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Sequenced Road Investments & Clearing Of The Mayan Forest

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Introduction

Roads are widely said to be one of the most important predictors of frontier expansion and deforestation in tropical forest regions, across a range of land dynamics . Though they are widely studied, careful documentation of the magnitude of roads' impacts is in fact relatively scarce. Not infrequently, a simple aerial or satellite snapshot is said to 'document' the impacts of reduced transport costs. More generally, average cross-sectional correlations of forest amount and road density are offered but are insufficient to demonstrate a causal link or to establish its magnitude. Further, even if causality and magnitudes were well established, within the design of development policies for which the balance of development and degradation outcomes is important, it would be helpful to know how deforestation and related consequent impacts vary with the context in which the road investment is made .

We suggest, and demonstrate, that to address these questions it is exceptionally helpful to be able to track the sequence of road investments underlying the most recent available road map as well as the sequence of clearing underlying the latest forest map.

Without knowing the timing of road investments and clearing, we can misrepresent the direction of causality between them. For example, an early unpaved road may increase access to and clearing of forest frontiers, which in turn may affect other decisions such as by local governments to provide various services, and eventually to pave over unpaved roads after much clearing has occurred. A decade or two later, cross-sectionally linking the paved roads as causes of nearby deforestation may misrepresent paving's impact.

Recent studies in the Brazilian Amazon have focused incorporating measures of road and forest *change* to avoid such errors . These studies, looking at locations receiving road investments (Pfaff, Walker et al. 2007) and also at their neighbors who do not receive road investments (Pfaff, Robalino et al. 2007) refute the suggestion in Andersen et al. 2002 that new roads will lower rates of deforestation in a county. The cited papers show that deforestation rises not only in census tracts which receive roads but also in nearby tracts in the same county without roads investments. They include fixed effects for the counties used in Andersen et al.2002, since the census tract data they employ provides over 20 times (roughly 6000 vs. 3000) the observations.

Andersen et al. 2002 also appropriately regress deforestation, or forest change, on prior changes in roads. How, then, do they arrive at such a prediction given the above? The answer is the combination of a good idea with the limited data. The good idea was to analyze how road impact differs as a function of context, in particular prior clearing. Estimating an interaction, using the county data, suggested that more prior clearing led to lower road impact. Extrapolated, this suggested that new roads could lower clearing.

Pfaff, Walker et al. 2007 reevaluated these results by examining the much more numerous census tract observations in groups distinguished by level of prior clearing (0% , 1-50%, 51-75%, >75%). The dominant first two categories show strong increases in deforestation from roads investments. And while the last category is insignificant (with fewer observations), for 50%-75% prior clearing the increase in deforestation resulting from new roads investments is higher, not lower, than it is for the more pristine areas.

Such an outcome could arise because of the costs and hence non-instantaneous pace of adjustment on the frontier. When a road enters a previously less developed or pristine area, the labor and capital required to carry out all of the land-cover change that may suddenly be economically worthwhile are not present. Clearing primary forest is hard work, especially on ones own small land holdings. In contrast, in locations where some economic activity and forest clearing have already occurred, a rise in profitability due to a change in transport cost may more quickly be responded to and thereby may generate more additional deforestation in the first decade after the new road investment.

This would not mean that in the long-run new clearing versus baseline is higher. Yet based on these results alone, a decision maker could conclude that new roads into pristine areas will promote less additional deforestation than new roads following paths of prior development. Here, though, we see another value of observing the sequence of roads investment over time. Pfaff et al. 2006, for instance, shows that new roads through a given site lead to follow-on investments in roads (such as paving of unpaved roads). Thus, it could easily be the case that entering the pristine area with a new road creates more additional deforestation over time than investment that follows upon past roads.

Such a perspective is relevant for current comment upon such famous ongoing policy initiatives as the "Avanca Brasil" program and the "Mesoamerican Road Interconnection Program (RICAM)" proposal. Each suggests the expansion of a road network within a region featuring a mix of developed and quite pristine areas.

To enhance understanding of road impacts across diverse landscape contexts, here we take a similar approach to the Mayan forest (noting, given the importance of data resolution above, that here we use pixel data). The Selva Maya is an important tropical forest, the second biggest in the Americas after the Amazon and the largest continuous forest patch of the 'Mesoamerican hotspot' which contains around 7% of the world species . Located across Mexico, Belize and Guatemala, Selva Maya is subject to different policy, cultural and historical influences and to a grand road expansion program that will intersect its core . Given its biological importance and the environmental services it provides at a local and global scale, this region is a good case to consider road impacts.

We focus on four questions: 1) what are the short and medium term effects of paved and unpaved roads investments on deforestation?; 2) do these impacts differ when roads are placed in areas with existing pressure vs. in less developed locations?; 3) do the effect of non-road drivers also vary with development contexts? We might expect that roads in previously pristine areas a new road will be the dominant predictor; and 4) using a different measure of context, do road impacts vary across the countries? For example, countries with high subsidies in agriculture may experience more impact .

METHODS

Study Area and Data Processing

The study area comprises the majority of the Petén of Guatemala, most of Belize with the exception of the Toledo district in the south, and a large portion of the states of Campeche and Quintana Roo in Mexico. The total area covers around 100,000 km^2 which is delimited by four LANDSAT satellite images (Figure1). The region has tropical semi-deciduous forest , with an average of 1350 mm of annual rainfall and a pronounced dry season between February and June.

To remotely sense deforestation we used LANDSAT images in three time periods: (1) pre-1980, (2) 1980-1990, and (3) 1990-2000 (Table 1). For the base year (1980), we mosaicked four images from 1974 to 1980 to obtain a low cloud-free composite image of the study area. Likewise, the image dates composited for the 1990 image ranged from 1988 to 1990. Sufficient cloud-free images from 2000 were available for that year's image mosaic. To equalize the resolution of the entire dataset to that of the coarsest data (MSS), TM and ETM+ images were resampled to a pixel resolution of 60x80-m.

Table 1. Path and row of satellite images used to estimate deforestation.

Path & Row	Receptor / Satellite	Date of Image
20-47	MSS / Landsat 3	January 1978
19-47	MSS / Landsat 3	February 1978
20-48	MSS / Landsat 3	February 1974
19-48	MSS / Landsat 3	December 1980
20-47	TM / Landsat 5	April 1988
20-48	TM / Landsat 5	November 1988
19-47	TM / Landsat 5	November 1990
19-48	TM / Landsat 5	December 1989
20-47	ETM / Landsat 7	March 2000
20-48	ETM / Landsat 7	March 2000
19-47	ETM / Landsat 7	April 2000
19-48	ETM /Landsat 7	September 2000

Two approaches were used to map deforestation in the three periods. For the pre-1980 period, we classified each image independently into forest and non-forest using the Maximum-Likelihood (supervised) classification algorithm and then combined the resulting forest/non-forest maps into a single mosaic. Training data for these classifications were collected from locations for which the land cover was known for 1980. To map deforestation for the 1980-1990 and 1990-2000 periods, we subtracted Normalized Difference Vegetation Index (NDVI) images of each period's beginning date

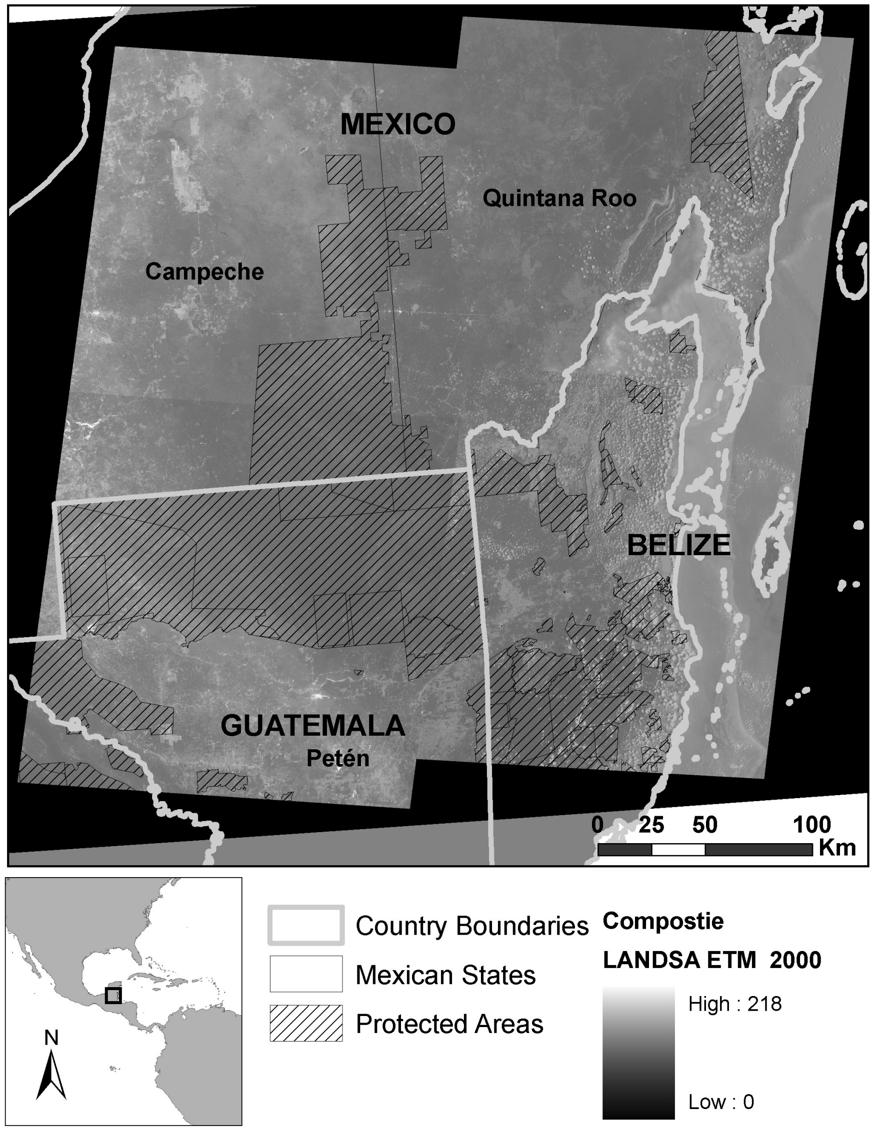

Figure 1 Study Area delimited by four LANDSAT images

from the period's end-date NDVI and identified deforestation from the histogram of differences (Yuang *etal.*1998). To avoid interpreting phenological changes as deforestation, we classified the 2000 image into forest and non-forest types by Maximum-Likelihood and removed forest pixels from the change maps. The classification of the 2000 image, based on in situ training data collected in 2003, had a

Kappa statistic of 0.8369 . Clouds and water were also removed from each year by Maximum-Likelihood.

The likelihood of forest clearing can be influenced by soil, elevation, slope, distance to previous deforestation and land tenure . We aggregated into four types a 24 types soil map classification from Garcia and Secaira (2006), based on soil characteristics and spatial continuity. For elevation, we used a 90m resolution digital elevation model . We calculated distance to deforestation for the pre-1980 and 1980-1990 periods, with the Euclidian distance algorithm of ARCmap ver. 9.1. We defined as "main markets" population centers that were present in the study area before 1980 and by 2000 had a population above eight thousand people. Small markets were defined as population centers that held between 2000-8000 people by the year 2000 and were present pre-1980. We computed the Euclidian distance to main and small markets. Protected areas boundaries for 1980-1990 and 1990-2000 were obtained from the CONABIO and Garcia and Secaira (2006) databases, no protected areas existed for the pre-1980 period. The country of Belize, the Petén of Guatemala and the states of Campeche and Quintana Roo in Mexico were defined as dummy variables. Mexico was divided in two states, due to their contrasting land use policy and history.

To track the evolution of road investments, we used a regional a road map for the year 2000 and we complemented it by digitalizing missing roads from the 2000 LANDSAT images. The García and Secaira (2006) roads layer has the attributes of each road as paved or unpaved. We obtained data on road pavement dates from CEMEC and

Wildlife Conservation Society-Guatemala (WCS), as well as from the Mexican Ministry of Communication and Transportation (SCT). We digitize which segments were paved or unpaved for the pre-1980 and 1980-1990 periods by using the Landsat images, with these data we assigned to each road the paved or unpaved category. The two road types for three periods yielded to six variables (paved and unpaved per period: 80, 80-90 and 90-2000, Figure 2). For the six road variables we computed the Euclidian distance. To analyze the impact of roads on deforestation in each time period, we assigned to each of the 15000 random sampling points, the distance to the closest road segment. This eliminated noise of considering roads that were really distant to the sampled point, since people access forests using the closest road to the target area; for example, if the target is within at 1km distance form road type A and in a 100km distance from road type B, people will more likely use road type A to access that forest parcel.

All the GIS layers were resampled to a pixel resolution of 10,000 square meters, which we defined as parcels; this resulted into a study area of 9,177,507 hectares. We defined this parcel unit based on the broader scale data layer a Digital elevation Model

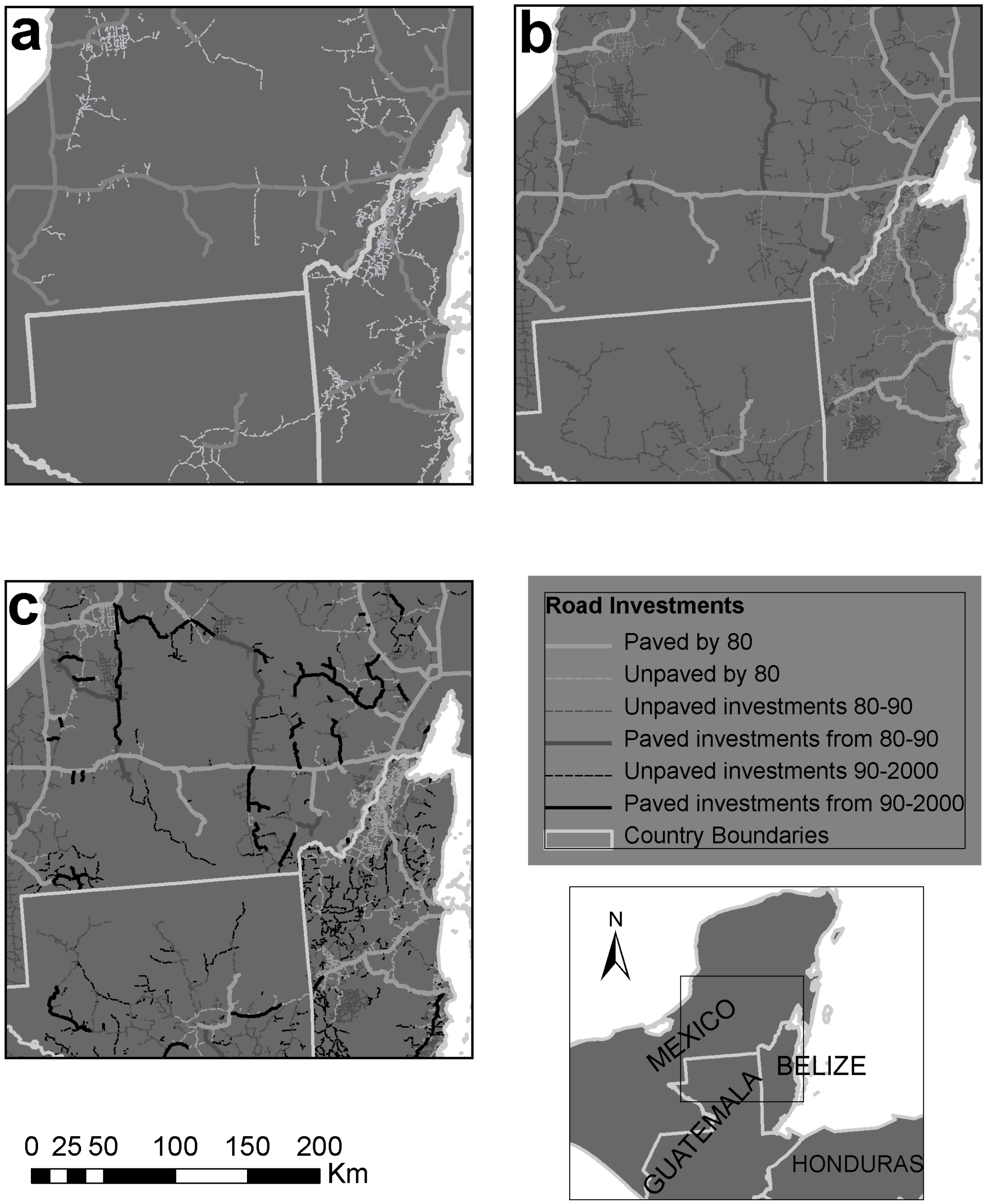

Figure 2 Road Investments: by 1980 (a), from 1980 to 1990 (b) and from 1990 to 2000 (c).

(DEM,Shuttle.Radar.Topography.Mission:http://edc.usgs.gov/srtm/data/obtainingdata.html). We randomly sampled 15,000 parcels using Hawks' tools . We dropped the variables of transport cost distance to markets and roads density because it showed strong colinearity. The means and standard deviations of each variable can be seen in Table 2.

Model of Deforestation and Road Investments

According to economic theory the likelihood of a parcel of land being deforested will be higher if the profits of clearing a forest parcel are higher than the profits of leaving the land under forest cover . For this project we only focused on long-term land use change, therefore we did not quantify reforestation, only total forest loss. Based on previous research on deforestation drivers, we assumed that the likelihood of clearing a parcel will be influenced by distance to a road type investment (paved and unpaved) as well as the time of road placement. We assumed that the parcel characteristics that are likely to influence the profitability of deforestation are elevation, travel cost to the markets, soil type and protected areas status . We did not include slope since the area is a flat plateau with an average elevation of 300m.

Table 2. Summary Statistics

Covariates	Mean or proportion for deforested parcels		
	By 1980	From 1980-1990	From 1990-2000
Distance to unpaved roads by 1980 (Km)	1.368	19.947	14.921
Distance to unpaved roads investments: 1980 to 1990 (Km)	–	2.99	4.107
Distance to unpaved roads investments: 1990 to 2000 (Km)	–	–	7.599
Distance to paved roads by 1980(Km)	8.687	22.544	32.911
Distance to paved roads investments: 1980 to 1990 (Km)	–	29.926	37.231
Distance to paved roads investments: 1990 to 2000 ,Km	–	–	15.36
Distance to Markets > 8000 people: type 1, Km	30.786	42.74	52.73
Distance to Markets > 2000 and <8000 people: type 2, Km	20.862	26.048	28.433
Elevation (m)	59	96	125
Distance to water sources (Km)	10.455	10.995	10.097
Protected areas in 1990 dummy	–	0	–
Protected areas in 2000 dummy	–	–	0.084
Distance to deforestation in 1980 (Km)	–	4.326	6.638
Distance to deforestation in 1990 (Km)	–	–	1.414
Campeche dummy	0.26	0.41	0.18
Quintana Roo dummy	0.25	0.31	0.27
Guatemala dummy	0.067	0.044	0.51
Belize dummy	0.43	0.13	0.038
Soil A dummy	0.62	0.54	0.64
Soil B dummy	0.19	0.31	0.16
Soil C dummy	0.003	0.044	0.1
Soil D dummy	0.0091	0	0.0026
Soil E dummy	0.0061	0	0
Soil F dummy	0.024	0.031	0.0013
Soil G dummy	0.024	0.019	0.01
Soil H dummy	0.024	0.0093	0.0064
Soil I dummy	0	0	0.0013
Soil J dummy	0.073	0.037	0.065
Soil K dummy	0.024	0.0031	0.0077
Total number of observations / No. of deforested	**15,432 / 332**	**15,139 / 324**	**14,917 / 790**

To analyze temporal and individual effects of each type of road investment (paved/unpaved) we ran a separate model for each time, resulting in twelve different models. For deforestation in 1980 we used two models to evaluate the impact of 1980 paved and unpaved roads separately, while using the same covariates in each model. For the second period (80-90), we generated four models: two for paved/unpaved 1980 roads, and two for the 80-90 paved/unpaved roads. For the last period, we ran six models: four that to incorporate the effects of 1980 and 80-90 roads from the two previous periods and two more for the paved/unpaved road investments from 1990 to 2000.

To understand the effects of roads given the landscape context, we divided our sample in two development categories: 1) high developed areas, and 2) low development or "pristine" areas. High developed areas included all the points located within 25Km of past road investments; low development areas included all the points situated beyond the 25Km distance. To verify the robustness of our results, we re-analyzed the data using distance to previous deforestation instead of distance for roads, and we varied the distance threshold from 10km to 50 Km.

We used a Generalized Linear Model (GLM) approach to understand the probability of deforestation in a parcel given the covariates mentioned above. The outcome variable is deforestation (y= 1 if a parcel is deforested, y = 0 if a parcel is not deforested). For pre-1980 we considered all the deforested cells in the landscape present at that time, without knowing the period when the deforestation took place. For the second period: 1980-1990, we excluded all the deforested parcels present in 1980, therefore y= 1 only for parcels that were deforested during that decade. We followed this same protocol for the third period: 1990-2000.

We modeled deforestation at each point i as a Bernoulli process (y_i ~ Bernoulli (p_i)) with probability p_i to be deforested; we linked this probability with relevant covariates through a logit-link function of the form:

$$\ln\left(\frac{p_i}{1-p_i}\right) = \mathbf{x}_i\boldsymbol{\beta} + \boldsymbol{\varepsilon}_i \qquad (1)$$

where $\mathbf{x}_i$ is the vector of covariates (i.e distance to road, elevation, country, soil type, etc.) for point *i* and $\boldsymbol{\beta}$ is the vector of parameters linking $\mathbf{x}_i$ and $\boldsymbol{p}_i$.

Although the covariates that we used had an inherent spatial structure, we tested for the effect of spatial autocorrelation by including in the GLM an autocovariate term . This means that the model takes the form:

$$\log\left(\frac{P_i}{1-\theta_i}\right) = \mathbf{x}_i\boldsymbol{\beta} + \alpha A_i \qquad (2)$$

where xi is the vector of covariates for point i as described above, α is a parameter for the autocovariate term Ai. This last is calculated as

$$A_i = \frac{\sum_{j=1}^{k_i} w_{i,j}\hat{P}_j}{\sum_{j=1}^{k_i} w_{i,j}} \qquad (3)$$

and is a weighted average of the number of points *ki* in a radius of 5 km around point i each with a weight $w_{i,j}$, which is equivalent to $w_{i,j} = 1/h_{i,j}$ where $h_{i,j}$ is the Euclidean distance between points *i* and *j*. The parameter $\hat{P}_j$ represents the estimated probability of deforestation for point *j* at each Gibbs step. If there is a spatial effect that is not controlled by the covariates, it is expected that the distribution of parameter α will be significantly different from 0 (i.e. 0 will be outside the 95% credible intervals). Since the spatial autocorrelation term from this analysis was not significant, we did not include it our model.

RESULTS & DISCUSSION

The short and medium term effects of paved and unpaved roads investments on deforestation.

The results from this analysis show that both paved and unpaved roads are significant deforestation drivers in the Mayan Forest. The only exception, was the coefficient for distance to paved investments in the 80-90 period, which were non significant for deforestation during the same period. However, for the following period (90-00), it was highly significant (Table 3). This lag effect of the 80-90 paved roads on subsequent deforestation is logical, since most of these paved roads were built by the end of the 1980s. As can be seen in Table 3, unpaved roads showed a consistent impact on deforestation that lasts for at least two decades. Unpaved roads built by 1980 were highly significant for the 1980s (with a coefficient of -0.37 and a standard error of 0.000) and for deforestation in the 1990s (with a coefficient of -0.24 and a standard error of 0.000). In this way, we show that even type of investment (paved and unpaved) in each period lowers transport costs on average in such a way as to increase rates of deforestation (with the caveat that for one period new paved investments have no significant impact). That sets the stage, then, for examining the context dependence of road impacts to shed light on the choices facing the policy planner.

Table 3. Log-regression coefficients of deforestation covariates resulted from the per road type, per period models.

	Unpaved by1980		Paved by 1980		Unpaved Investments 80-90		Paved Investments 80-90		Unpaved Investments 90-00		Paved Investments 90-00	
	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
DEFORESTATION present by 1980 (Total sampling units: 15,432 / Total deforested sampled units:332) 2.15% of deforestation initially												
Intercept	-0.37	0.07	-0.87	0.06								
Closest dist.	**-0.72**	**0.00**	**-0.87**	**0.00**								
Campeche	0.19	0.34	-0.41	0.47								
Quintana Roo	-0.55	0.00	-0.26	0.48								
Guatemala	-0.35	0.28	-1.24	0.14								
Elevation	0.00	0.01	0.00	0.50								
Dist to markets 1	-0.01	0.01	-0.01	0.06								
Dist to markets 2	-0.02	0.00	-0.01	0.06								
Soil dummy B	0.61	0.01	0.06	0.92								
Soil dummy C	-1.43	0.17	44.83	0.94								
Soil dummy D	0.03	0.85	0.20	0.65								
Sample size/def	*10937*	*275*	*4495*	*57*								
DEFORESTATION from 1980-1990 (Total sampling units:15,139 /deforested sampled units: 324) 2.15% of deforestation in a decade												
Intercept	-1.98	0.00	-1.71	0.05	-2.50	0.00	6.07	0.20				
Closest dist.	**-0.37**	**0.00**	**-0.11**	**0.60**	**-0.38**	**0.00**	**0.16**	**0.63**				
Campeche	0.70	0.03	1.36	0.09	2.71	0.00	-6.32	0.10				
Quintana Roo	-0.22	0.47	0.94	0.21	0.61	0.11	-7.65	0.07				
Guatemala	0.00	1.00	-16.10	0.99	1.80	0.00	-	-				
Protected Areas	-12.39	0.98	-14.07	1.00	-11.21	0.97	-	-				
Elevation	0.00	0.67	0.01	0.13	0.00	0.04	-0.06	0.04				
Dist. to def 80	0.01	0.86	-1.89	0.01	0.00	0.90	-0.74	0.19				
Dist to markets 1	-0.01	0.09	-0.03	0.01	-0.02	0.00	-0.01	0.84				
Dist to markets 2	-0.01	0.06	-0.04	0.04	-0.01	0.03	0.05	0.17				
Soil dummy B	0.34	0.37	0.32	0.70	0.50	0.12	-	-				
Soil dummy C	1.22	0.03	-	-	0.67	0.18	-0.04	0.98				
Soil dummy D	-0.09	0.76	-0.07	0.92	-0.12	0.70	0.66	0.64				
Sample size/def	*3296*	*97*	*1856*	*19*	*9597*	*200*	*390*	*8*				

Table 3. Continues in the following page.

	Unpaved by 1980		Paved by1980		Unpaved Investments 80-90		Paved Investments 80-90		Unpaved Investments 90-00		Paved Investments 90-00	
	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
DEFORESTATION 1990-2000 (Total sampling units:14,917 / deforested sampled unitis:790) 5.3 % of deforestation in a decade												
Intercept	-2.72	0.00	-1.74	0.01	-2.69	0.00	2.77	0.16	-4.49	0.00	-16.31	0.98
Closest dist.	**-0.24**	**0.00**	**-0.24**	**0.17**	**-0.17**	**0.00**	**-0.69**	**0.08**	**-0.25**	**0.00**	**-0.24**	**0.00**
Campeche	1.13	0.00	1.33	0.12	0.62	0.13	-3.66	0.02	2.40	0.00	14.59	0.99
Quintana Roo	1.15	0.00	1.23	0.06	0.91	0.01	-3.99	0.01	2.00	0.00	14.30	0.99
Guatemala	3.78	0.00	-14.27	0.99	2.40	0.00	-	-	3.85	0.00	16.23	0.98
Protected Areas	-15.54	0.98	-14.51	0.99	-0.84	0.00	-12.08	0.99	-1.34	0.00	-0.37	0.52
Elevation	-0.01	0.00	-0.01	0.13	0.00	0.00	-0.02	0.02	-0.01	0.00	-0.01	0.02
Dist. to def 80	0.08	0.15	-0.04	0.83	-0.03	0.02	-0.24	0.63	-0.02	0.16	-0.02	0.51
Dist. to def 80-90	-0.40	0.00	-0.17	0.31	-0.15	0.00	0.04	0.89	-0.02	0.57	-0.20	0.10
Dist to markets 1	0.02	0.00	0.01	0.44	0.01	0.00	0.04	0.04	0.01	0.09	0.01	0.10
Dist to markets 2	-0.01	0.15	-0.02	0.03	-0.01	0.00	-0.02	0.31	0.00	0.43	0.00	0.65
Soil dummy B	-0.12	0.71	-0.79	0.17	-0.05	0.85	-0.68	0.67	-0.02	0.97	-0.31	0.54
Soil dummy C	0.13	0.81	-	-	1.11	0.00	-	-	1.41	0.01	-0.30	0.81
Soil dummy D	-0.04	0.88	-1.08	0.01	-0.05	0.83	-0.34	0.77	0.43	0.38	-0.15	0.72
Sample size/def	*1953*	*157*	*1284*	*38*	*5303*	*324*	*317*	*20*	*5083*	*180*	*977*	*71*

Differences of road impacts given the landscape context.

Our results show that the impact of roads investments on deforestation is highly dependent on the landscape context (Tables 4 & 5). Both distance to previous roads and to previous deforestation are important elements that directly affect the magnitude of deforestation promoted by new investments. Road impact was higher where prior development and clearing are likely to have occurred. Conversely, impact was lower in pristine areas when the prior distance to the closest road was relatively high (with a coefficient of -0.4 vs -0.23 for 1980s deforestation, Tables 4 & 5). These results were consistent even when we varied the cutoff dividing the samples to see how the 'developed vs. pristine' definition affects results.

Two results stand out from this examination, first the importance of context on road impact and second, investments in high developed areas have a higher impact than when are placed in previously less accessible areas (or pristine areas), this supports previous findings on roads impact in the Brazilian Amazon (Pfaff *et al.* 2007a & 2007b).

Differences of deforestation drivers impacts, other than roads given the landscape context.

Previous studies show that the benefits of clearing land for agriculture or cattle depends on the access to markets, the distance to roads, as well as on the biophysical conditions of the land such as soil quality and elevation . However, our results show that when a road is placed in the forest frontier (low-developed area)

Table 4. Results from the logit-models of 80-90 deforestation in high and low developed.

Output variable Deforestation from 1980 to 1990 (Y=1)						
Sample = points which in 1990 were closest to 80-90 unpaved investments						
"close" = <=25km	High Development CLOSE from 1980 roads			Low Development FAR from 1980 roads		
Covariates	**Coeff**	**SE**	**Sig**	**Coeff**	**SE**	**Sig**
(Intercept)	-2.54876	0.449714	***	-11.38	0.1074	
Unpaved roads 90-80	-0.44899	0.049386	***	-0.23	0.06	***
Campeche, Mexico	2.501916	0.381564	***	11.59	1.00	
Quintana Roo, Mexico	0.477885	0.388239		9.63	0.100	
Petén, Guatemala	2.065306	0.404955	***	9.51	0.020	
Protected Areas 80-90	-11.2285	0.33166		NA	NA	
Elevation (mts)	-0.00366	0.001459	*	-0.01	0.00	
Distance to def. in 1980 (Km)	-0.00174	0.019976		0.06	0.03	.
Distance to main markets	-0.01424	0.005142	**	-0.01	0.01	
Distance to small markets	-0.00841	0.006515		-0.02	0.02	
Soil B dummy	0.636963	0.329528	.	-1.20	1.25	
Soil C dummy	0.512129	0.543185		-0.18	1.49	
Soil D dummy	-0.11371	0.319694		-0.24	1.10	

Table 5. Results of the logit-models of 90-00 deforestation in high and low-developed areas

Output variable Deforestation from 1990 to 2000 (Y=1)						
Sample = points which are closest to 90-00 unpaved investments						
"close" = <=25km	CLOSE from 80-90 roads			FAR from 80-90 roads		
Covariates	**Coeff**	**SE**	**Sig**	**Coeff**	**SE**	**Sig**
(Intercept)	-4.485961	0.631553	***	-27.490	0.180	
Unpaved roads 90-00	-0.24483	0.039156	***	-0.189	0.048	***
Campeche, Mexico	2.39708	0.548414	***	9.451	0.680	
Quintana Roo, Mexico	1.996857	0.530345	***	8.988	0.680	
Petén, Guatemala	3.84759	0.535137	***	11.090	0.500	
Protected Areas 90-2000	-1.344767	0.28346	***	-0.926	0.378	*
Elevation (mts)	-0.005437	0.001655	**	-0.009	0.003	*
Distance to def. in 1980 (Km)	-0.017385	0.012517		-0.019	0.022	
Distance to def.80-90 (Km)	-0.017416	0.031051		-0.127	0.074	.
Distance to main markets (Km)	0.006851	0.003995	.	0.013	0.009	
Distance to small markets (Km)	-0.004189	0.005256		0.009	0.010	
Soil B dummy	-0.022048	0.530106		14.770	0.140	
Soil C dummy	1.408547	0.545566	**	16.960	0.130	
Soil D dummy	0.43429	0.490547		15.630	0.20	

versus an already developed one, the only highly significant predictor of deforestation is the distance to the closest road. In areas far from existing roads in 1980, the only high significant predictor of 1980 to 1990 deforestation was the distance to the roads built during this period (-0.23, Standard Error SE 0.06), only the distance to cleared land in 1980 resulted had low-significance (0.06, SE 0.03, Tables 4 & 5) being all the other variables non significant. For deforestation from 1990 to 2000, roads built in this period were the only highly significant variable (-0.189, SE 00.4) as well, only protected areas and elevation resulted to had a low significance (0.93, SE 0.38 and 0.009, SE 0.003). On the other hand, when development has already occurred in an area (existing roads and cleared land exist close to the new investments), not only the distance to the closet road but also a number of others factors thought to affect net benefits of land uses are highly significant predictors of deforestation rates; such as the country or state, protected areas, soil type and elevation (Tables 4 & 5). Our results stress the important role of roads as main deforestation drivers in the forest frontiers, even if its immediate impact is lower than for the roads placed in already developed areas, these new roads investments are the ones that shape the future clearing and the development patterns in the forest. In the long term we can expect that the impact of roads in these pristine areas will increase by promoting further development in the region.

The role of country/state on deforestation.

Our analysis shows the role of countries or states on deforestation. When roads are placed far from previous development the country/state covariate were not significant deforestation drivers for both 80-90 and 90-00 deforestation (Tables 4 & 5). However, when roads investments were placed in a developed area (close to other roads or previous deforestation) they were highly significant covariates. For 1980 to 1990 deforestation we can see that Campeche (2.5 with a S.E 0.39) and Petén (2.0 with a S.E 0.42, table 3) were significant and positive deforestation drivers, being Campeche slightly more significant than Petén. However for 1990 to 2000 deforestation not only Campeche (2.39 with a S.E 0.5) and Petén (3.84 with a S.E 0.53), were significant, but as well Quintana Roo (1.9 with a S.E 0.53, Table 5).

These results are consistent with what we would expect to be the indirect effects of national and state policies on deforestation. Since 1980, the discovery of oil in the state of Campeche promoted high immigration mainly to the coast; however, the rise in income in the state supported the conversion of tropical forest for the production of sugar cane and rice. During the same period, Guatemala suffered from the bust of cotton prices in the South Coast, which promoted the migration toward other countries, although while many of the migrants used the Petén as a transit area, some subsistence farms where established in the Petén. This was mainly when the FAR armed forces, that were settled in the Petén during the conflict, started their exile to Mexico in 1985 . From 1985 to 1989 not only subsistence farms established in this area, the forest conversion for the cultivation of cannabis drastically increased from at least 225 to 1,220 hectares . On the other hand, it is not rare to see that Quintana Roo and Belize were not significant covariates for the 80-90 deforestation. Most of the investments in Quintana Roo were focused for the truism industry in the Caribbean coast; and the subsidies in the forest were mainly focus to forestry management. In 1983 most of the ejidatarios[1] that owned land in the forest, formed part of the Forestry Pilot Program, which goal was to introduce a participative management of the forests with a sustainable harvest for timber and non-timber products. This big initiative from the Mexican and German government, was able to support the conversion of 500,000 has of tropical forest into forestry ejidos, belonging to five forestry societies . In the case of Belize from 1980 to 1990, there were few investments for agriculture or other land uses in the study area. Most of the land conversion was done for sugar cane production in the 1970s, which was mainly subsided by England and exported to England (Bolland 1985). However, during the 80s we can observe Belize was in the early years of its independence, and did not had strong policies for forest conversion, with the exception in 1986, when the government provided more than 15,000 acres to Belizean families and Salvadorian refuges, near to Belmopan the capital. Most of the investments were focus on the coast for truism (Anne 1998).

The country and state covariates for 1990 to 2000 deforestation as well reflect the effects of the country and state policies during that decade. This time not only Campeche and Petén were significant predictors of deforestation, but as well Quintana

[1] Ejidatarios are cooperative members that are granted usufruct rights to the land through the agrarian reform program, they live in the ejido and the decision making process of the land use is decided by a general assembly. The ejido is a cooperative landholding system established in Mexico by the President Lazaro Cardenas since 1934.

Roo (Table 5). In this case the Petén, showed the highest coefficient (3.84) and from our analysis on deforestation we can see that Petén had the highest proportion of deforestation (Figure 3). Although in 1990 the Mayan Biosphere Reserve (RBM) was created, during this decade different factors made the Petén the one of the main destines for migrants. In 1994 started the repatriation process of the refuges from the armed conflict and the government gave them land in the Petén. At the same time the finding of oil in the north west of the RBM, promoted the investment of roads and the construction of an oleo duct in the area. At the same time, the peasants from the South Coast continued to migrate to this region, since the bust in cotton prices and other products left them without jobs, and the ones that could not migrate to the US were in search of subsistence land in the Petén (Grandia 1992). However, the land where peasants had established has subsequently been occupied by big land owners mainly for the development of cattle ranges. By 1999 around 50% of the owners of parcels had 92% of the land; this accelerated the invasion of landless peasants to the protected areas. By 1996 there were 41 illegal communities in the RBM which increased to 80 by 1990 (Clark 2000). This shows the indirect effects of national policies, since the Petén's coefficient raised from 2.0 to 3.8 in one decade, making it the state with the highest impact on

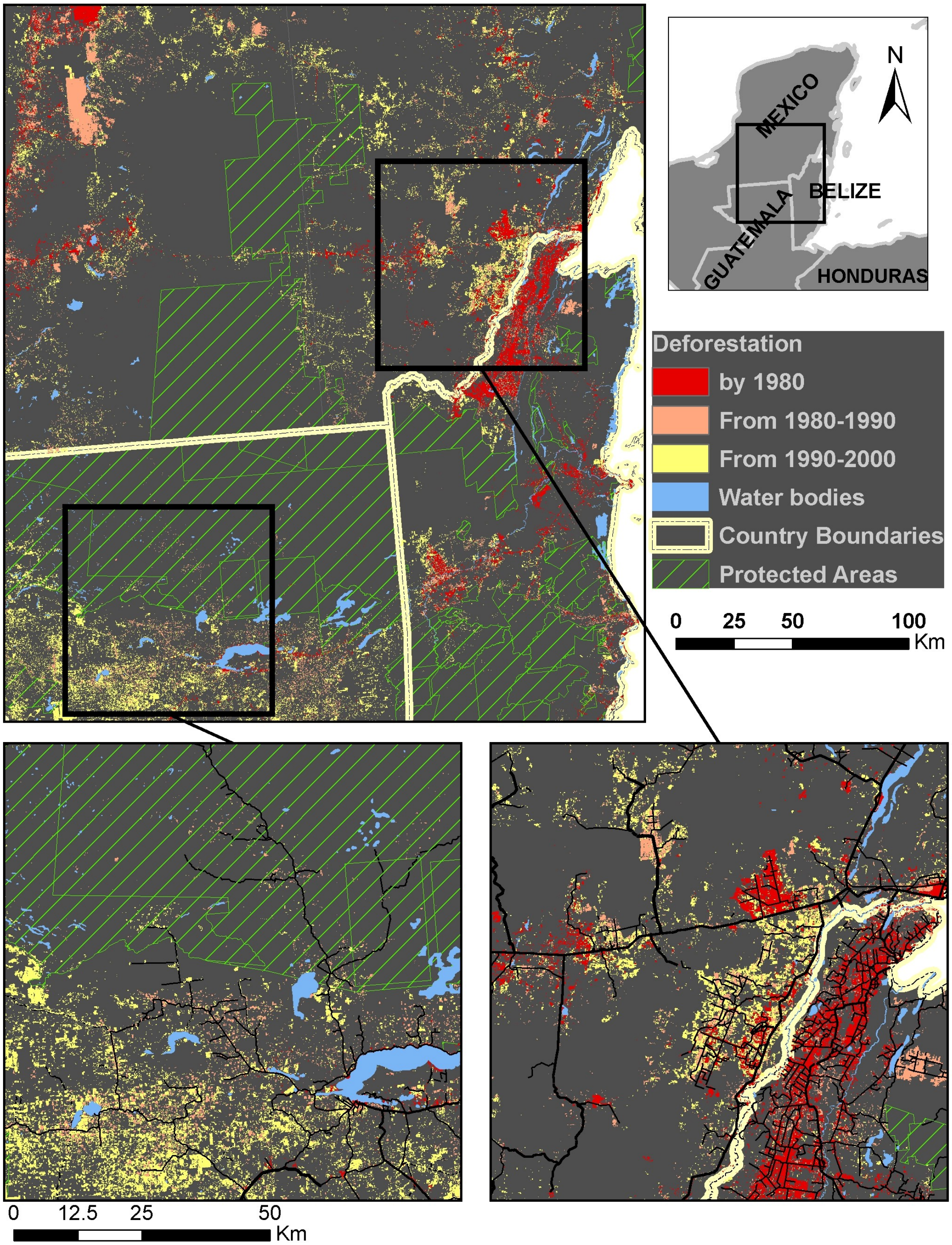

Figure 3 Deforestation in the study area by 1980, from 1980 to 1990 and from 1990 to 2000.

deforestation for the region. Campeche continued with a similar impact than in the previous decade, the main investments targeted the agriculture and cattle ranging. In the case of Quintana Roo, during this decade, most of the support from the federal government to the Forestry Ejidos stopped, and subsidies to support Chile plantations started . It could be that the lack of support to forestry ejido was one of the triggers for forest conversion, during the 90s Quintana Roo is a significant driver of deforestation, even if it is lower than Campeche and the Guatemalan state of Petén. At the same time Belizean economy relayed in the ecotourism, not just for its beaches but as well in the rainforest, only in the Toledo District, was promoted the agriculture for the production of critics , however this district was not included in our study area.

What are the implications of these results for decision makers?

Understanding the impact of road investments on forest clearing is crucial for the design of development policies in tropical forests. The combination of our five results reflects the spatial and temporal tradeoffs facing a policy planner. A new road into a previously undeveloped area will be *the* determinant of the long term future path of development and deforestation, by shaping the new forest frontier, even if, in the short term, its magnitude is lower than a road placed in an already developed area. Therefore, the area affected is not cleared in the first decade at the same rate as paths of new roads located in the development trajectory where activity is already ongoing. Nevertheless, in the long term, we can expect that the impact of roads in the pristine areas will increase by promoting development in the region, which as a result will promote new roads by providing political and economic incentives for further investments . Consequently, because the roads into undeveloped areas very clearly determine that new paths of clearing arise that are likely to be followed by even more investment and deforestation. As well it is important to consider that the impacts will be different given the country or state of investment, however, we found that for the Selva Maya, when a road is placed in a low developed or pristine area the country or state effects seems to do not be significant. But in the long term it will definitely shape the expansion of the agriculture frontier.

A development planner that contemplates the conservation and management of tropical forests needs as well to consider road effects beyond its impacts on deforestation. Roads impact on habitat quality and fragmentation may play a key role as indicators of were to place a road. Although, as our results show that in the short term, a road may promote less deforestation in a pristine area than in a developing area, its impact on fragmentation of certain species may be higher. Further studies that include this type of analysis will be an important contribution to the existent literature on roads impact on tropical forests. To pursue this type of analyses and to understand the long-term effects of roads on deforestation will be essential for the proper long term management of tropical forests.

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