Institutions and Deforestation in Africa[1]

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Using tree cover data from satellite images we estimate the relationship between institutions and deforestation in Africa. In particular, we investigate the relationship between current rates of deforestation and measures for current institutions, colonial institutions and precolonial institutions. We find a significant and robust relationship between deforestation and protected areas; type of colonial rule and local precolonial institutions. While these results highlight the persistence of institutions and the continued role of non-state institutions, they also highlight the usefulness of current institutions (i.e., the use of protected areas) in arresting current rates of deforestation in Africa.

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Introduction

There have been concerted international efforts to reduce deforestation dating back to at least the United Nations Conference on Environment and Development (the Earth Summit) in 1992.[2] These efforts continue in earnest, primarily through the United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD+). In addition, there have also been numerous national and sub-national programmes implemented aimed at conserving and/or preserving forests. In one respect, these regulatory efforts have been a success; according to the United Nations Millennium Development Goals Report (2013:42) 'close to 75 per cent of the world's forests are covered by national forest programmes'. However, despite this, deforestation remains the second largest source of the world's anthropogenic carbon dioxide emissions and presents a significant risk to global biodiversity through habitat destruction (see FAO 2010, van der Werf et al. 2009 and Burgess et al 2012). According to the Millennium Development Goals Report (2013: 42) the largest net losses of forest remain in the developing world; with around 3.6 million hectares lost per year in South America and 3.4 million hectares lost per year in Africa for the period 2005 to 2010. The Report (2013:42) goes on to say '[f]orests are disappearing at a rapid pace, despite the establishment of forest policies and laws supporting sustainable forest management in many countries.' As can be seen from Figure 1, parks (henceforth protected areas) have only limited success in halting deforestation.

[2] See Statement on Forest Conservation from the United Nations Conference on Environment and Development Rio de Janeiro, 3-14 June 1992) http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm.

<INSERT FIGURE 1>

[Caption: An example of the variable impact of protected areas (green) and deforestation (red) in Ivory Coast. Whereas deforestation did not occur in Mont Sanghe and Tai National Parks in the period 2000-2012, this image indicates that Marahoue National Park and Gaoulou Natural Park were dramatically deforested in the same period. Source: Hansen/UMD/Google/USGS/NASA]

The literature on the effectiveness of protected areas in reducing deforestation is vast but mixed. Pfaff et al (2014:7-8) note that while protected areas have been assumed to lower deforestation 'solid evidence is limited'. The seminal work of Bruner et al (2001:1), who studied 93 protected areas in 22 countries, found that the majority were 'successful at stopping land clearing'. Numerous authors since have focused on addressing issues of selection bias (acknowledging that protected areas are unlikely to be randomly selected) and definitional issues (state versus non-state protections). Once controlling for physical attributes (e.g. topography, proximity to urban areas and roads) a number of authors have found that state parks are partially effective in reducing land clearing (see Joppa and Pfaff 2010 and Campbell et al 2008). While much of this empirical work has been contained to Central and South America, Green *et al* (2013) have recently found that state protected areas in Tanzania are associated with a reduction in forest loss by around 40 per cent and that the majority of remaining forest lies within the borders of these protected areas.[3] In relation to state versus non-state protections, Hays (2006) and Bray et al (2008), have shown that forests protected by informal rules and non-state grouping (e.g.

[3] Green et al (2013:63) also note that 'Much of our current knowledge of the causes and mechanisms of habitat loss is based upon research undertaken in Latin America and Asia....and Africa, in particular, has had few studies devoted to special modelling of habitat loss.

community forests) achieve similar outcomes as forests protected by state legislation (e.g. national parks).

An obvious reason for state protections having only limited success in reducing deforestation is the prevalence of corruption and illegal deforestation on state controlled land. Using a model of competitive rent seeking and exploiting changes in local state governance in Indonesia, Burgess et al (2012) provide compelling empirical evidence that a key determinant of deforestation is a lack of enforcement of state protections due to corruption among local politicians and bureaucrats. Such analysis builds on the extensive *state* institutions literature, inspired by the seminal works of Acemoglu et al (2000) that highlighted the enduring importance of extractive versus inclusive colonial institutions and La Porta et al (1998) who highlighted the enduring effects of different types of colonial legal transplants on a range of economic and development outcomes; including environmental and resource management.

Given that the FAO (2010:10) claims that over 95 per cent of African forests are publically owned and approximately 80 per cent are managed by the state, an emphasis on state institutions and forest management may seem justified. However, the narrative that indigenous institutions were largely swept away and replaced by European colonial institutions has been forcefully challenged, not only by the vast legal pluralism literature (see Griffiths 1986) but also by the recent econometric analysis of Ziltener and Muller (2007), Gennaioli and Rainer (2007) and Michalopoulos and Papaioannou (2013, 2014). Making use of precolonial data compiled by Murdock (1967) these authors have all found a strong relationship between measures of

economic development and precolonial institutions.[4] This work is premised on the grounds that European colonisation of Africa was actually quite limited, both in terms of space and time, and that many post-colonial states remain (or became) weak. On this, Michalopoulos and Papaioannou (2013:115) note that the 'inability of African states to provide public goods and broadcast power beyond the capitals led African citizens to continue relying on the local ethnic-specific structures rather than the national Government', while Acemoglu et al (2013:31) note that in Africa the 'majority of the population lives in rural areas and where the national state often lacks capacity and the power to "penetrate" society'. Recent large-scale survey data (AFRObarometer) has also confirmed the vital role that indigenous institutions continue to play in Africa, especially in relation dispute resolution and the protection of property rights (Logan 2013). If precolonial institutions do continue to persist in Africa, it raises the possibility that, depending on their type, they may have positive or adverse effects on resource management, including management of timber resources and deforestation.

There is also a growing literature exploring relative strength of 'traditional' local leaders (e.g. chiefs or village headmen) and colonial institutions (e.g. direct versus indirect rule) and the interaction of these two sets of institutions. While in many cases colonisation was characterised a relatively undisturbed continuation of precolonial institutions or their attempted dismantlement through direct rule; some suggest that colonisation in some cases led to a *strengthening* of power of traditional rulers through the widespread practice of indirect rule where local leaders were

[4] Some such as Michaels (2009) and Larcom (2014) have argued that there were often far bigger differences between the precolonial institutions the colonisers encountered than they brought with them. For instance, from the early 15th century the forest kingdom of the Edo-speaking people (Benin) was a highly centralised and stratified society. It had a powerful standing army and the Oba (king) collected taxes and owned all the land in the country (Bradbury 1957). This can be contrasted with the Mbuti people who live in Ituri Forest in the Democratic Republic of the Congo. Some of whom remain hunter-gatherers, and live in small, decentralised and independent communities (Turnbull 2012).

provided military support in return for their allegiance (Acemoglu et al 2013, Mamdani 1996). Acemoglu *et al* (2013) suggest that this practice may continue to have adverse effects on contemporary African development and have found that chiefs with fewer checks and balances produce worse economic development outcomes for their people, primarily through their ability to engage in self-interested (corrupt) behaviour made possible through their control of land and natural resources. Similarly, Gennaioli and Rainer (2007:5) argue that in precolonial societies that were 'centralized' local leaders remained 'accountable' under colonisation as these societies had a high degree of accountability for local leaders, which largely remained in place. For example, an incompetent or corrupt chief could be replaced by a paramount chief or king. However they argue that in 'fragmented' societies (e.g. petty chiefdoms) where accountability mechanisms were weak or absent colonisation often saw 'unprecedented power to abusive local leaders, leading to tyranny and disorder'.

Methods

We aim to ascertain the relationship between different types of institutions (current, colonial and precolonial) and current rates of deforestation in Africa. We do this by exploring the statistical relationship between deforestation from 2003 to 2008 obtained from satellite data within the boundaries of 683 precolonial societies in Africa and within the boundaries of 48 nation states. As we wish to focus our analysis on the role of institutions, we regress our measure for deforestation with measures for the three types of institutions while controlling for all known and likely drivers of deforestation (see Geist and Lamin 2002 and DeFries *et al* 2010), including population density, geographic characteristics, forest stock, economic variables, and country fixed effects.

Data

Spatial data on deforestation

Deforestation is measured by: *tc_forestdiff*[5], which represents change in the fraction of forested land within the boundaries of each precolonial society for 2003 to 2008 and where negative values indicate deforestation. We derived this variable by reclassifying percent tree cover data into forest and non-forest, using a threshold of at least 30% of tree cover for a pixel to be considered forest (Couturier et al. 2012; Bodart et al. 2013; Mayaux et al. 2013). We used this binary classification of forest cover to calculate the fraction of forested area in each precolonial society for the years 2003 and 2008 and the variable *tc_forestdiff* reflects the difference in this fraction of forest cover between both years. Tree cover data in raster format were derived from MODIS images (ISCGM 2013). The tree cover rasters have a resolution of 30 and 15 arc-seconds respectively and each pixel represents the percentage of canopy cover in a range from 0 to 100%. Figure 2 illustrates the change in forested area in each precolonial society between 2003 and 2008. In our sample, the mean is a negative fractional change in forested area of 1.694% with a standard deviation of 23.698. The most significant changes in forest area are a decrease of 75.105% and an increase of 72.605% (see table 1).

<INSERT FIGURE 2>

Current Institutions

Current institutions are represented by the rule of law and protected forests. For rule of law, we use the World Bank's rule of law index, which measures the extent to which agents have

[5] Alternative data sources of deforestation are commented on in the appendix.

confidence in a society's rules and abide by the rules (Kaufmann et al. 2008). The index is normalized and runs from -2.5 to 2.5 with higher values indicating better rule of law. In our sample, we find a mean value of -0.861 with a standard deviation of 0.553 and a minimum of -1.912. Protected forests refer to the percentage of area within a precolonial society that is protected and which was declared as such on or before 2003. Our operational definition of protected forests is broad and includes protected forests governed both by the state and non-state actors. To construct our measure of protected forests we explored the attribute table of the Protected Planet dataset in order to identify the types of protected areas to include in our analysis (Protected Planet 2013). Due to inaccurate spatial data, we eliminated UNESCO Biosphere Reserves and replaced Ramsar areas with data from the Ramsar website (Ramsar 2013). We also excluded protected areas labelled as marine reserves and whose status was 'proposed' or 'not reported'. In order to merge overlapping protected areas we then dissolved all areas into a single multi-part polygon. The resulting data layer thus classifies the continent into protected and not-protected. We then calculated the percentage of area protected within each precolonial society. In our sample, the mean ratio of protected area to the total land area was 12.333% with a standard deviation of 18.304%.

Colonial Institutions

To represent colonial institutions, we use Ziltener and Kunzler's (2013) data on the duration of colonial rule and the form of political domination. The form of political domination measures different levels of political domination: no colonial domination, semi-colonialism, indirect rule with minimal interference in internal affairs, indirect rule with significant interference in internal affairs, and direct rule. As our dataset did not include any states characterized by no colonial

domination or semi-colonialism, we only included the two categories of indirect rule and direct rule. Indirect rule is characterized by the colonial power having: claimed exclusive rights over the colonized society's foreign relations; defended (or likely to have defended) the society from third countries; deployed an actor to influence and check the decisions made by the indigenous leader; and held direct control over some administrative structures. We follow Ziltener and Kunzler (2013) in distinguishing between two kinds of indirect rule: indirect rule with minimal interference in internal affairs – where societies retained a high level of domestic autonomy - and and indirect rule with significant interference in internal affairs - where the colonial power exerted a strong influence on domestic affairs. Societies classified as having been under direct rule are defined as societies where the traditional political system was replaced with a new political structure (see further details in the supplementary table 1).

We also use an intensity of colonisation measure that is the sum of the logarithms of the duration of colonial rule and the form of political domination, and a binary measure of legal origin, where 0 represents countries with British legal origins and 1 represents countries with French legal origins (La Porta et al. 1999; 2008).

Precolonial Institutions

We use quantitative ethnographic data from Murdoch (1967) to represent precolonial institutions. Specifically, we focus on the measure of Jurisdictional Hierarchy which measures the degree of centralization of precolonial societies and institutions and gives the number of jurisdictional levels transcending the local community for each level. A score of 0 represents that there was no political authority beyond local level (No Central Authority); a score of 1 represents petty chiefdoms (Petty Chiefdoms); a score of 2 represents paramount chiefdoms or their equivalent

(Paramount Chiefdoms); and a score of 3 represents that they were part of larger states (Precolonial States). We also use Murdoch's (1967) data on the succession of local chiefs as a further precolonial institution measure. Specifically, we created a categorical variable disaggregating chief succession into: hereditary; democratically elected; elected from above; and elected by social standing.

<INSERT TABLE 1>

Control variables

We compiled a number of control variables that are suggested to be related to deforestation (see supplementary table 1). We categorized these controls into four categories: population density, geographic controls, economic development controls and forest stock controls. Among these control variables, road density was generated internally. Specifically, our measure of road density is the ratio of roads to the total area in a precolonial society, measured in km of road per $100km^2$. Vectorial data on roads for Africa were obtained from Columbia University (CIESIN 2013). Using QGIS v.2.0.1, we simplified the geometry in the original vectorial file using a tolerance of 0.0001. We then calculated the total length of roads (in km) for each precolonial society and multiplied this length by 100 and divided by the total land area of each precolonial society (in km^2). We validated the road data and this procedure against the road density data from the World Bank[27] and obtained an acceptable correlation coefficient (0.68). Summary statistics for our control variables can be found in the appendix.

Data analysis

We build on the existing economic literature on institutions (Acemoglu et al 2001, 2002, La Porta et al 1999, 2008, Ziltener and Muller 2007, Gennaioli and Rainer 2007, Burgess et al (2012), Michalopoulos and Papaioannou 2013, 2014) to extend the literature on deforestation by exploring the relationship between current, colonial and precolonial institutions and current rates of deforestation by estimating variants of the following model:

$$d_{i,c} = \alpha_0 + \beta C_i + X'_{i,c}\Phi + c_c + \varepsilon_{i,c} (1)$$

where, $d_{i,c}$ is the current rate of deforestation in each precolonial society i in country c. C_i represent our current, colonial and precolonial institutional measures, $X_{i,c}$ is a vector of control variables that consist of the broad headings of population density, geographical, economic development and forest stock controls, and c_c are country fixed effects. To account for the possibility of spatial correlation we use double clustered standard errors at the ethnic-family level and country level (Cameron et al. 2011; Michalopoulos and Papaioannou 2013). Where possible, we include country fixed effects to account for time invariant differences that are country specific. We selected our base categories for form of colonial rule, jurisdictional hierarchy and chief succession as the category with the most observations (see table 1).

Results

Table 2 presents the least squares estimates for current institutions (rule of law, protected areas), colonial institutions (duration, form, intensity and legal origins) and one of our two measures of precolonial institutions (jurisdictional hierarchy) with our *tc_forestdiff* measure of deforestation. Controlling for population density, geography, economic development and forest stock, column 1 estimates the relationship between current institutions and deforestation. We find that only

protected areas is significant at the 1% level. Column 2 estimates the relationship between colonial institutions and deforestation. Among our set of colonial institution measures, political form, intensity and legal origin are all statistically significant with relatively strong coefficients. Societies characterized by significant indirect rule and direct rule see a notable negative fractional change in forested area relative to a society with minimal indirect rule, at the 5% and 1% significance levels, respectively. Meanwhile societies with a higher level of colonial intensity exhibit positive fractional change in forested area at the 5% level. Societies with French legal origins see a substantially positive fractional change in forested area at the 5% level compared to societies with British legal origins. Column 3 estimates the relationship between one measure of precolonial institutions, jurisdictional hierarchy, and deforestation and finds no statistically significant relationship.

Column 4, which provides estimates for current, colonial and precolonial institutions, finds that the variable protected areas is highly significant with a one percent increase in the percentage of the precolonial society which was declared as protected leading to a 0.168% fractional increase in forest area. Furthermore, we find that relative to a precolonial society characterized by insignificant indirect rule, societies with significant indirect rule are likely to have a fractional decrease in forest area of 10.501% at the 5% significance level and that societies with direct rule are likely to have an even larger decrease of 14.418% at the 1% significance level. Our measure of colonial intensity is significant at the 10% level and suggests that countries with a higher level of colonial intensity are likely to have a fractional increase in forest area. This stands in stark contrast to the coefficients on the duration of colonisation and political form of domination suggesting interesting interactions between different measures of colonial institutions. Legal

origin is also statistically significant at the 5% level and suggests that precolonial societies with French legal origins are likely to see a 10.02% fractional increase in forested area compared to societies with British legal origins. Regarding precolonial institutions, we find that precolonial societies characterized by paramount chiefdoms see a 3.809% fractional increase in forested area compared with societies characterized by petty chiefdoms but only at the 10% significance level.

Lastly, column 5 includes country fixed effects to help account for country-specific time invariant differences. The use of country fixed effects, however, resulted in dropping current and colonial institutions that have zero within standard deviation meaning that only protected areas and jurisdictional hierarchy are included. This resulted in a significant decrease in the R^2 value. We find that protected areas continue to be significant at the 1% level with a positive coefficient. The coefficient of paramount chiefdoms also continues to be positive and is now statistically significant at the 1% level.

<INSERT TABLE 2>

Table 3 focuses on the estimates for precolonial institutions – including the succession types of local chiefs – on our measure of deforestation. Columns 1 to 3 control for population density, geographic controls, economic development controls and forest stock controls and include country fixed effects. As country fixed effects are included, we are not able to control for our measures of current and colonial institutions. In column 1, we find that, at the 5% significance level, precolonial societies with chief succession determined by social standing see a 8.296% fractional decrease in forest area relative to a society with hereditary succession. In column 2,

paramount chiefdoms is highly significant with a positive coefficient. Column 3 includes both our measures of precolonial institutions. Both succession by social standing and paramount chiefdoms remain significant with slightly reduced coefficients.

Columns 4 to 6 control for current and precolonial institutions at the expense of including country fixed effects, resulting in a significant increase in our R^2 values. As in columns 1 and 3, social standing remains highly significant and sees an increase in the coefficient to 11.831 in column 4. Notably, the coefficients for both democratically elected chiefs and chiefs elected from above have switched signs, although neither measure is statistically significant. As in columns 2 and 3, paramount chiefdoms continues to be positive and significant in column 5, albeit at the 10% level and with a slightly lower coefficient. Column 6, which includes both chiefs and jurisdictional hierarchy, sees chief election by social standing remain significant at the 5% level with a coefficient of -11.344. Notably, paramount chiefdoms are no longer statistically significant.

Comparing the results of column 3 – which includes country fixed effects at the expense of current and colonial institution controls – and column 6 – which does not include country fixed effects but includes current and colonial institution controls, we find that the coefficient of succession through social standing has more than doubled and reduced in statistical significance from 1% to 5%. Another difference is that the signs for societies with democratically elected chiefs and chiefs elected from above have switched from having positive coefficients in column 3 to having negative coefficients in column 4. A final major difference between columns 3 and 6 is that paramount chiefdoms, which were significant in column 3 at the 5% level are no longer significant in column 6.

<INSERT TABLE 3>

Discussion

This empirical investigation into institutions and deforestation in Africa enables us to make a contribution to both the deforestation and institutions literatures. In relation to the deforestation literature our results confirm the important role that protected areas (whether they be governed by the state or non-state organizations) play in reducing deforestation in Africa. They also suggest that concerns over enforcement or actual implementation of these protections (in terms of rule or law or corruption) may be exaggerated, in Africa at least. In terms of institutions, our results highlight the persistent effects of *both* colonial and precolonial institutions on current resource use. Our results also give weight to the 'legal pluralist' view that there are multiple forms of governance (institutions) in Africa. A discussion of the results in terms of current, colonial and precolonial institutions is presented below; followed by a brief discussion of the policy implications in the conclusion.

Perhaps the most important result in terms of current institutions is the usefulness of protections to reduce deforestation in Africa. While protections are clearly not a failsafe method, our results suggest that on the whole they do indeed reduce deforestation in Africa, something that remains contested in the literature. Indeed we show that a one percent increase in land declared as protected leads to a 0.168 percent increase in forest area. Importantly, our results also suggest that confidence (or lack of it) in enforcement of legislation (as measured by the variable rule of

law) may be overstated in terms of deforestation. While we have provided a notable example of the limitations of state protections in relation in the Ivory Coast, our results should provide encouragement to policy makers in Africa (whether they belong to strong or weak states) suggesting that legislative protections can reduce deforestation.

Our results in relation to colonial institutions and deforestation (something that is completely new to the literature) shows the persistent effects of colonial institutions on current measures of institutional efficiency. While evidence of the persistent effects of colonial institutions is nothing new to the literature in terms of economic development, to our knowledge, *it is* in terms of deforestation and resource use more generally. Furthermore, our results are particularly noteworthy as they suggest *the form* of colonial domination has persistent effects. In particular, our results provide evidence that the more 'direct' the colonial domination, the higher rates of deforestation. While the transmission mechanism for this result is unclear, one explanation is that the more 'direct' the form of colonisation, the more that it destroyed or morphed precolonial institutions. This explanation is plausible as Ziltener and Kuenzler's (2013:6) definitions are in terms of 'interference'. They distinguish between 'indirect rule with little interference in internal affairs' (little more than a tribute or client state); 'indirect rule with strong interference in internal affairs'; while direct rule captures instances when colonizers not only created new political entities, but also founded completely new dynasties or chieftaincies 'without historical precursors'. Interestingly, while the duration of colonial domination (with a mean of 110 years) was negative but insignificant, the interaction term of both type and duration (intensity) was *positive* and significant (albeit at the 5 per cent/10 per cent level). This result suggests that a lot

of colonisation might be better than a little (or even none) in terms of deforestation. Such a result suggests that new institutions (just like concrete) take time to set.

Our final results relate to the impact of precolonial institutions on deforestation. Most importantly, they show that precolonial institutions continue to impact on resource management outcomes, something new to the literature. These results provide further evidence for the view that while colonisation undoubtedly had a profound effect on many parts of Africa and its people, precolonial institutions continued (and continue) to play an important role in resource management, regardless of whether these institutions were (or are) recognised by the state; something the legal pluralism literature has taken for granted for a long time. Indeed, the anthropologists Ziltener and Muller (2007:339) even suggest that the role of precolonial institutions may be growing over time and talk of a 'return to the past' through the continual process of decolonisation via dissipating colonial states. Such an argument suggests that the facade of colonial institutions is slowly crumbing and giving way to the stronger and more resilient indigenous institutions.

In terms of jurisdictional hierarchy our results show that compared to the base case of petty chiefdoms (where there is the least oversight of traditional leaders), all other forms of precolonial jurisdictional hierarchy are associated with higher levels of forestation (noting that only paramount chiefdoms show any statistical significance). While there are a number of potential transmission mechanisms that could link precolonial institutions to current rates deforestation, the degree accountability of non-state officials is likely to play an important role as chiefs and other customary leaders often continue to control access to land in Africa, either formally or

informally (Acemoglu et al 2013). The results in relation to *local* precolonial institutions (the succession of chiefs) are perhaps the most illuminating. Compared to the base case of hereditary succession, the results indicate that both democratically elected chiefs and chiefs appointed from above are associated with higher levels of forestation (albeit with no statistical significance). Most importantly however, the results show that chiefs appointed through 'social standing', the form of succession that would be most open to strategic manipulation, are associated with a large and significant increase in deforestation. These results provide compelling evidence that variations in precolonial *local governance* continues to have enduring effects on resource use.

Conclusion

To our knowledge, this empirical investigation is the first to investigate a link between natural resource management and current, colonial and post-colonial institutions. Importantly, we find each broad type of institution continues to play a role in current rates of deforestation in Africa, but not as some may have expected. Our results suggest that protected areas do in fact reduce deforestation while a measure of rule of law does not. We find that the more heavy handed the form of colonisation (in itself) the higher the degree of deforestation – however we also found that the interaction term between type of colonisation and duration to have a positive effect on forestation; suggesting a non-monotonic relationship between intensity of colonisation and deforestation. Finally, we show that in areas where local leaders who are appointed through non-transparent means are associated with higher levels of deforestation. In terms of policy guidance, our results are rich: they should give encouragement to those who wish to reduce reforestation through the use of protected areas, despite the notable failures. They also caution

relying on non-state governance where local leaders are appointed through non-transparent means.

Figure 1: Deforestation in Ivory Coast within National Parks

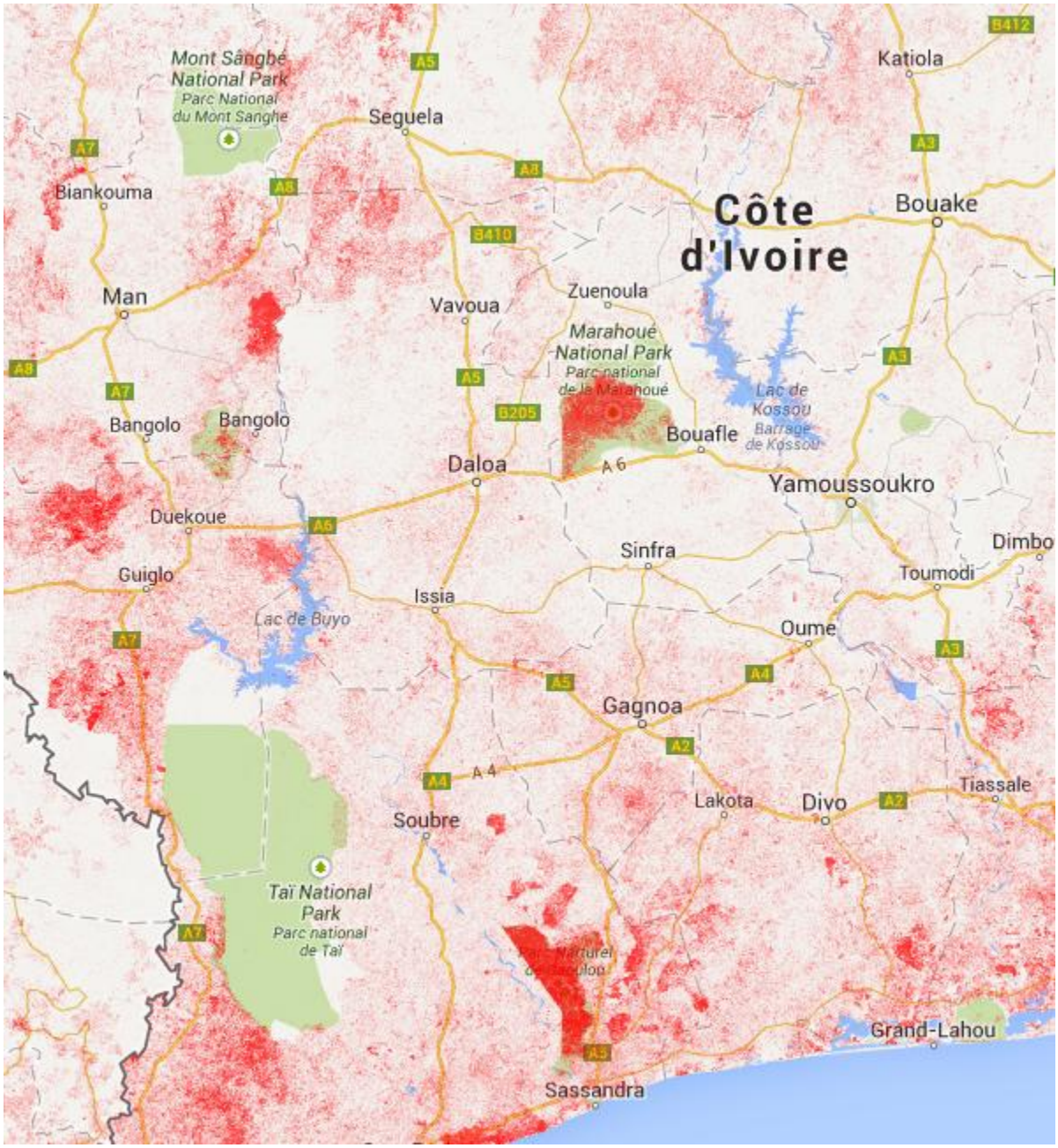

Figure 2: Deforestation in Precolonial Boundaries

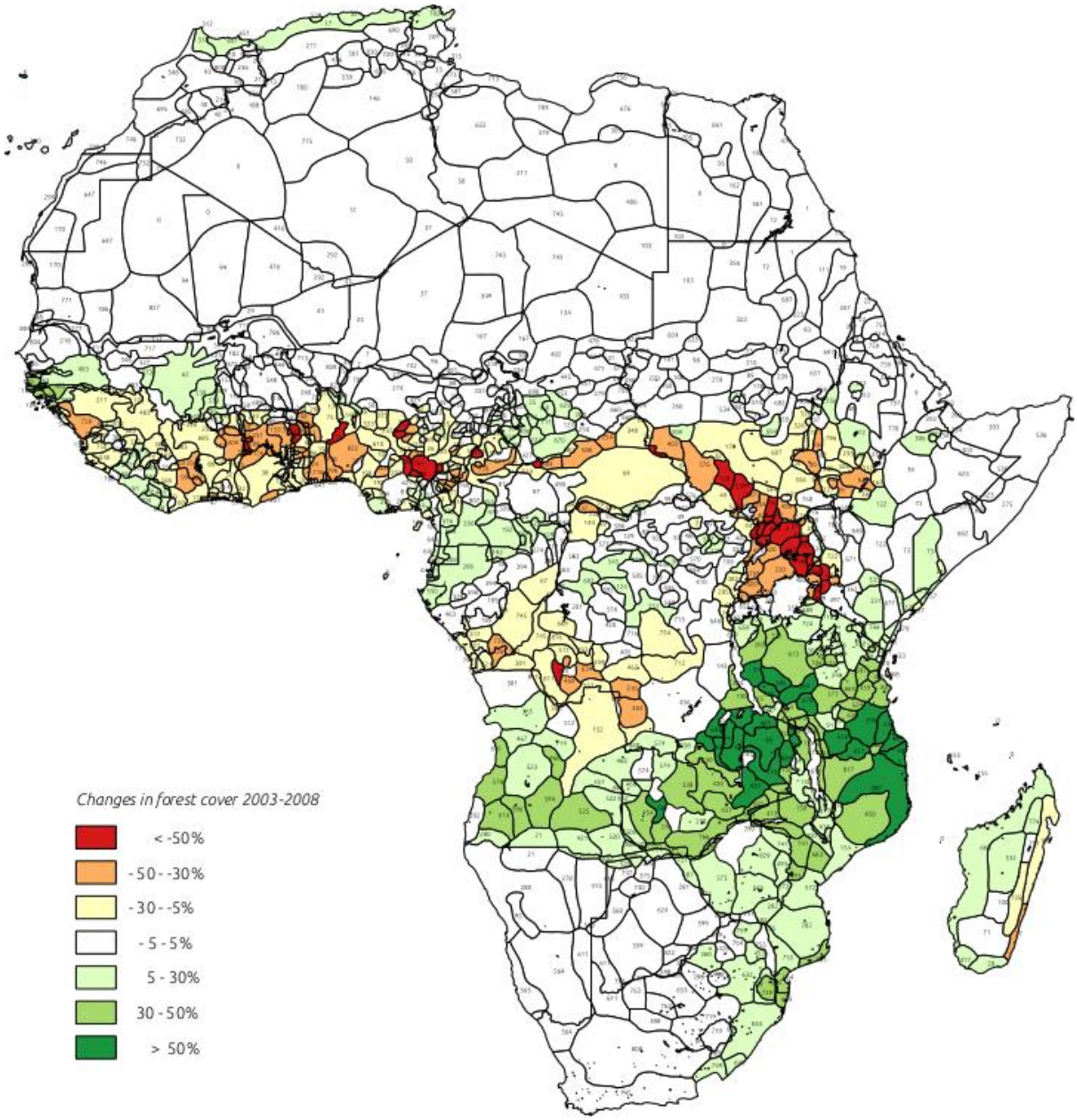

Table 1: Summary statistics

Variable	N	N = 1	Mean	Std. Dev.	Min	Max
Deforestation	683	-	-1.694	23.698	-75.105	71.605
Current institutions						
Rule of law	683	-	-0.861	0.553	-1.912	0.708
Protected areas	683	-	12.333	18.304	0	100
Colonial institutions						
Colonial duration	668	-	110.967	79.878	15	469
Indirect rule (minimal)	668	241	0.361	0.481	0	1
Indirect rule (significant)	668	216	0.323	0.468	0	1
Direct rule	668	211	0.316	0.465	0	1
Colonial intensity	668	-	5.584	0.603	4.094	7.537
Legal origins	680	376	0.553	0.498	0	1
Precolonial institutions						
No central authority	679	176	0.259	0.439	0	1
Petty chiefdoms	679	264	0.389	0.488	0	1
Paramount chiefdoms	679	167	0.246	0.431	0	1
Precolonial states	679	72	0.106	0.308	0	1
Hereditary	645	531	0.823	0.382	0	1
Democratic	645	50	0.078	0.268	0	1
From above	645	38	0.059	0.236	0	1
Social standing	645	26	0.040	0.200	0	1

Table 2. Institutions and current rates of deforestation

	(1)	(2)	(3)	(4)	(5)
Current institutions					
Rule of law	-6.291			-5.022	
	(4.236)			(4.537)	
Protected areas	0.161***			0.168***	0.128***
	(0.052)			(0.046)	(0.038)
Colonial institutions					
Duration		-0.036		-0.032	
		(0.029)		(0.031)	
Form					
Significant indirect rule		-11.670**		-10.501**	
		(4.796)		(5.010)	
Direct rule		-15.889***		-14.418***	
		(3.787)		(4.024)	
Intensity		8.890**		7.639*	
		(4.128)		(4.471)	
Legal origin		10.259**		10.020**	
		(4.475)		(4.324)	
Precolonial institutions					
Jurisdictional Hierarchy					
No central authority			1.979	1.741	3.620
			(3.539)	(2.999)	(2.247)
Paramount chiefdoms			4.347	3.809*	4.737***
			(2.826)	(2.276)	(1.710)
Precolonial states			0.335	0.332	2.106
			(3.237)	(2.817)	(2.837)
R^2	0.453	0.490	0.441	0.514	0.342
Population density	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes
Economic development controls	Yes	Yes	Yes	Yes	Yes
Forest stock control	Yes	Yes	Yes	Yes	Yes
Country fixed effects	No	No	No	No	Yes
Observations	683	668	679	664	676

Table 1 presents OLS estimates associating deforestation and institutional variables, with double-clustered standard errors in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level. The base category for jurisdictional hierarchy is petty chiefdoms. The base category for form is indirect rule with minimal interference. Controls are as follows: Population density; Location Controls (Distance to sea, Distance from national border, Distance from capital city, Longitude and Latitude, Land suitability for agriculture, Elevation, Malaria stability index); Economic Development Controls (Light density, Road density); Forest stock controls (forest area in 2003). As duration, form, intensity, legal origin and rule of law have zero within standard deviation, we are unable to include country fixed effects in estimations (1)-(5).

Table 3. Precolonial institutions and current rates of deforestation

	(1)	(2)	(3)	(4)	(5)	(6)
Precolonial institutions						
Chiefs						
Democratic	0.591		0.470	-0.689		-0.805
	(1.749)		(1.869)	(2.225)		(2.292)
From above	0.800		0.267	-2.052		-2.828
	(2.322)		(2.246)	(4.119)		(3.986)
Social standing	-8.296**		-7.802**	-11.831***		-11.344**
	(3.429)		(3.407)	(4.420)		(4.435)
Jurisdictional Hierarchy						
No central authority		3.918	3.542		1.741	1.536
		(2.401)	(2.315)		(2.999)	(3.049)
Paramount chiefdoms		4.941***	4.128**		3.809*	3.729
		(1.842)	(1.933)		(2.276)	(2.394)
Precolonial states		2.193	1.202		0.332	0.022
		(2.709)	(2.927)		(2.828)	(2.971)
R^2	0.30	0.328	0.316	0.514	0.514	0.520
Current institutions	No	No	No	Yes	Yes	Yes
Colonial institutions	No	No	No	Yes	Yes	Yes
Population density	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Economic development controls	Yes	Yes	Yes	Yes	Yes	Yes
Forest stock control	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	No	No	No
Observations	642	676	638	632	664	628

Table 2 presents OLS estimates associating deforestation and precolonial variables, with double-clustered standard errors in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level. The base category for chiefs is hereditary succession and the base category for jurisdictional hierarchy is petty chiefdoms. Controls are as follows: Current institutions (rule of law, protected areas); colonial institutions (duration, form, intensity, legal origin);Population density; Location Controls (Distance to sea, Distance from national border, Distance from capital city, Longitude and Latitude, Land suitability for agriculture, Elevation, Malaria stability index); Economic Development Controls (Light density, Road density); Forest stock controls (forest area in 2003). As duration, form, intensity, legal origin and rule of law have zero within standard deviation, we are unable to include country fixed effects in estimations (1)-(3).

Appendix

Choice of deforestation data

In order to calculate the measure of deforestation, tc_forestdiff, we use data from ISCGM for the years 2003 and 2008 (ISCGM 2013). Only recently another suitable alternative data have been published (Hansen et al. 2013), which provides a deforestation measurement between 2000-2012. Both sources are based on MODIS satellite images and are provided in resolutions of 15-30 arc seconds and 30m respectively. The ISCGM data are provided as percent tree cover for each of the two years, and it allows applying different definitions of forest cover and deforestation. The Hansen data are provided as a single raster indicating forest loss in binary mode, hence no alternative definitions of deforestation may be employed.

We used the ISCGM data initially and we compared both sources when the Hansen data was made publicly available in February 2014. The single-year estimations of tree and forest cover aggregated by precolonial societies resulting from both sources are fairly consistent (correlation > 0.75). However, we found drastic divergences in the estimations of deforestation (correlation of < 0.05). Most strikingly, in our estimations using data from Hansen et al. (2013), there was no statistically significant relationship between deforestation and our measure of protected areas (see table S1). We finally use the ISCGM data due to these theoretically and empirically inconsistent results.

Sensitivity analyses performed by using different definitions of forest cover over the ISCGM data indicated that the differences between deforestation results obtained from both sources may lie in the actual satellite data processing or in the year of collection rather than in the definition of forest cover. Hansen et al. (2013) also indicate that the correlation of their estimates with FAO and national estimates of deforestation are lower for the African continent, and that this correlation increases by lowering the tree cover percentage threshold set to define forest cover, in order to include the diversity of forests in Africa. However the data provided by Hansen is insufficient to implement alternative definitions of forest with lower thresholds.

Plausibly, deforestation estimates based on the difference between two years may be very sensitive to small variations in the baseline forest cover or tree cover data that are compared, hence noise or bias inherent to the source may have an amplified influence. Understanding the divergences and the comparative validity of deforestation measurements from different sources may be subject of further research.

Table S1. Institutions and current rates of deforestation (using *g_net*)

	(1)	(2)	(3)
Protected areas	-0.000	0.000	-0.000
	(0.000)	(0.001)	(0.000)
R^2	0.256	0.40	0.254
Current institutions	No	No	Yes
Colonial institutions	No	No	Yes
Precolonial institutions	No	No	Yes
Population density	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes
Economic development controls	Yes	Yes	Yes
Forest stock control	Yes	Yes	Yes
Country fixed effects	No	Yes	No
Observations	683	660	628

Table S1 presents OLS estimates associating deforestation and protected areas, with double-clustered standard errors in the parentheses. ***, **, and * indicate statistical significance at the 1%, 5% and 10% level. Controls are as follows: Current institutions (Rule of law); colonial institutions (duration, form, intensity, legal origins); Population density; Location Controls (Distance to sea, Distance from national border, Distance from capital city, Longitude and Latitude, Land suitability for agriculture, Elevation, Malaria stability index); Economic Development Controls (Light density, Road density); Forest stock controls (tree cover area in 2000). As duration, form, intensity, legal origin and rule of law have zero within standard deviation, we are unable to include country fixed effects in estimation (3).

Table S2: data description

Variable	Description	Source
Forest area in 2003	The area of forested land in 2003 within the boundaries of each precolonial society. Forested land is defined as land where the tree cover is at least 30%.	Calculated using raster data based on MODIS images for the year 2003; Available from http://www.iscgm.org/
Forest area in 2008	The area of forested land in 2008 within the boundaries of each precolonial society. Forested land is defined as land where the tree cover is at least 30%.	Calculated using raster data based on MODIS images for the year 2008; Available from http://www.iscgm.org/
Deforestation (*tc_forestdiff*)	The fractional change in forested land within the boundaries of each precolonial society between 2003 and 2008.	Calculated using raster data based on MODIS images for the years 2003 and 2008; Available from http://www.iscgm.org/
Rule of law	A composite variable that measures the extent to which agents have confidence in a society's rules and abide by the rules.	Available at http://info.worldbank.org/governance/wgi/index.aspx
Protected areas	The percentage of the precolonial society area which was declared as protected on or prior to 2003.	Available from www.protectedplanet.net and http://ramsar.wetlands.org/
Colonial Duration	The duration of colonisation in years.	Ziltener and Kuenzler (2013)
Colonial Form	A measure of different levels of political domination, where 0 represents indirect rule with minimal interference in internal affairs; 1 represents indirect rule with significant interference in internal affairs; 2 represents direct rule.	Based on Ziltener and Kuenzler (2013)
Colonial Intensity	A measure of the intensity of colonisation. Calculated as the sum of the logarithms of colonial duration and colonial form.	Calculated using data from Ziltener and Kuenzler (2013).
Legal origin	A binary variable where a value of 0 represents British legal origin and a value of 1 represents French legal origin.	Available from http://scholar.harvard.edu/shleifer/publications?page=2
Jurisdictional hierarchy	A categorical variable where a value of 0 represents a precolonial society characterized by no political authority beyond the local level; a value of 1 represents a precolonial society characterized by petty chiefdoms; a value of 2 represents a precolonial society characterized by paramount chiefdoms; a value of 3 represents a precolonial society characterized by a precolonial state.	Murdoch (1967) available from http://eclectic.ss.uci.edu/~drwhite/worldcul/EthnographicAtlasWCRevisedByWorld Cultures.sav
Succession of chiefs	A categorical variable where a value of 0 represents a precolonial society	Murdoch (1967) available from http://eclectic.ss.uci.edu/~drwhite/worldcul/Ethnographic

	where succession of chiefs is hereditary; a value of 1 represents democratic election; a value of 2 represents election from above; and a value of 3 represents election by social standing.	AtlasWCRevisedByWorld Cultures.sav
Population density	Population density per square kilometer in 2000 (log).	Available from http://na.unep.net/siouxfalls/datasets/datalist.php
Distance from closest sea	The geodesic distance (in 1,000km) from the centroid of each precolonial society to the nearest coastline.	Available from http://www.gmi.org
Distance from national border	The geodesic distance (in 1,000km) from the centroid of each precolonial society to the nearest border.	Michalopoulos and Papaioannou (2013)
Distance from capital city	The geodesic distance (in 1,000 km) from the centroid of each precolonial society to the capital city of the current country .	Michalopoulos and Papaioannou (2013)
Latitude	The geographical latitude of a precolonial state.	Michalopoulos and Papaioannou (2013)
Longitude	The geographical longitude of a precolonial state.	Michalopoulos and Papaioannou (2013)
Land suitability for agriculture	The average value of an index consisting of the climatic and soil suitability for agriculture.	Available from http://www.sage.wisc.edu/iamdata/grid_data_sel.php
Elevation	Average elevation (in kilometres).	Available from http://www.sage.wisc.edu/atlas/data.php?incdataset=Topography
Malaria stability index	The average value of an index taking into account types of mosquiotoes indigenous to a region and their prevalence.	Kiszewski et al. (2004)
Light density	The average luminosity across pixels in 2007 and 2008 (log).	Available from http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html
Road density	The ratio of roads to the total area in a precolonial society measured in kilometres of road per 100 square kilometres (log).	CIESIN (2013) Available at http://sedac.ciesin.columbia.edu/data/set/groads-global-roads-open-access-v1

Table S3: descriptive statistics of control variables

Variable	N	Mean	Std. Dev.	Min	Max
Population density (log)	683	2.899	2.022	-4.605	7.432
Distance from closest sea	683	0.589	0.421	0.001	1.704
Distance from national border	683	0.102	0.111	0.001	0.617
Distance from capital city	683	0.504	0.387	0.011	1.882
Latitude	683	4.537	12.066	-32	37
Longitude	683	16.347	16.638	-32	48
Land suitability for agriculture	683	0.435	0.241	0.001	0.979
Elevation	683	0.634	0.467	0	2.181
Malaria stability index	683	0.724	0.329	0	1
Light density (log)	683	-2.946	1.701	-4.605	3.225
Road density (log)	683	5.437	1.178	0	6.510

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