*	*After CVM*
Density of Official Roads 2007	-63***	36.8*	-35.2	-41.3*	-0.1	-18.2
GDP per capita 2003	19.9	15.1	1.8	70.2***	-30.5	21.7
Population density 2000	-29.6	-35.2	-40.2*	4.8	19.2	-1.7
Population density 2000^2	-12.1	1.9	-2.7	7.0	24.7	-4.7
Area in agriculture	10.6	44.8**	9.9	96.5***	-17.6	29.1
Mean slope	-10.7	-12.4	-10.3	23.9	-28.9	11.4
Forest cover 2000	50.7**	-36.8*	-20.1	-32.8*	-23.4	-22.8
Eastern region	-214.3***	-13.3	-6.9	-71.8***	-49.6**	0.0

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Tables 19 and 20 focus on the impacts from PAs created between 2000 and 2008. We find that Federal PAs of the Sustainable Use type have significant negative impacts upon the change in unofficial roads density under both propensity score and covariate matching, while the Federal Integral PAs do not have a significant effect. Matching also improves covariates balance for this category, however. The subset of recent State PAs also shows some significant negative effects on road growth, especially for the Integral Protection type. However, though the standardized bias shows up as non-significant for most covariates, the magnitude of the bias remains relatively high for several of them.

Table 19: Impact of Federal PAs created between 2000-08, Matching Results and Balance in Characteristics

	Federal Sustainable created in 2000-2008			Federal Integral created in 2000-2008		
	Means Comparison	*PSM*	*CVM*	*Means Comparison*	*PSM*	*CVM*
Impact on Unofficial Roads density 08-10	-0.00917**	-0.00882**	-0.00708**	-0.00564	-0.0176	-0.00377
	(0.00385)	(0.00400)	(0.00283)	(0.00699)	(0.0111)	(0.00712)
Standardized bias (%)	*Before Matching*	*After PSM*	*After CVM*	*Before Matching*	*After PSM*	*After CVM*
Density of Official Roads 2007	-35.9**	-3.8	-8.9	-68.1*	-40.8	-34.6
GDP per capita 2003	-56***	-14.4	-22.6	46.5	-43.9	26.2
Population density 2000	-19.1	-6.4	-0.5	-27.7	-30.3	-14.7
Population density 2000^2	-11.7	-18.5	0.7	-11.9	-18.4	21.2
Area in agriculture	-7.9	15.5	-1.6	41.6***	-7.0	3.4
Mean slope	-68.6***	1.3	-7.2	12.6	1.5	7.8
Forest cover 2000	57.9***	-17.5	-7.7	23.3	-15.1	23.9
Eastern region	-71.5***	20.3	0.0	13.3	-24.3	0.0

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 20: Impact of State PAs created between 2000-08, Matching Results and Balance in Characteristics

	State Sustainable created in 2000-2008			State Integral created in 2000-2008		
	Means Comparison	*PSM*	*CVM*	*Means Comparison*	*PSM*	*CVM*
Impact on Unofficial Roads density 08-10	-0.0110*	-0.00499	-0.00546*	0.00618	-0.0201***	-0.0131*
	(0.00606)	(0.00337)	(0.00285)	(0.00732)	(0.00192)	(0.00701)
Standardized bias (%)	*Before Matching*	*After PSM*	*After CVM*	*Before Matching*	*After PSM*	*After CVM*
Density of Official Roads 2007	-70.4**	-18.4	-4.4	-20.7	47.5	-16.7
GDP per capita 2003	3.9	1.7	0.3	49.6	-0.4	15.2
Population density 2000	-26.6	0.8	29.0	-28.6	-32.8	-60.9
Population density 2000^2	-11.8	25.1	35.0	-11.9	-16.4	-52.1
Area in agriculture	-54.7*	-9.1	-9.4	129.6***	-9.2	12.5
Mean slope	-48.8	-37.1	-6.1	19.9	35.9	-4.1
Forest cover 2000	68.2**	-32.9	-31.8	-29.4	-54.8	-31.5
Eastern region	-209.4***	0	-20.9	9.4	20.8	0

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.5 Discussion

The results of my analyses show that municipalities with higher fractions of their area in Federal PAs consistently have lower increase in unofficial roads density. That is consistent with the results of previous analyses of not only the Federal PAs' local forest spillovers but also their impacts on individual migration decisions in Brazil's Amazon. The PAs' impacts on unofficial road building could, thus, be interpreted as yet another mechanism for PAs' influence on deforestation outside their boundaries, one which was suggested but not formally evaluated by Brandao and Souza (2006) for the state of Para.

Given recent expansion of PAs in the region, national and international efforts to strengthen conservation and the evidence that Federal PAs may shift development, we believe further study is required to understand the implications of forest protection for local livelihoods and for strategies that optimally spatially integrate conservation and development in order to maximize welfare gain. Roads are a key driver of development paths -- providing access to resources as well as likely attracting migrants, capital and other development investments. However, investments in transport networks may not generate these benefits in regions where conservation may have signaled lower income or employment opportunities. These results suggest that to increase environmental and socioeconomic benefits simultaneously, in a context like the Amazon, an optimal strategy could involve spatial intensification of conservation and development activities. Future efforts may test this by explicitly modeling conservation-development dynamics.

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