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Modeling peat- and forestland conversion by oil palm smallholders in Indonesian Borneo

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Abstract

The effect of industrial oil palm expansion on deforestation and peatland conversion in Southeast Asia has been well documented. Despite being the fastest growing producer group by area, the effects of smallholder expansion in contrast is yet to be fully understood. By combining spatial analysis with farm and farmer surveys, this article examines the types of land use changes associated with independent smallholder oil palm expansion in Indonesian Borneo. We furthermore estimate through predictive modeling how plot and smallholder characteristics influence the probability that smallholder plantation establishment involved peat- and/or forestland conversion. Results point to an increasing rate of especially peatland conversion due to rising scarcities of suitable lands on mineral soils. They also demonstrate how oil palm smallholders involved in environmentally detrimental land conversions are less likely to be experienced oil palm farmers and more likely to belong to indigenous groups, be incompliant of sustainability standards and have experienced fire. This highlights the importance of improved peatland management and targeted extension support in smallholder oil palm landscapes to both mitigate and reduce the impact of smallholder oil palm expansion.

Key words: Indonesia, oil palm, smallholders, peat, forests

1. Introduction

Smallholders are the fastest growing producer group in Indonesia's oil palm sector. The total area cultivated with oil palm by smallholders is expected to grow from approximately 40% of the total national acreage in 2016 of 11.9 million ha to over 60% by 2030 [1]. Much of this is expected to involve independent oil palm smallholders in the provinces of Indonesian Borneo, where approximately 57% of oil palm planted in Indonesia was concentrated between 2005 and 2015 [2][1]. In contrast to Sumatra, Indonesia's historical epicenter of oil palm cultivation, significant reserves of affordable and suitable land remain available [3-4]. Since much of these lands contain (peat)forests, the expansion of oil palm in Indonesian Borneo has since 2005 surpassed logging as the leading driver of forest conversion [5-7]. This has contributed significantly to, amongst others, greenhouse gas emissions, peat and/or forest fires and biodiversity loss [5, 8, 9].

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[1] There are two broad smallholder categories in Indonesia: tied or 'plasma' smallholders and independent smallholders. Tied smallholders benefit from financial, technical and input support, provided by companies under contractualized guaranteed off-take arrangements. Independent smallholder in contrast do not benefit from such support structures, typically selling to different mills through arms-length marketing relations [16].

In the absence of reliable data on the distribution of smallholder oil palm, deforestation, also in other areas of Indonesia, have largely been ascribed to industrial plantation establishment. It has been claimed that the impact of corporations on deforestation significantly outweighs that of smallholders [10]. Corporation are often said to expressly target forestlands to offset the costs of plantation establishment with timber revenues, while independent smallholders instead prioritize conversion of lands owned by the household that were previously cultivated with lesser profitable or more labor-intensive crops such as rubber and rice [10-12]. However, due to rising global supply chain pressures to enhance sustainability performance, corporations are increasingly required to comply with both voluntary and mandatory certification schemes such as the Roundtable for Sustainable Palm Oil (RSPO) and the Indonesian Sustainable Palm Oil (ISPO) and adopt self-regulatory zero deforestation commitments [13]. Evidence suggests that while this has reduced deforestation by compliant companies [5, 14], because independent smallholders are *de facto* confronted by fewer regulatory demands and more difficult to capture by corporate traceability systems many are able to convert (peat) forests with disproportionate impunity [15-17]. Rather, some contend that corporate efforts to augment sustainability performance threatens to push smallholders into ecologically sensitive landscapes by increasing demand and competition for non-forestlands [18-19]. The extension of moratoria on primary forest and peatland conversion (declared by Presidential Instruction in 2011 and 2016, respectively) are likely to make such spillover effects more pronounced since they only apply to corporations [13].

In popular discourse and literature, it is widely claimed that blanket interventions to address smallholder sustainability challenges are likely to be ineffective because they fail to adequately account for smallholders' tremendous heterogeneity [17-18, 20]. For example, deforestation and/or peatland conversion is frequently attributed to migrants and entrepreneurial elites that are better resourced, possess greater risk tolerance and are more inclined to operate under shorter planning horizons than indigenous smallholders [15-16, 21-22]. This article seeks to establish such associations. It employs econometric estimation techniques using results from remote sensing analysis and plot and producer surveys to model the changing prevalence and determinants of forest- and/or peatland conversion by independent oil palm smallholder in the provinces of West and Central Kalimantan. We complement this with a brief analysis of sustainability performance across plot types. In doing so, this article points to a potential upsurge in environmentally detrimental land use changes in Indonesian Borneo and challenges some of the popular assumptions underlying the dynamics of smallholder oil palm expansion.

2. Methods

2.1 Site selection and sampling approach

Through manual photo interpretation of post 2016 high-resolution satellite imagery obtained through Google Earth and SPOT-7, we mapped smallholder oil palm plots in West and Central Kalimantan (see [23] on the utility of Very High Resolution Satellite Imagery for visual interpretation of croplands). These are two of five provinces in Indonesian Borneo, which collectively account for approximately 55% of the surface area, 62% of oil palm cultivated and

57% of independent oil palm smallholders in Indonesian Borneo [2]. Differences in planting patterns and road networks help distinguish smallholder oil palm from industrial plantations [16]. Larger plots that resemble industrial plantations, but were located outside designated concession areas (based on maps from [24]), were visited for further verification. For the purpose of this analysis, we define a smallholder plot as a contiguous area of oil palm with similar stand age without concession rights (being processed) that is owned by a private individual. Spatial analysis of planting patterns and canopy size helped differentiate between adjoining plots. Field-based triangulation confirmed this to be a highly reliable method. Based on these results, we randomly sampled 947 smallholder plots across two major oil palm landscapes and smallholder expansion hotspots in West Kalimantan and two in Central Kalimantan, representing an estimated 10% of the total number of smallholder plots in the study areas. These landscapes cover the districts of Sanggau and Sintang and Kapuas Hulu in West Kalimantan and the districts of Kotawaringin Barat and Pulang Pisau in Central Kalimantan. The landscapes, accounting for approximately 19% of independent smallholders in West and Central Kalimantan [2], were selected for best representing realities elsewhere in the provinces. These realities can be characterized on the one hand as well-established, pioneer oil palm landscapes (e.g. Sanggau and Kotawaringin Barat), with an abundance of industrial plantations, many of which established in the 1990s, and a comparatively mature production infrastructure and on the other hand landscapes where industrial plantations are a more recent phenomenon, with comparatively few mills actively sourcing from independent smallholders (e.g. Sintang/Kapuas Hulu and Pulang Pisau). Forest cover ranged from 52% in Kotawaringin Barat to 76% in Kapuas Hulu, with other major oil palm producing districts in Central and West Kalimantan not studied also all falling with this range. See [17] for more background information on selected landscapes.

2.3 Plot and producer surveys

At each of the 947 plots, we conducted a plot survey. This involved amongst others collecting information and photographic evidence on extent of different soil types comprised within the plot (e.g. mineral and peat), 20 plot-level GPS reference points and an evaluation of compliance with best oil palm management practices. The plot owner was subsequently interviewed using a structured producer survey instrument. Data was amongst others collected on household characteristics and activities, the nature of prior experiences with oil palm management, different types of land uses contained within the plot prior to conversion, modes of and timelines for plot acquisition, compliance with the requirements of ISPO, prevalence of plot fires and management practices (see Table 2 for an overview of the variables used as predictors in our model).

2.4 Land use/land cover change analysis

For the purpose of this analysis, we sought to identify which plots involved oil palm cultivation on peat soils and/or natural forestland. Recognizing that a unified definition of natural forests is lacking, we follow the definition from [25] and [26]. These define natural forests in the Indonesian context as contiguous land areas exceeding 0.5 ha, with trees with a minimum height of five meters and a canopy density of 60% or more. Tree plantations are not considered natural forests. In the analysis, we reclassified global deforestation data from [27] to reflect these definitions, overlaying it onto a map developed of the boundaries of sampled plots. A smallholder was considered to have deforested for the purpose of developing an oil palm plantation when the plot owner reported a non-agricultural land use on the plot prior to planting and we detected a deforestation event on the plot no more than two years before the reported planting year. Because [27] data is only available from the year 2000, we restricted our analysis to plots planted with oil palm between 2002 and 2016 in order to capture the two-year lag between forest clearance and planting. This resulted in 64 plots being dropped from the analysis.

One of the key limitations of [27] data is that it poorly distinguishes between natural and planted forests [28], which, if not accounted for, would result in an overestimation of oil palm-led deforestation. Therefore, a deforestation event signaled on a plot fully planted with, for example, rubber, acacia or eucalyptus (sometimes also in combination with annual crops) was reclassified to a non-forested prior land use. This resulted in a reclassification of 106 out of the 374 plots where a deforestation event was detected up to two years before planting. Two plots were dropped from the analysis since plot owners reported that their plot was not previously fully developed and we were unable to ascertain with confidence on the basis of satellite imagery that the other land use was forest. Given differentiated and subjective local perspectives on what constitutes a forest, we did not depend on smallholder characterization of non-agricultural lands.

Furthermore, since existing high-resolution land cover maps such as those produced by [29] and [30] are unlike [27] not available at annual intervals over the time period of interest and/or offer insufficiently high resolution to effectively characterize the prior land use of small plots, we opted to instead rely on self-reported information on prior agricultural activities[2]. Even though this could theoretically result in mischaracterizations, since no forests could be observed within two years of oil palm planting on any of the plots that farmers claimed were fully planted with annual crops immediately prior to conversion (11.0% of the sample) suggests that few, if any, farmers are likely to have misrepresented their forest plantations, where in contrast to annual we could not reliably verify prior forest cover.

Whether peat soils were contained within sampled plots was established through visual inspection. This was based *inter alia* on the presence of soil organic matter, drainage systems, leaning palms and mounding practices. Due to resource constraints, we were unable to establish peat depth. Only 38% and 25% of sampled plots containing peat soils corresponded with peat thickness maps developed by [31-32], respectively; corroborating data quality concerns raised about peat distribution maps [33]. Nevertheless, field measurement results suggest that shallow peat is rare in Kalimantan, with 85% of peat soils estimated to have a thickness of more than 2 meters [33].

Based on the above results, sampled plots where grouped into the following four categories based on their land use before conversion: (1) *other land uses*, which may be agricultural (e.g. subsistence and/or cash crop agriculture) or non-agricultural (e.g. fallowed land, grass- and shrublands or forestland not conforming with our forest definition); (2) *non-forested peat*, which contained peat soils but no forests conforming with our forest definition, which may have been used for agricultural activities prior to conversion; (3) *forestland*, which contained forests conforming with our forest definition, with mineral soils and in some cases also agricultural or other non-agricultural land uses; and (4) *peat forest*, which contained both peat soils and forests

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[2] For example, with a minimum mapping unit of [29] is 6.25 ha (0.25 cm^2 at 1:50,000).

conforming with our forest definition and in some cases agricultural or other non-agricultural land uses. These four categories represent our dependent variable (see Table 1 for descriptive statistics).

Table 1: Descriptive statistics of dependent variables

Prior land use	Number of plots	Proportion of total sampled plots
Other land use	428	48.6%
Non-forested peat	203	23.0%
Forestland	120	13.6%
Peat forest	130	14.8%
Total	**881**	**100%**

2.5 Econometric estimation strategy

The explanatory variables we employ to estimate the determinants of different types of land uses being converted to oil palm by smallholders include (1) plot characteristics (e.g. size, distance by road to district capitals, mode of acquisition and land legality); (2) socio-economic characteristics (e.g. migration status, age, education, gender and income sources) and (3) nature of prior oil palm experience (e.g. as a plantation laborer or through possession of other oil palm plots) immediately prior to land conversion (see Table 2 for descriptive statistics). As highlighted by [16] and [17], these types of variables are especially relevant in the Indonesian context for explaining differentiation within smallholder oil palm systems; especially with respect to sustainability performance. Similar variables and approaches have also been employed and validated elsewhere [34-39].

In order to estimate determinants of converting peat and/or forest, we develop a multinomial logistic regression model (MNL). The MNL is a non-linear model that allows for multiple discrete land use changes. The model is specified as [40]:

$$P_{il} = \frac{\exp\,(\beta_{il}X_{il})}{\sum_{k}^{l}\exp\,(\beta_{ik}X_{ik})}$$

Where P_{il} is a stochastic variable denoting the probability that household i converts land use category l to oil palm instead of any of the other land uses (k). P_{il} is a function of X_{il}: a vector of the explanatory variables. ε_l is assumed to be independent and identically distributed with mean zero [41].

We account for unobserved heterogeneity by controlling for landscape fixed effects and use inverse probability weights to adjust for differentiated probabilities of plots being sampled at a landscape level. Using the control function approach [42], we tested for and rejected the presence of suspected endogenous regressors that may result in inconsistent parameter estimates. Further robustness tests, confirming correct model specification, involved estimation using a multinomial probit model, multicollinearity tests, the Hausman test to test for a violation of the Independence of Irrelevant Alternatives (IIA) assumption and likelihood-ratio tests to examine the utility of (further) combining dependent variable categories. Based on these results, no variables were dropped and no dependent variable categories were combined. For the purpose of parsimony, we, through stepwise elimination of explanatory variables based on model Bayesian Information

Criterion (BIC) scores, develop and present below both a full model and a more parsimonious model.

Table 2: Descriptive statistics for explanatory variables

Independent variable set	**Variable**	**Description**	**Mean (SD)**
Plot characteristics	Size	Plot size (in ha)	5.84 (21.28)
	Distance	Road distance of plot to district capital (in km)	15.70 (11.97)
	Legality	Dummy variable for plot location on land designated for oil palm (APL, *Areal Pengunaan Lain*)	91.27%
	Bought	Dummy variable for plot acquisition through market transaction (as opposed to acquired through inheritance or allocation through transmigration or customary tenure systems).	50.41%
Socio-economic characteristics	Age	Age of plot owner at time of conversion	41.07 (9.03)
	Education	Count variable (0-5) of the level of attained education of plot owner	2.41 (0.90)
	Gender	Dummy variable for plot owner being male	96.38%
	Origin	Categorical variable:	
	1. Non-indigenous non-migrant	Plot owner is a 2nd or more generation migrant of non-indigenous origin	25.18%
	2. Non-indigenous migrant	Plot owner is a first-generation migrant of non-indigenous origin	31.18%
	3. Indigenous	Plot owner identifies with an ethnic group indigenous to relevant districts	43.65%
	Commerce	Dummy variable for plot owner' household's engagement in commerce at the time of plot acquisition	16.76%
	Civil Service	Dummy variable for plot owner household's engagement in civil service at the time of plot acquisition	7.68%
	Subsistence	Dummy variable for plot owner household's engagement in subsistence crop farming at the time of plot acquisition	19.56%
	Cash crop	Dummy variable for plot owner household's engagement in cash crop farming at the time of plot acquisition	36.09%
Prior experience	Plantation laborer	Dummy variable for plot owner household's experience gained through plantation labor employment	22.58%
	Other plots	Dummy variable for plot owner household's experience gained through prior ownership of other oil palm plots, including plasma (cf. footnote 1)	33.88%
	Stand age	Years since planting of sampled plot	6.28 (2.71)

While the primary objective of the article is to examine land use change determinants, we do marginally extend our analysis through a cursory analysis of differences between smallholders with different types of plots (based on prior land uses) with respect to (1) incidence of fire; (2) degree of compliance with sustainability standards; and (3) adherence to good agricultural practices (GAP) (see Table 3 for more information). For this, we present for the sake of simplicity the results from Analysis of Variance (ANOVA) and Chi-Square tests. To establish whether these results remain statistically valid when controlled for confounding variables and self-selection biases, we developed (but do not report the results of) a two-stage multinomial logit-based selection bias correction model [43]. This produced identical results to those reported in Table 4; at least with respect to the statistically significant differences between groups.

Table 3: Descriptive statistics for sustainability performance indicators

Variable	**Description**	**Mean (SD)**
Fire	Binary variable for farmers having experienced fire on the sampled plot following planting of oil palm	13.9%

Compliance	Count variable ranging from 0 to 5 for compliance with five major ISPO requirements [17]: (1) located on land designated for oil palm production; (2) planting material sourced from certified source; (3) membership of an officially recognized farmer group; (4) possession of appropriate land documentation; (5) possession of plantation permit.	2.31 (0.95)
Good agricultural practice	Continuous variable ranging from 0 to 1 for adherence to 14 different good agricultural practices [17], developed into an index using the principal component analysis approach proposed by [44].	0.68 (0.14)

3. Results

3.1 The nature of land use change

As can be seen in Table 1, the majority (51%) of sampled smallholders converted lands containing peat and/or natural forests for oil palm. Of those converting such lands, 44% converted non-forested peatlands, 27% forest and 29% peat forests. Some 45% of plots containing non-forested peatlands were used for other agricultural purposes prior to conversion to oil palm, notably for the production of rice and rubber. This points to the likely presence in many such plots of a drainage infrastructure prior to oil palm cultivation; implying that net ecological impacts associated with peat subsidence and oxidation cannot solely be attributed to oil palm cultivation. However, the environmental effects of oil palm cultivation typically outweigh that of rice cultivation since the latter demands less extensive management of the water table due to its natural adaptation to swamp conditions [45]. Much of the other non-forested peatlands had been degraded by logging or abandoned following some prior agricultural development. In the case of Pulang Pisau, where much of the sampled smallholder plots were found to be located on non-forested peatlands, much of the forest was cleared for the purposes of establishing the infamous Mega Rice Project (MRP) in the 1990s, which ultimately failed. Few of the sampled plots were, however, found in ex-MRP areas with extensive canal development.

None of the plots involving conversion of forests on either peat or mineral soils were under agricultural production prior to conversion; despite our approach technically allowing for multiple land uses on plots categorized as forest or peat forests. This may have been a possibility on the two plots dropped from the analysis. Nevertheless, the absence of agriculture prior to conversion does not guarantee that solely ‘primary’ forests were converted. Likely, the integrity of some of these forests may have been compromised by selective logging in the past; an industry that long formed the backbone of the Kalimantan economy prior to the upsurge in oil palm cultivation in the 1990s. Some plots do contain other land uses; notably trees with < 60% canopy cover and shrubland, which most often constitutes regrowth (e.g. in the context of shifting cultivation systems).

3.2 Land use change determinants

Table 4 summarizes the full and parsimonious MNL regression model of peat- and/or forestland conversion determinants. The base variable in our model is ‘other land uses’.
We can observe no major differences in the results between the full and parsimonious models, suggesting that our full model is not ill-specified and can also be used well for predictive purposes. Nevertheless, in our below discussion and in the reporting of odds ratios and predicted probabilities we restrict ourselves to the results of the parsimonious model.

Table 4: Multinomial logistic regression results

	Full model						Parsimonious model					
Dependent variable	Non-forested peat		Forest		Peat forest		Non-forested peat		Forest		Peat forest	
Independent variable	*Coef. (SE)*	*Odds ratio*	*Coef. (SE)*	*Odds ratio*	*Coef. (SE)*	*Odds ratio*	*Coef. (SE)*	*Odds ratio*	*Coef. (SE)*	*Odds ratio*	*Coef. (SE)*	*Odds ratio*
Size (log)	0.102 (0.159)	1.107	0.317 (0.169)*	1.373	0.498 (0.156)***	1.646	0.063 (0.155)	1.065	0.286 (0.170)*	1.332	0.495 (0.146)***	1.640
Distance	0.027 (0.015)*	1.027	0.057 (0.013)***	1.059	0.061 (0.016)***	1.063	0.021 (0.015)	1.021	0.056 (0.014)***	1.058	0.060 (0.016)***	1.062
Legality	0.368 (0.463)	1.443	0.117 (0.552)	1.124	-0.061 (0.458)	0.941						
Bought	-1.210 (0.436)***	0.298	1.016 (0.383)***	2.761	-0.714 (0.650)	0.490	-1.230 (0.433)***	0.292	1.013 (0.377)***	2.753	-0.671 (0.622)	0.511
Age	0.014 (0.016)	1.013	-0.011 (0.016)	0.989	0.020 (0.023)	1.020						
Education	-0.264 (0.182)	0.768	0.036 (0.194)	1.037	-0.025 (0.230)	0.975	-0.380 (0.171)**	0.684	0.036 (0.177)	1.037	-0.108 (0.206)	0.898
Gender	-0.761 (0.679)	2.140	-0.460 (0.560)	1.583	0.250 (1.079)	0.779						
Non-indigenous migrant	-1.302 (0.384)***	0.272	-0.768 (0.507)	0.464	-0.398 (0.445)	0.672	-1.332 (0.365)***	0.264	-0.826 (0.522)	0.438	-0.417 (0.428)	0.659
Indigenous	0.369 (0.392)	1.447	1.245 (0.480)***	3.472	1.468 (0.453)***	4.339	0.219 (0.378)	1.245	1.178 (0.461)**	3.247	1.375 (0.423)***	3.954
Commerce	-0.047 (0.404)	0.954	0.328 (0.478)	1.389	0.091 (0.418)	1.096						
Civil Service	0.857 (0.592)	2.357	0.381 (0.657)	1.464	1.109 (0.646)*	3.031	0.943 (0.561)*	2.569	0.257 (0.657)	1.293	1.142 (0.618)**	3.134
Subsistence	0.530 (0.380)	1.700	0.354 (0.463)	1.425	0.481 (0.489)	1.618						
Cash crop	-0.729 (0.380)*	0.482	0.053 (0.350)	1.055	-0.745 (0.485)	0.475	-0.766 (0.353)**	0.465	-0.043 (0.328)	0.958	-0.886 (0.459)*	0.412
Plantation laborer	-0.205 (0.391)	0.815	0.131 (0.425)	1.140	-1.177 (0.461)**	0.308	-0.278 (0.345)	0.757	-0.031 (0.390)	0.970	-1.306 (0.422)***	0.271
Other plots	-0.846 (0.372)**	0.429	-0.854 (0.291)***	0.426	-1.053 (0.477)**	0.349	-0.836 (0.376)**	0.433	-0.881 (0.285)***	0.414	-1.011 (0.466)**	0.364
Stand age	-0.153 (0.064)**	0.859	-0.006 (0.066)	0.994	-0.128 (0.077)*	0.880	-0.164 (0.062)***	0.849	0.004 (0.067)	1.004	-0.143 (0.073)**	0.866
Constant	-2.578 (1.587)	0.162	-4.130 (1.497)***	0.025	-5.030 (2.159)***	0.005	-0.182 (0.747)	0.833	-3.749 (0.909)***	0.024	-4.019 (1.009)***	0.018
Fixed effects	YES		YES		YES		YES		YES		YES	
McFadden’s R^2	0.259						0.253					
Prob > chi^2	0.000						0.000					
N	810						810					
Wald Chi^2 (48)	12,978.8						17,259.4					
BIC	65,16.2						6,463.6					

* Significance < 0.1; ** Significance < 0.05; *** Significance < 0.01

Note: Heteroscedastic-robust standard errors are reported in parentheses

Plot characteristics

Results show that plot size positively predicts forest and peat forest conversion. Every 100% increase in plot size increases the odds of converting such lands on the sampled plots by 12.4% and 21.5%, respectively. The comparatively high costs of converting forests and preparing peat infrastructure tends to attract better resourced farmers developing larger plots of land. Similarly, plots located further from districts capitals are also more likely to involve conversion of forest and peat forest, with the odds increasing by 5.8% and 6.2%, respectively, for every additional kilometer the plots is located from the district capital. This demonstrates how remaining forested plots are more likely to be located away from major urban areas, where population pressures are less significant.

While the majority of sampled farmers acquired their plots through some form of commercial transaction, it is negatively associated with non-forested peat development. The odds that a farmer converts a plot with non-forested peat that was obtained through inheritance or through allocation by government or customary authorities is 3.4 times higher than a farmer with a similar plot that was bought. This suggests that such plots were likely to have long formed part of existing farming and land tenure systems and/or be of lesser interest to those seeking to purchase lands. Conversely, plots involving forest conversion are 2.8 times more likely to have been bought than acquired through other means. Because sales of timber stock can offset costs of acquisition and plantation establishment, certain farmers expressly seek out forestland.

Socio-economic characteristics

We find that smallholders converting non-forest peat are less likely to be educated and less likely to be non-indigenous migrants (section 3.3 examines this further). Moreover, plot owners are less likely to have been involved in the cultivation of cash crops (notably rubber). Typically, farmers with a better understanding of the limitations and risks of cultivating perennial crops are less inclined to establish new plantations on marginal soils. We do observe a positive association between prior engagement in civil service employment and non-forested peat conversion.

In the case of plots involving forest conversion, plot owners are considerably more likely to be indigenous. Results show similar trends for plots containing peat forests, but also observe associations similar to non-forested peat conversion; namely, a negative association with cash crop cultivation and an even stronger positive association with employment in civil service.

Prior experience

Results demonstrate that prior experience with oil palm management is generally negatively associated with converting peat and/or forestland. Specifically, smallholders previously owning other oil palm plots are less inclined to convert both peat and forestland than smallholders that newly venture into oil palm. In the case of smallholders that gained experience working on industrial plantations, we can only observe a tendency to avoid lands containing peat forests. In similar vein to smallholders with prior experience cultivating other plantation crops, these results point to relevant experience fostering risk avoidant oil palm development strategies.

3.3 Land use change trajectories

Figure 1 depicts changes in the predicted probabilities of converting different types of land over time, disaggregated by the origin of the plot owner. Results show that the predicted probabilities of converting other land uses has been declining steadily over time, dropping from 55% to 15% between 2002 and 2016. A drop in predicted probabilities for plots with forests can also be observed, declining from 11% to 3%. For plots containing non-forested and forested peat, predicted conversion probabilities instead increased between 2002 and 2016, from 22% to 59% and 12% to 23%, respectively. These findings suggest that land on mineral soils is becoming scarcer, thereby driving expansion onto areas where oil palm cultivation is costlier and riskier. Projecting results to the future suggests that these patterns are likely to persist, with peat soils projected to become the primary source of new land for oil palm cultivation in future across the four landscapes.

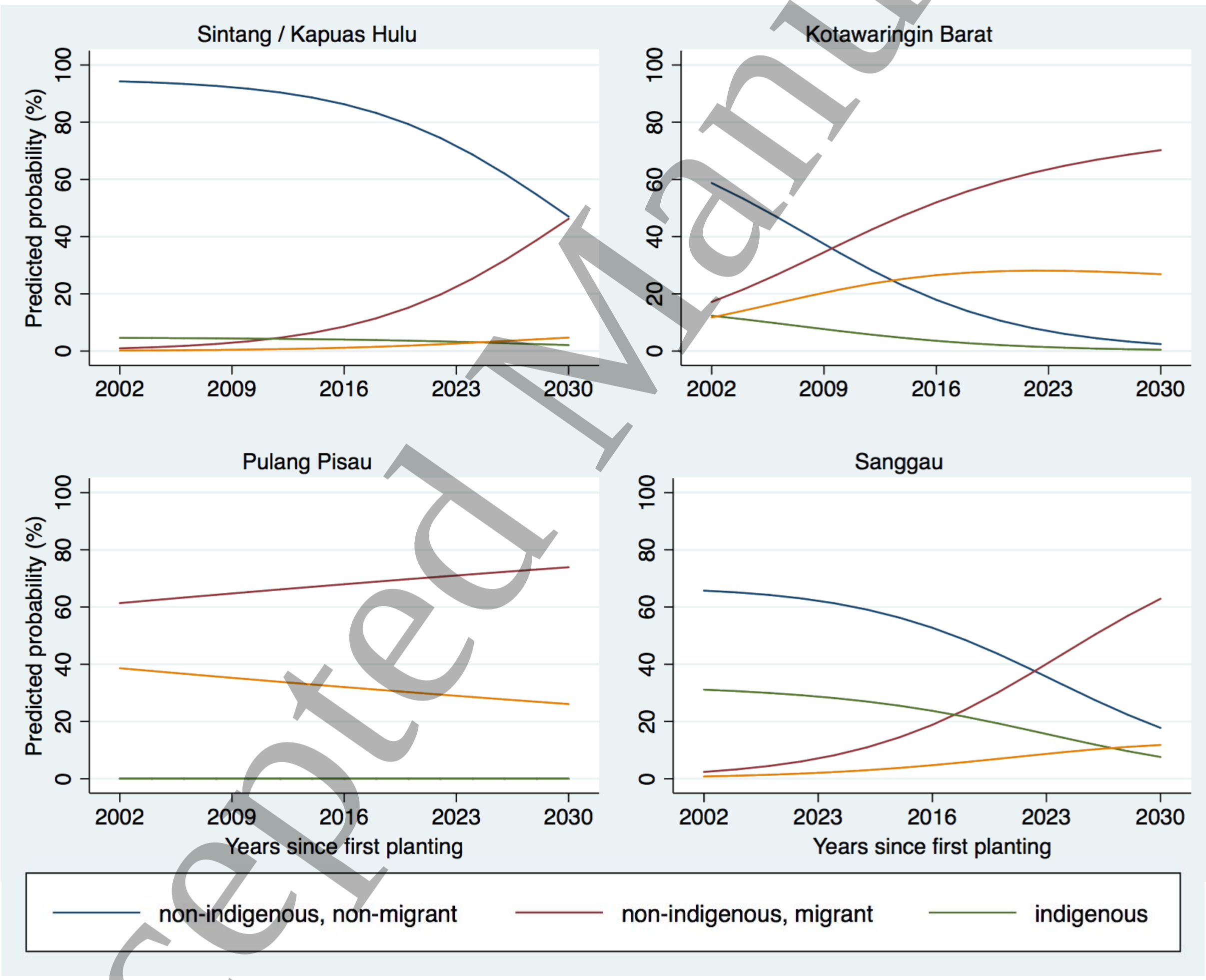

Figure 1: Land use changes dynamics, disaggregated by producer origin

Figure 1 also shows that while predicted probabilities for converting most plot types follow similar trajectories for farmers of different origin, significant differences in predisposition can be observed. We find that migrant farmers are most likely to convert other land uses and least likely to convert non-forested peat and forests. Indigenous farmers, in contrast, are most likely to be involved in conversion of forest and peat forest. However, second or more generation migrants were found to be most inclined to convert plots with non-forested peat.

While aggregating results across the study landscapes offers important insights into overarching land use change patterns, they do hide land use change trajectories unique to each study landscape. For this, Figure 2 presents landscape disaggregated predicted probabilities over time. This shows that in all but Pulang Pisau, the primary type of land that was converted in the 2000s was other land uses, but that this has steadily declined over time. Since all sampled plots in Pulang Pisau are located on peatlands, no such conversions were observed. Rather, most lands contained non-forested peat, which is increasing over time as fewer peat forests remain. In the other landscapes, an increase in the probability of converting land with both non-forested and forested peat is evident. Nevertheless, like Pulang Pisau, non-forested peat is projected to become the primary type of land use converted for smallholder oil palm development in future. However, our model cannot account for future policy developments or changes in land use competition dynamics that could fundamentally alter land use change trajectories. In the absence of sufficiently reliable data on peat soil distribution, our model also assumes no major medium-term constraints in the supply of available land with peat soils.

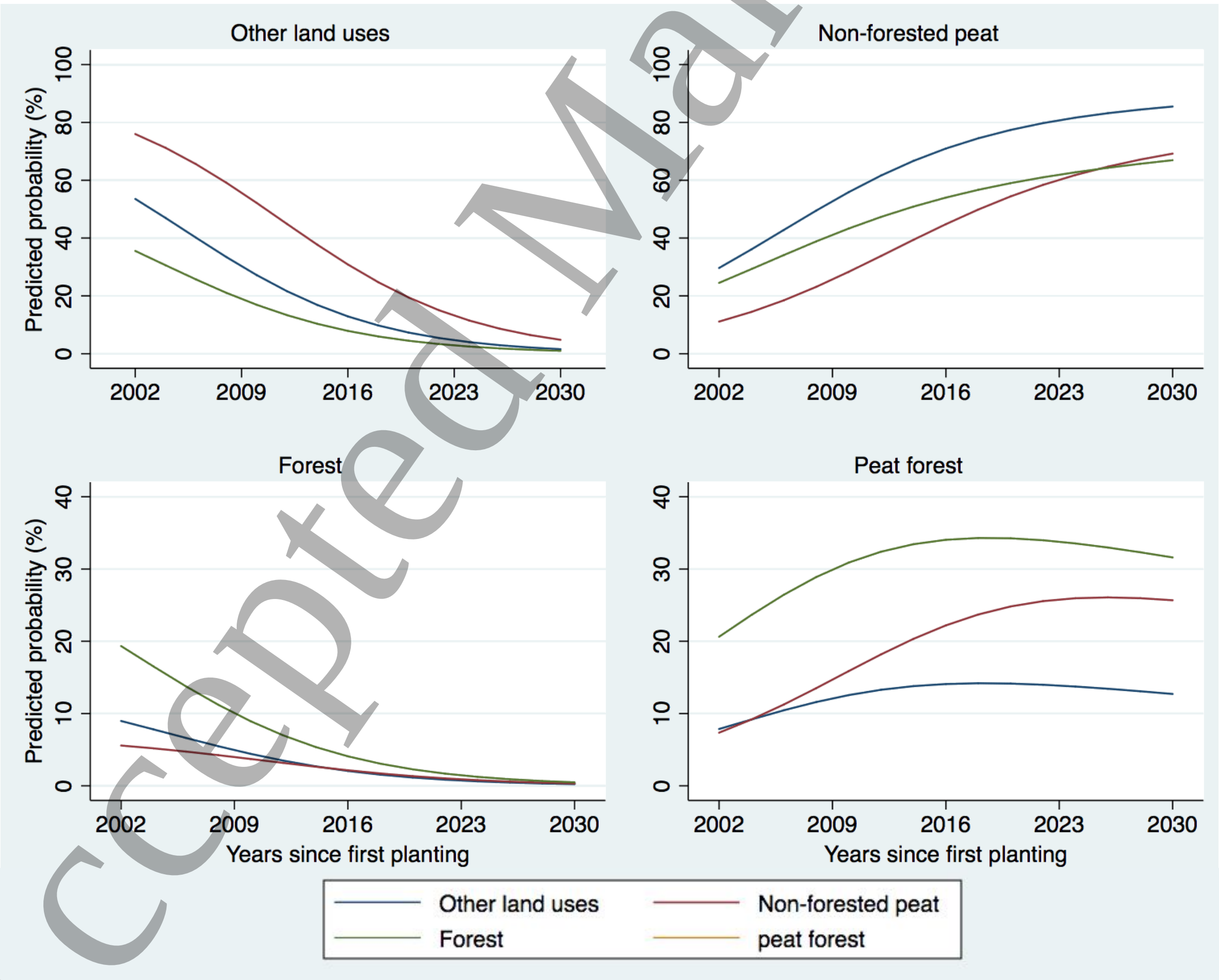

Figure 2: Land use changes dynamics by landscape

3.4 Differentiated sustainability performance

Table 5 presents the results of the analysis of sustainability performance of smallholders that converted plots with different types of prior land uses. It shows that compliance with sustainability standards is weakest for farmers that converted peat. This can be attributed to such farmers lacking relevant experience, being more inclined to develop state land and/or pursuing speculative strategies. Non-forested peat farmers were also found to have on average the lowest scores on our GAP index. The increased susceptibility of drained peat soils to fire is also clearly reflected by findings. These show that 30-37% of plots with peat experienced (unwanted) fire, as opposed to 3-4% of plots without peat.

Table 5: Sustainability performance across plot types

Variable	Other land uses (mean)^a	Non-forested peat (mean)^b	Forests (mean)^c	Peat forests (mean)^d	Summary statistics
Compliance	2.557 $^{b\ d}$	2.162 $^{a\ d}$	2.379 ^{d}	1.632 $^{a\ b\ c}$	F=36.9***
GAP score	0.700 ^{b}	0.637$^{a\ c\ d}$	0.704 ^{b}	0.686 ^{b}	F=10.15***
Fire	0.029 $^{b\ d}$	0.302$^{a\ c}$	0.017 $^{b\ d}$	0.366 $^{a\ c}$	Chi^2=149.7***

* Significance < 0.1; ** Significance < 0.05; *** Significance < 0.01
Note: Superscripts denote statistically significant differences between individual groups at the < 0.05 level.

4. Discussion

4.1 Drivers of land use/land cover change

Results build on other studies demonstrating the socially differentiated patterns of smallholder land use decisions. Specifically, we find that non-forested peat conversions tend to occur on land obtained through inheritance or allocation by farmers that are non-migrants, comparatively uneducated, lack relevant prior experience and are not actively engaged in the cultivation of other cash crops. The conversion of forest on mineral soils in contrast is associated with larger plots, located away from administrative centers that were obtained through commercial transaction. Farmers converting forests are more likely to be indigenous than those converting other land uses and non-forested peat and lack prior oil palm cultivation experience. The conversion of peat forest is similarly associated with large plots, which are especially likely to be located furthest from administrative centers. Plot owners are also most likely to not have gained any relevant prior experience and be of indigenous origin and employed in civil service.

These results suggest that the conversion of forests on both peat and mineral soils is associated with more affluent farmers, given the high costs of converting large areas of forestland (especially on peat) [39, 46]. This is in line with results from [39, 47-48]. A dynamic, sometimes illicit, market for forestland can be found in many oil palm landscapes in Indonesia [15-16, 49]. Our results however do not confirm findings from others that show a negative association between off-farm sources of income and forest conversion [22]. Rather, with our results revealing a positive association between civil service employment and peat conversion, we show that farmers with ties to public bureaucracy are more inclined to develop on marginal lands. This corroborates findings from [16] in Sumatra, who argue that political elites are especially likely - by virtue of the protection afforded by those ties - to employ high-risk, speculative, strategies.

Even though migrant farmers are widely depicted as being more risk tolerant due to short-term profit horizons and more inclined to venture into high-risk areas given lack of understanding of local dynamics and conditions [21-22], our results strongly refute this narrative; at least, for oil palm farmers in Kalimantan. While [16] present a convincing case that some non-indigenous groups, notably those of Chinese origin, may have lower risk aversion and be better resourced to expand onto (peat)forests, we did not observe significant differences in propensities across non-indigenous groups when accounting for ethnicity in our model. The comparatively high probability of indigenous groups in Kalimantan expanding into forestlands is likely a reflection of differentiated migration patterns across Indonesia. As shown by [17], many of the smaller, less affluent oil palm smallholders in Kalimantan are landless migrant laborers that are unlikely to be adequately resourced to (buy and) expand onto forestlands and more likely to have benefitted from government land allocations under transmigration schemes. We observe that indigenous groups are better embedded and able to navigate the local political networks and land markets that enable (peat)forest conversion.

4.2 Differentiated sustainability performance

Analysis of select indicators of smallholder sustainability performance show that farmers on both forested and non-forested peatlands experience the highest regulatory incompliance levels, the lowest adoption rates of GAP and the highest rates of fire hazard. Since inexperienced oil palm farmer that are likely to have limited experience with developing peat drainage systems and proper water table management have an increased probability of converting land with peat soils is of particular concern, given the environmental implications of peat mismanagement. Furthermore, the low compliance levels pose significant challenges to promoting uptake of sustainable production practices and is likely to reinforce negative feedback loops between incompliance and GAP adherence. As others have shown, failure to comply with the legality requirements under especially ISPO reduces smallholders' access to credits, extension support and improved planting material [17, 50], thereby depriving them of the means that enable upgrading. Furthermore, since access to (premium) oil palm markets is becoming increasingly conditional on compliance not only with existing industry standards but also with voluntary corporate commitments to combat deforestation and peatland conversion [51-52], major processors are discouraged from developing stronger productive linkages with smallholders that could facilitate technological spillovers [17]. Peat farmers, which from environmental perspective are especially needing improved public and private support, are particularly confronted by these structural barriers given rising industry concerns over peat fires and greenhouse gas emissions.

4.3 Changing land use/land cover change dynamics

Between 2002 and 2016 we find that approximately half the smallholders in the sampled landscapes converted peat and/or forestland. However, results show that conversion patterns have profoundly changed over time. The probability that smallholder convert land without forest and peat declined over the study period from 55% to 15%, with especially rates of peat conversion rapidly increasing over time. In the absence of more rigorous check and balances, our projections point to this trend persisting in most of the sampled landscapes. This suggests that as corporate producers are increasingly paying heed to land use/land cover change impacts and face barriers to accessing available forest- and peatland (e.g. through Indonesia's moratoria) [5, 13-14], independent smallholders are increasingly filling the space left behind. We therefore challenge findings from [10], with findings suggesting that rising scarcities of other land uses in the sampled landscapes is driving smallholders to either expand onto peripheral lands with marginal soils or convert other crops cultivated on peat due to oil palm's relative profitability on peat soils, at least in the short term [53].

While this study's design permits it to draw conclusions about land use dynamics in the four study landscapes, we recognize that care should be taken in extrapolating results to Indonesian Borneo or even Indonesia at large. While some of the similarities in the trends observed across landscapes (bar the admittedly idiosyncratic Pulang Pisau) gives reason to assume some level of external validity, it must be recognized that marked differences in population composition, market conditions, public policy and/or availability of peat or forests may produce dissimilar dynamics. Furthermore, while we expect smallholder oil palm expansion to continue enhancing pressure on peatlands in future, in landscapes where such expansions are beginning to exhaust available peatlands profound changes in smallholder land use dynamics may be expected in future.

5. Conclusion

Despite oil palm smallholders being the fastest growing producers' group by area in Indonesia, surprisingly little is known about smallholder land use determinants and patterns. As a more convenient unit of analysis and object of activism, much of the literature [5-7, 18, 54] and civil society campaigns instead focus on the environmental impacts of industrial plantation development. Although corporations are increasingly aligning their practices with international sustainability norms, smallholders that lack the capacity and incentives to follow suit are clearly falling behind [17, 50]. With this article, we sought to fill this critical void and contribute to more informed and targeted policy making. Its results show how plot and socio-economic characteristics and prior oil palm experience can positively predict land use conversion dynamics. Significantly, we debunk the popular notion, especially in Indonesian polity, that much of smallholder-driven deforestation and peatland conversion is attributable to migrant groups. We also show how conversion of particularly fragile ecosystems such as peat forests is associated with larger farmers and political elites. A worrisome trend in oil palm producing landscapes in Kalimantan of rising land scarcities and resultant dependency on land containing peat soils for expansion was furthermore observed.

These findings demonstrate the importance of more explicitly accounting for (the challenges associated with) changing smallholder land use decisions in Indonesia's land management policies. This could include a combination of (1) extending the moratoria from corporations to smallholders; (2) resolving ambiguities arising from inconsistencies between central, provincial and district government land use plans; (3) undertaking strategic environmental impact assessments within districts to identify land suitable for oil palm expansion (as is being done in Pulang Pisau); and (4) building district government capacities and incentives to implement and monitor adherence to provincial regulations. Complementary intervention support to break the vicious circle of incompliance and unsustainable production practices could furthermore fulfill a number of sustainable development objectives simultaneously by *inter alia* raising farming productivity and incomes, strengthening access to offtake markets and reducing pressure on fragile ecosystems. This could be achieved by improving smallholder access to high quality inputs and technical support by strengthening productive linkages with agribusiness through more progressive sectoral regulation and incentives, streamlining bureaucratic procedures to help smallholders overcome compliance barriers and explicitly targeting smallholders (and their practices) on peatlands by public extension and credit support programs.

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