Land property rights and agricultural intensification at forest margins in Indonesia

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Abstract

This study examines the potential of property rights to enhance land-sparing agricultural intensification in Sumatra, Indonesia, using data from a panel survey of farm households and satellite imageries. Provision of land titles is found contributing to significant increases in the use of farm inputs and to higher crop yields. However, we show that farmers located at the forest margins are less likely to hold land titles due to government restrictions. Without land titles, farmers are constrained to intensify production. In order to increase agricultural output, they can instead expand their farm to surrounding forestland. Tolerating deforestation by farmers while denying formal titles for land at the forest margins can, therefore, contribute to economic marginalization and increased deforestation. Besides increasing farmer's access to land titles over non-forest land, policy responses could include a better recognition of farmers' customary land rights and simultaneously protecting forest land without recognized claims.

The loss of tropical forest remained strikingly high in our current decade; since 2010 annual net loss is at 6 million hectares globally (FAO 2016), entailing severe ecological and social problems (Fearnside 2005; Butler & Laurance 2009; Barnes et al. 2014; Wilcove et al. 2013). Among infrastructure, mining and urban expansion, agricultural expansion is the most important direct driver of deforestation (Gibbs et al. 2010). The demand for agricultural land is even likely to increase due to a growing global population, rising incomes, and changes in dietary habits. These trends will be in particular pronounced in tropical countries, threating the conservation of the remaining tropical forest (Laurance et al. 2014). Facing these global developments, increasing agricultural intensity and productivity, thus level of input and output per unit of land respectively, is often seen as fundamental not only to meet the rising demand for agricultural products but also to curtail further deforestation (Stevenson et al. 2013; Ewers et al. 2009; Phalan et al. 2011a; Green et al. 2005). Farmers could satisfy local and global demand and sustain a higher living standard using less land. Moreover, broader economic development would be spurred, which is also often related with decreasing deforestation rates. Although some evidence and future developments indicate that a land-sparing agricultural intensification is necessary process - however not sufficient - to sustain important ecosystems functions of tropical forests, entailing also an intensive debate amongst scholars about alternative approaches (Perfecto & Vandermeer 2010; Steffan-Dewenter et al. 2007; Tscharntke et al. 2012), strikingly few evidence exists how a land-sparing agricultural intensification can be implemented on a local scale and why current efforts often fail.

In our study, we propose that property right institutions over land resources are fundamental for agricultural production and deforestation outcomes. Land is the main source of farmers' livelihood but also a major mean for accumulating and inheriting wealth. The institutions shaping access, use and transfer of land are hence central for farmers' decision making (Deininger & Feder 2001). We show in our study that while greater tenure security induced by formal land titles has the potential to induce agricultural intensification, the institutional setting often inhibits potential land-sparing effects.

Land tenure for forest land is often different from that for agricultural land. Literature mostly focuses on the effect of forest land tenure on future deforestation decisions. This literature builds on concepts such as strategic deforestation if only productive land can be titled and realization of long-term benefits of forest such as forest products or conservation payments through secure long-term ownership (Liscow 2013; Damnyag et al. 2012; Robinson et al. 2014; Araujo et al. 2009). For agricultural land, a comprehensive body of literature covers the effect of tenure security and land titles on agricultural intensity and productivity (Deininger et al. 2011; Fenske 2011; Bellemare 2013). Only a few papers, however, explicitly assess the effect of secure tenure of agricultural land for improving productivity and the potential sparing of forest land. To address this gap, we analyze data from different sources. A unique panel dataset is combined with detailed quantitative information on farmers' agricultural practices with remote sensing data on historic land-uses for this purpose. Second, we use additionally detailed information on legal and customary institutions to understand their role for agricultural productivity and deforestation.

With increasing land scarcity, economic theory suggests that in particular private land titles can increase agricultural intensity and productivity. Following the literature, three causal pathways exist through which land titles affect agricultural intensity and productivity. First, the *assurance effect* is defined as an increase in investment triggered by a higher security to yield the benefits from long-term investments. Second, since land is the most valuable asset of farmers, the *collateralization effect* is based on the increase in attainable investment capital using land titles as collateral for formal credits. Third, the *realizability effect* states that land titles enable farmers to allocate their land more efficiently through participating in the land market or renting out (Besley 1995; Feder & Feeny 1991). While some empirical studies find indeed a significant positive impact of increased tenure security or land titling on agricultural intensity and productivity (Banerjee et al. 2002; Deininger et al. 2011; Goldstein & Udry 2008; Grimm & Klasen 2015; Holden et al. 2009), others find no significant impact (Bellemare 2013; Brasselle et al. 2002; Jacoby & Minten 2007; Quisumbing & Otsuka 2001). Recent literature reviews imply, however, a rather positive impact (Fenske 2011; Lawry et al. 2016).

Linking agricultural productivity and deforestation, Angelsen and Kaimowitz (Angelsen & Kaimowitz 2001) argue that an increase in farm productivity could diminish the rate of deforestation. First, by increasing yields local and global demand can be met using less land resources. Second, farmers need less land to reach a subsistence level of income. Third, a more productive agricultural sector could spur broader economic development, leading to more off-farm income opportunities, lower population growth and improved land governance capacities. While empiric evidence is scarce, some studies found evidence that indeed increasing agricultural intensity and productivity can help to spare land from agricultural conversion (Barbier & Burgess 1997; Phalan et al. 2011b; Ewers et al. 2009). However, growth in agricultural productivity can also increase deforestation rates in particular if productivity increases are aligned with infrastructure investments such as road construction or labor-saving technologies. Moreover, productivity increases could escalate the costs of direct conversation payments and induce rural in-migration (Maertens et al. 2006; Phelps et al. 2013). This indicates that, although a land-sparing effect is possible, certain intensification pathways can overrule this positive effect.

Despite the potential productivity increasing and thus land-sparing effects of land titles, land titles are often difficult to obtain because of high costs but also due to ill-defined land tenure. This is in particular the case in the transition zones of forests and agriculture where public tenure and customary land claims overlap (Robinson et al. 2014). “Unproductive” land such as forests is often under public tenure (Agrawal et al. 2008), however, local farmers have long-standing customary claims and deforest land even when the encroached land is not eligible for land titling (Resosudarmo et al. 2014). Yet, without incentives to increase agricultural output through intensification at forest margins, output increases can also be achieved by further expansion into the surrounding forest. Therefore, because of the institutional setting of overlapping customary land claims and only partly enforced legal regulations concerning state forest the positive effects of land titles via agricultural productivity might not get realized at forest margins, losing out potential decreases in deforestation rates.

Based on this framework, we formulate three research hypotheses to systematically delineate the effects of land property rights on land-sparing agricultural intensification. First, possession of land titles increases agricultural intensity and productivity. Second, farms close to the forest margin are less likely to have a land title due to ill-defined land tenure. Third, due to their inability to intensify cultivation, farmers expand their farm land in forest margins, resulting in bigger farm sizes. The data set used to examine these hypotheses originates from Jambi Province of Sumatra, Indonesia. The research location suits the testing of the hypotheses for several reasons. The research location is characterized by a dual land tenure regime of state forest where private ownership is mostly restricted and non-forest land where land is eligible for private land titling. Local agriculture is dominated by smallholder farmers, which are often found to involve in deforestation, creating overlapping customary and government land claims (Resosudarmo et al. 2014). Finally, Indonesia is a hotspot of tropical deforestation. In 2012 Indonesia’s deforestation rate with 0.84 million hectares was worldwide unique, surpassing even deforestation rates in Brazil (Margono et al. 2014), threating various ecosystem functions (Clough et al. 2016).

Results

Descriptive statistics. The sample includes details of 473 farm-households from 28 autochthonous villages from Jambi Province, Sumatra, Indonesia. The household heads were interviewed both in 2012 and in 2015. The respective number of surveyed plots is 902 in 2015 and 808 in 2012. Locations of the households are depicted in Map 1 and Map 2 in Figure 1.

[figure 1 here]

Based on the historic satellite imagery, about 17% of the land area in 5 km radius around farmers’ residence was covered with forest in 1990. This was reduced to 3% in 2013. Local agriculture is dominated by oil palm and rubber cultivation. Albeit the rapid proliferation of oil palm cultivation by smallholders in Indonesia (Euler et al. 2016), about 86% of our sampled households were found cultivating rubber. About 34% of these farmers use modern, material inputs such as chemical fertilizers and herbicides. Average farm size is 4.1 hectares, reflecting the land-demanding cultivation of plantation crops. The household sample is also characterized by a significant share of migrants (25%), who settled in the study area without any government support such as the transmigration program. Proliferation of land titles is low; a great share of plots is held under mere customary tenure. About 10% of the rubber plots in 2015 had a systematic land title (recognized by all government authorities). Figure 2 shows that farmers' procurement of systematic land titles are a rather recent phenomenon in the study area. Land titling has occurred substantially later than most deforestation activities of the smallholders. We also found that 24% of plots have a sporadic (recognized by local authorities) land title. While being relative cheap, they are not acknowledged by national government and are associated with lower credit access. Detailed descriptive statistics are reported in Table 1.

[figure 2 here]
[table 1 here]

Land titles and agricultural intensity and productivity. Table 2 includes the model estimates of the effect of land titles on land productivity at household level as well as plot level. For the household-level model, column (1) presents the result of a fixed effects model, while column (2) – (3) include the results of the random effects models. Column (2) includes all households, while column (3) is migrant households only. A Hausman test did not reject the consistency of the random effects estimates in the household and plot level models, which are hence the focus of the coefficient interpretation (Wooldridge 2002). For the key variable systematic land titles, coefficient magnitude is significant at 0.01 level in all random effects specifications. A 10% increase in titled land results in a land productivity increase of about 3.6% in the household model. The magnitude of the effect increases for migrant households. This is expected since migrants are likely to benefit more from land titling: first, due to smaller family networks, access to formal credit is more important; second, due to lower levels of security within customary tenure compared to locals bigger increases in tenure security are expected for migrants through land titling. For sporadic land titles no significant effect could be observed. Columns (4) – (6) reports the results of estimating with plot-level data. Columns are ordered in the same structure as for household-level models. In the plot level models the effect of systematic land title is also found significant at 0.01 level in all random effects specifications. Plots with a systematic land title were 15% more productive compared to the non-titled ones. The magnitude of the effect is smaller in plot-level models compared to the household-level models. This is expected because of increased investments in untitled plots through better credit access derived using titled plots. Moreover, farmers can more easily sell and purchase or rent out titled plots and thereby also increase efficiency of inter-plot resource allocation. To address unobserved heterogeneity of the plots which might affect land titling as well as productivity, we control for soil quality. The model in column (7) includes farmers' perceived soil quality for a sub-sample of households, while the model in column (8) includes topsoil properties such as Carbon content, Carbon/Nitrogen ratio and bulk density for a small sub-sample of plots where precise soil measurements were taken in 2012. The results show that the effect of systematic land titles is still significantly positive.

[table 2 here]

The results for the effect of land titles on agricultural intensity in Table 3 support the findings from the productivity models. Possession of systematic land titles significantly increases both input expenditure, column (1) and (2), and labor input, column (3). In column (4) the regression estimates for migrant households indeed show similar coefficient magnitude, but due to lower number observations also bigger standard errors. The regression detects also a significant effect of sporadic land titles. Migrant households are often thought to be rather labor-constrained due to smaller family networks, that the land title effect is more pronounced in input expenditures for migrants is hence in line with expectations. Since we expect that parts of the effect of land titles on productivity run via higher input expenditures and labor input, we add the intensity proxies to the plot-level productivity model in column (5) and (6). As expected we observe that they have a highly significant positive impact on productivity. We further observe that the coefficient of systematic land titles decreases in magnitude compared to the plot-level model without intensity proxies in column (5) in Table 2. However, the decline is small indicating that there are other unobserved transmission channels. Concerning additional covariates in our models the results show that all variables have the expected sign based on agronomic theory such as the effects of tree age and plot size on productivity and socio-economic theory such as the effect of wealth on input expenditures.

[table 3 here]

Land titles at forest margins. Our results show the importance of land titles for agricultural intensity and productivity. If land titles can induce an intensification which also spares forest from conversion depends, however, also on their spatial distribution. If land titles are not prevalent at forest margins, farmers have less incentives to intensify and may increase output by expanding into forest land. We test hence in the second hypothesis whether the prevalence of land titles is lower at forest margins. The Indonesian government claimed areas with large coherent forest as state property, ignoring possible customary claims by autochthonous farmers. Significant parts of the classification of state forest took place in the 1980s (Indrarto et al. 2012), we take hence 1990 as reference point, to assess if household are located in an area which had been classified as state forest in 1990, and to determine the impacts of this spatial variable on procurement of land titles.

Map 3 in Figure 1 depicts the different land-use classifications and the radii around the households which were used as reference area to calculate the share of forest. Table 4 in columns (1) to (4) includes probit model estimates with the share of forest area in 1990 as independent variable. Being located in former forest areas decreases the likelihood of having a systematic land

title by 13% to 18% significantly across all three radii. We do not find consistent significant effects of the migration status and wealth index. Older plots are as expected significantly more likely to be titled and plots farer away from road are less likely to be titled. We control with this variable that the effect of share of forested area on land titles is not based on the remoteness of the plots.
Since land titles increase agricultural productivity, but are less likely at forest margins, we expect that farmers offset the lower productivity by increasing farm size. To test our hypothesis 3 we hence regress the forest share on farm size in 2015. The regression estimates on farm size in Table 4, columns (5) to (8) confirm that farms established in former forest margins are significantly bigger than farms established in longer settled agricultural zones. Although other transmission pathways are possible, this inclines that the institutional setting and land abundance at the forest frontiers incentivized extensive agricultural system, increasing the pressure on forest land.

[table 4 here]

Discussion. Our study demonstrates that secure property rights significantly enhance agricultural intensity and productivity. While the focus in current literature is on property rights on forest land and the effects on deforestation (Robinson et al. 2014), we study the potential of land titles on agricultural land to induce an agricultural intensification which could in the end spare forest from agricultural conversion without affecting farmer livelihoods negatively. The effectiveness of this process depends, however, on spatial patterns of intensification. When farmers have lower incentives to intensify their production, in order to increase agricultural output, they can expand their land area by encroaching surrounding forestland. We argue, therefore, that it is particularly important to encourage famers at the forest margins to intensify production and discourage extensive production systems, by providing secure property rights protection.

Similar to many other developing countries (Agrawal et al. 2008), Indonesia considers forest land as a state property. Forest governance in Indonesia, however, is constrained due to limited capacity to monitor, unclear spatial planning, and overlaps of customary and state land claims (Indrarto et al. 2012), leading to deforestation. While the encroachers are rarely met with pecuniary actions, the deforested land is often not eligible for formal land titling. Using historic remote sensing data we show that farmers located in former forested areas are less likely to have land titles for their plots. The inhibited land titling can hence push the agricultural practices from increasing agricultural intensity to expand land at forest margins. Indeed, farms at the former forest margins are bigger in size. The results imply that the institutional overlap of customary land claims of farmers and government claims over forest can be detrimental for further forest protection, losing out the potential forest land sparing of agricultural intensification. Sporadic land titles which are not restricted by forest extension in 1990 seem also not be a suitable remedy, since they show no significant effects on agricultural productivity. This could be because sporadic land titles, compared to systematic titles, have a lower value in the land market which can be due to the lower credit access but also because of the low recognition beyond the local level (see Figure 3) The contribution of this paper showing the potential of land titles to induce agricultural intensification and the reason why this potential is rarely harnessed through combining different type of data and different strand of literature is hardly discussed in current literature.

[figure 3 here]

There are some possible issues to be addressed concerning the results. First, we do not show that being located at former forest margins has a negative impact directly on land productivity and land investment. The reason for not showing a direct effect is that encroaching plots from forest is not only affecting land productivity through land titles, but also through other factors such as for example differences in soil quality (Guillaume et al. 2016). Second, if agricultural rents increase through higher productivity, further forest conversion is more attractive for agents outside the local agricultural sector, which could induce migration into rural areas. While this in general a valid argument, a recent study shows for the specific context of the research region that mostly autochthonous people involve in deforestation, but migrants rarely obtain land through direct deforestation or buy encroached land (Krishna et al. 2014). Finally, if increasing agricultural intensity leads to capital substituting labor, the freed labor could be used for further deforestation. Fertilizer application is, however, a classic example of an input which is capital-intensive and labor-intensive, while increasing land productivity. Herbicide application is a substitute for manual weeding; the amount of labor saved is, however, considerable small. The median of hours spent per year on chemical weeding is 9 hours and for manual weeding 19 hours in our data. Moreover, the results reported in Table 3 for labor input show that land titles increase labor intensity per hectare.

Researchers and policy makers often discuss two contrasting conservation options: extensive farming systems with a higher level of ecological functions but also higher land demand and intensive farming systems with decreased ecological functions and lower land demand (Green et al. 2005; Rudel et al. 2009; Tscharntke et al. 2012). The selection of one of these options is highly context-specific since their effects depend on the differences of the land uses in land productivity and ecosystem functions. Different settings and different valuations of ecosystem functions can hence produce a wide range of optimal land allocations and degrees of intensity (Steffan-Dewenter et al. 2007). Yet, in certain settings increases in agriculture intensity with complementary strategies such as stricter forest protection and natural resource management could be the best viable option that enhances agricultural development and reduces environment costs. The contrasting option of extensive agricultural systems is often characterized by low land productivity incentivizing further land expansion to satisfy demand and secure farmers' livelihood. Moreover, extensive agricultural system might not be able to sustain the same level of ecosystem functions as provided by forest (Clough et al. 2016). In particular the soil and biomass carbon storage of forests are crucial to mitigate climate change (Burney et al. 2010). Some ecosystem functions (e.g. conservation of mega fauna) can also be only maintained in large undisturbed natural environments such as forests (Phalan et al. 2011b).

This paper shows that addressing the existing inconsistencies between customary and legal land institutions at the forest margins could be an important factor to induce land-sparing agricultural intensification. This should not imply that farmers who involve in deforestation should be granted land titles in an easy and direct manner. Nevertheless, a system that does not actively impede smallholders' deforestation activities and simultaneously excludes them from the legal property systems maybe the worst option for forest protection and agricultural development. Besides increasing farmer's access to land titles over non-forest land, policy responses could include a better recognition of farmers' customary land rights and simultaneously protecting forest land without recognized claims. Sumatra already experienced the loss of most lowland forest before land titles coming to place and the question whether titles could have slowed down deforestation is rather hypothetical. However, a deeper understanding on the relationship could help protect forest cover in the current and future deforestation hotspots with similar institutional settings.

Methods

Study area. The empirical research was carried out in the province of Jambi which is situated centrally on the island of Sumatra, Indonesia. Jambi covers a total land area of 5.1 million hectares, and exemplifies the global replacement of tropical forest for agricultural production. Over the last decades, forest cover declined in Jambi, from 48% in 1990 to 30% in 2013 (Drescher et al. 2016). No exact data is available on the extent state forest was affected. However, 43% of Jambi's total area was categorized as state forest around 2000 (Komarudin et al. 2008), it can be hence inferred that the majority of the newly appropriated agricultural land was obtained from state land. Cash crop trees like rubber (*Hevea brasiliensis*) and oil palm (*Elaeis guineensis*) dominate the local agriculture at present, with strong involvement of smallholder farmers. For example, more than 40% of the Indonesian oil palm planation area is cultivated by smallholders farmers (Euler et al. 2016).

Land property rights. In order to understand the effect of land property rights on land-sparing agricultural intensification, we gathered detailed information on the local institutions. Land tenure in Indonesia can be differentiated into customary tenure, public tenure and formal private tenure. Historically, customary tenure regulated how land and its resources were accessed on the Indonesian archipelago before the Dutch colonization (Fitzpatrick 1997). Even after obtaining independence from the colonial rule, customary land tenure was acknowledged in the legal framework over land resources (Basic Agrarian Law; UUPA 5/1960), however, regional and national interest had strict priority. Although customary land claims exist, most of Indonesia's land territory is officially state property. During the New Order regime, the Indonesian government proclaimed exclusive property rights over the country's forest land with the Basic Forestry Provisions (No.5/1967). Through land use consensus of 1982 (Forest Land Use Consensus Plan or *Tata Guna Hutan Kesepakatan*) , about 74% of Indonesia's total land mass was classified as forest land, and was taken under the jurisdiction of the former Ministry of Forestry (Indrarto et al. 2012). Private property rights on forest land were restricted in most regions (Resosudarmo et al. 2014). In the absence of land titles, deforested land is undervalued in the market in the research region, making deforestation for speculative reasons unlikely (Krishna et al. 2014). Case studies, however, show that autochthonous communities have been encroaching forest land for agricultural use, especially when having customary claims (Angelsen 1995; Gaveau et al. 2009).

The land title that is nationally acknowledged in Indonesia is commonly called *systematic* title. *Systematic* means that registration is conducted for a certain number of adjacent plots. Farmers can acquire systematic land titles mainly through two ways: by directly approaching the National Land Agency or through subsidized national registration programs. Our data show mean expense to obtain subsidized systematic titles is at about 0.7 million IDR per hectare, mean expense for private applications was at 4.5 million IDR per hectare. Besides s*ystematic* titles, another form of land titles called *sporadic* titles is prevalent in rural Indonesia. Officially, sporadic titles were merely an interim document necessary for obtaining a systematic land title. On the local level it developed, however, into an own small-scale land title acknowledged by the local administration (Kunz et al. 2016). These documents are easier to procure with lower application costs at 0.126 million IDR. However, sporadic land titles are not recognized by the national government as a proper land title and the possession of this document only allow limited formal credit access when used as collateral.

Household survey data. The household survey data were collected in two rounds, 2012 and 2015, as part of a larger interdisciplinary research project. Sampling was based on a multi-stage framework. All five regencies in Jambi province located in the tropical lowland rainforest area were selected purposively, since deforestation was rampant in this region during the last 25 years. A more detailed description of the sampling framework is provided by Drescher et al. (Drescher et al. 2016) On total the survey covered 45 villages, from which the data from 28 randomly selected autochthonous villages and 5 purposively selected autochthonous villages were used for analysis. The purposively selection of 5 villages was due to interdisciplinary overlaps in the research project. In the selected villages, 6 to 24 farm-households were randomly selected. The sample size was adjusted to villages' differing population numbers to mitigate possible sampling bias. The sample includes 473 farm-households. The attrition rate between the two waves of surveys was low at 6%. Only 1% was due to refusals.

Rubber is the most prominent crop in the autochthonous villages of Jambi, it was hence possible to construct an extensive panel at the plot level with the same crop consistently planted over time. The rubber plots were matched based on tree age, acquisition pathway, distance from residence and roads and plot size. Out of the 690 rubber plots surveyed in 2015, about 476 were matched with the data from the previous wave (2012). 94 plots were not matched, since they were only acquired after the survey in 2012. 120 plots were not matched since farmers did not consistently report their plots or a clear identification was not possible. Out of the 476 plots for which land title status and acquisition pathway was recorded, detailed input and output data are available for 258 plots in both 2012 and 2015, which were productive in both waves.

In 2012 for a randomly selected subsample of farmers soil samples were collected in representative areas of the plantations, resulting in soil data for 92 rubber plots. Soil samples were collected with a 3.8 cm diameter ring from 0 to 5 cm depth. The collected soil was air-dried, sieved, oven-dried and weighed to calculate bulk density. Carbon and nitrogen contents of ground soil were measured using an elemental analyser (Guillaume et al. 2016). The approach to add precise soil quality measure to address the otherwise unobserved heterogeneity of plots is seldom used in the current literature (Bellemare 2013).

Remote sensing data. Historical land-use maps of the study area from year 1990 were obtained using Landsat satellite imagery. A spatial resolution of 30x30 m for geometric correction of the image tiles and rasterizing of the classified map was employed. The land-use classification is based on an automatic classification and an additional qualitative, visual interpretation to reduce miss-classifications. To check robustness, 200 ground control points were used in Jambi province, which showed an overall accuracy of 80%. We then combined the GPS coordinates of farmers' residence with the historic land-use map. To obtain a metric showing the extent of forest around a households' residence, we use radii over 2 km, 5 km and 10 km around households' residence as reference areas. In the final step, the share of forested area of the total area based on the land-use classification in 1990 within the different radii is calculated. Out of the 902 plots 83% were identified for being inside the radii of 10km. About 73% are in the 5km radius and 48% in the 2km radius. Analysis was adjusted based on these exclusion criteria.

Panel regression models. We use panel data at the plot level and the household level to estimate the effect of land titles on agricultural intensity and productivity. Micro-economic studies that examine land tilting often struggle to address the endogeneity biases (Brasselle et al. 2002). Omitted variable biases due to unobserved variables like soil quality and household characteristics are often thought to be likely for the effect of land titles. The potential use of instrumental variables to address this problem is often constrained due to the lack of appropriate instruments that could qualify the exclusion restriction (Bellemare 2013; Grimm & Klasen 2015; Fenske 2011). In this study, we opted for a multiple strategy approach to address the possible endogeneity bias while estimating the effects of land titles. One, we estimate fixed effects models which control for the time-invariant unobserved heterogeneity. A Hausman test is used to assess if the fixed effects estimates are substantially different from the random effects estimates, which albeit being more efficient are inconsistent when time-invariant unobserved heterogeneity is present. Two, we include a wide range of control variables that were seldom included in the existing literature. In particular, we control for soil quality as this factor could enhance the probability of demanding land titles as well as land productivity. Three, we examine the effects of land titles by splitting the sample into migrants and non-migrants, since we expect heterogeneous impacts of land titling across these two groups. Migrants have limited access to customary land, their perceived tenure security over land without titles is hence expected to be lower compared to autochthonous farmers. This would increase the assurance effect of land titles. Secondly, land titles may be more important for the migrants as collateral to secure formal credits, as their access family and community networks is limited (Okten & Osili 2004). This may increase the collateralization effect of land titles for migrants. If land titles increase intensity and productivity through the channels of tenure security and credit access, we expect a higher impact magnitude for migrants. If productive land would be rather titled, we would expect that migrants with lower tenure security to be rather inclined to title also less productive land, which would lead to smaller coefficient magnitudes for migrants. Reverse causality could be present in the case of strategic land investments activities to obtain a title for productive land; however in the institutional setting of the paper, land titling is not depending on productive or unproductive usage of land.

In the first step we estimate fixed and random effects models on land productivity at household level:

Eq. (1): $$\ln(PR_{it}) = \beta_0 + \beta_1\, SLT_{it} + \beta_2\, X_{it} + \mu_i + \varepsilon_{it} \qquad \text{(household level)}$$

where PR_{it} is the total rubber yield per year per hectare of household *i* at time *t*. SLT_{it} is the share of plantation land with systematic land title, the value 1 being all land titled. The matrix X_{it} includes the share of land with sporadic land title and additional farm and household characteristics such as age, gender and education of household head, a wealth index and farm size. The wealth index is derived based on the households' assets such as ownership of television, different kind of vehicles, refrigerator and washing machine. A principal components analysis was used to determine the weights for a general index of the assets (Filmer & Pritchett 2001). μ_i is the unobserved time-invariant heterogeneity of the model, while ε_{it} is the iid error term. We then estimate again fixed and random effects models on land productivity but at plot level:

Eq. (2): $$\ln(PR_{pit}) = \beta_0 + \beta_1\, LT_{pit} + \beta_2\, X_{it} + \beta_3\, S_{pit} + \mu_i + \varepsilon_{pit} \qquad \text{(plot level)}$$

where PR_{pit} is the rubber yield per year per hectare on plot p of household i at time *t*. LT_{pit} is a binary variable taking the value 1 if the plot is titled. S_{pit} includes additional plot characteristics such as tree age, distances and managing practices. While Eq. (2), the disaggregated plot-level model, allows to control for plot characteristics, Eq. (1) measures besides the assurance effect of land titles on the plot level additional household-level effects of land titles such as enhanced credit access. In the sampling framework villages are the primary sampling unit and households are likely to be similar in the same village. We hence cluster heteroskedastic-robust standard errors at the village-level. Clustering at the highest sampling level adjusts for the nested multi-level clustering of plots, households and villages (Cameron et al. 2011; Pepper 2002).

In the second step, to further support the findings from the land productivity models, we examine the effect of land titles on land investment. We use two different outcome variables, total expenditures of applied fertilizer and pesticide per hectare and labor input measured in working hours per hectare. There can be other unobserved impact pathways of land titles on land productivity, like seed quality, more efficient allocation of land or the usage of more skilled labor. Still, a positive effect would further support the robustness of the results. A random effects tobit model was applied to estimate the effect of land titles on input expenditures to accommodate for the censored nature of the outcome variable (Wooldridge 2002). For the labor input model we use a standard random effects model.

Eq. (3): $INV_{pit} = \beta_0 + \beta_1 \, LT_{pit} + \beta_2 \, X_{it} + \beta_3 \, S_{pit} + \mu_i + \varepsilon_{pit}$ (plot level)

Eq. (4): $\ln(LS)_{pit} = \beta_0 + \beta_1 \, LT_{pit} + \beta_2 \, X_{it} + \beta_3 \, S_{pit} + \mu_i + \varepsilon_{pit}$ (plot level)

where INV_{pit} is total expenditures on applied fertilizers and pesticides per hectare per year by household i at time t on plot p. LS_{pit} is labor input of both family work and wage work measured in hours. We include further INV_{pit} and LS_{pit} into the productivity model Eq. (2) to observe if the effect magnitude of land titles is diminishing.

Spatial regression models. To estimate the marginal effect of households' proximity to the forest margins in 1990 on the prevalence of land titles, we use the following probit model specification:

Eq. (5): $P(LT_{ip} = 1) = \beta_0 + \beta_1 \, F_i + \beta_2 \, Z_{ip} + \beta_3 \, Z_i + \varepsilon_{ip}$ (plot level)

where LT_{ip} is a dummy indicating if the plot is titled in 2015. F_i is the share of forest land in 1990 based on the remote sensing data around a household residence at center within a circle with 2 km, 5 km or 10 km radii. The variable is ranging from 0 (no forest in the circle in 1990) to 1 (completely forested in 1990). For the models where the 2 km radius is used, plots away from the residence place by more than 2 km are excluded, same holds for the 5 km and the 10 km radius. Further robustness check was performed by replacing F_i with a binary variable indicating if the plot was directly encroached from forest versus being purchased for a sub-sample of plots with available information. Z_{ip} and Z_i include further controls on plot and household level. We included both oil palm and rubber plots in the estimation, although the number of oil palm plots is small compared to rubber plots. All models were tested for the presence of spatial autocorrelation using Moran's I and Anselin's and Florax's Lagrange Multiplier tests (Baltagi 2003). These tests did not reject the assumption of zero spatial autocorrelation.

If land titles lead to increased agricultural intensity but land titles are less likely at the forest margin we expect that farms are bigger at the forest margins. We further test hence our hypothesis if farms established in areas with forest in 1990 are bigger compared to farms in longer-settled agricultural zones. Since Moran's I and Anselin's and Florax's Lagrange Multiplier tests did reject the assumption of zero spatial autocorrelation, we defined a spatial lag model with total farm size in hectares in 2015 as outcome variable to account for the data structure:

Eq.(6): $\ln(FS_i) = \rho W \ln(FS_i) + \beta_0 + \beta_1 F_i + \beta_3 V_i + \varepsilon_i$ (household level)

where FS_i is the total farm size owned by the household i in hectares. V_i includes further controls on household level. W is a N × N spatial weights matrix (N=Number of households) based on the inverse Euclidian distance between the households' residence. The parameter ρ measures the degree of spatial correlation. We set a distance threshold at the minimum distance for every producer to have at least one neighbor. Since with increasing number of neighbors the individual weight of one neighbor should be adjusted, the weights matrix is row standardized, such that for each i, $\sum_j w_{ij} = 1$ (Baltagi 2003). The so-called spatial lag $\rho W \ln(FS_i)$ can be hence interpreted as a weighted average of the farm sizes of neighboring households.

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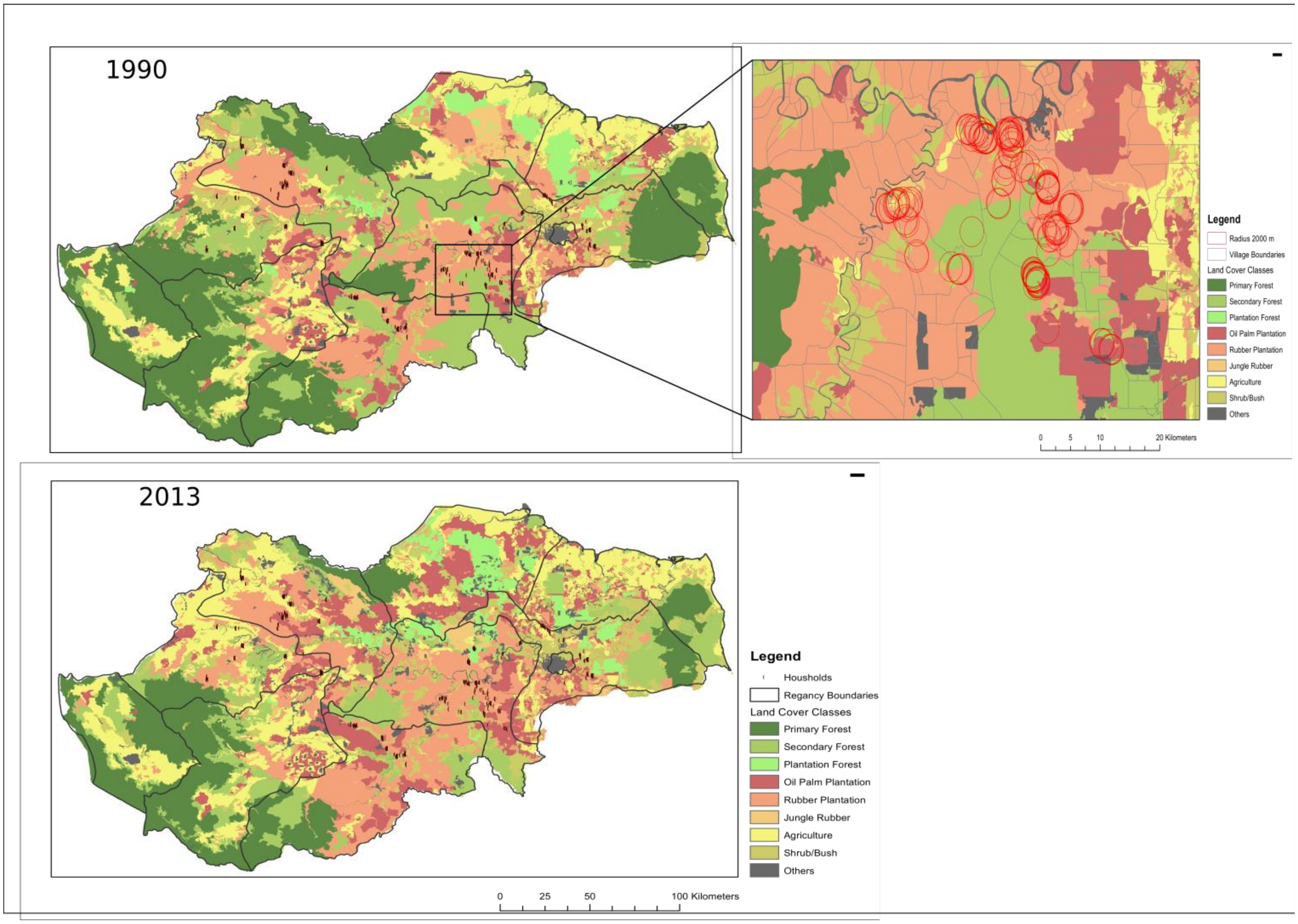
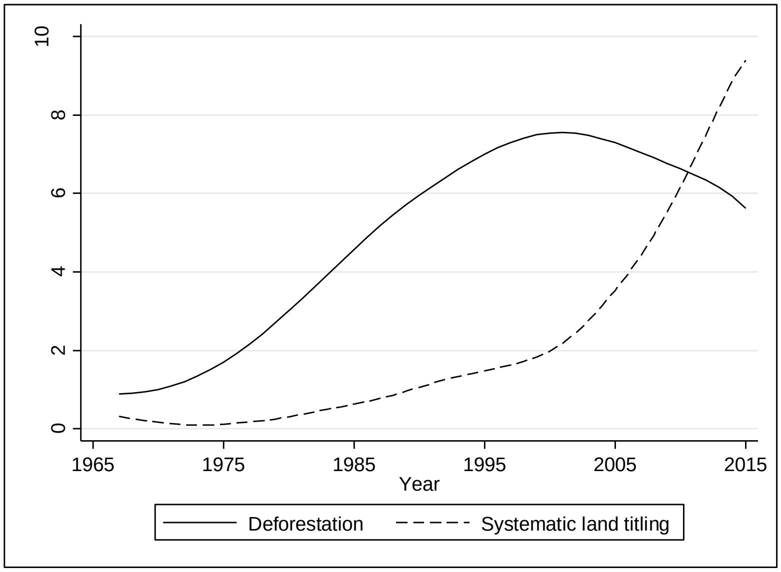
FIGURES

Figure 1: Map of land uses in Jambi Province in 1990 and 2013



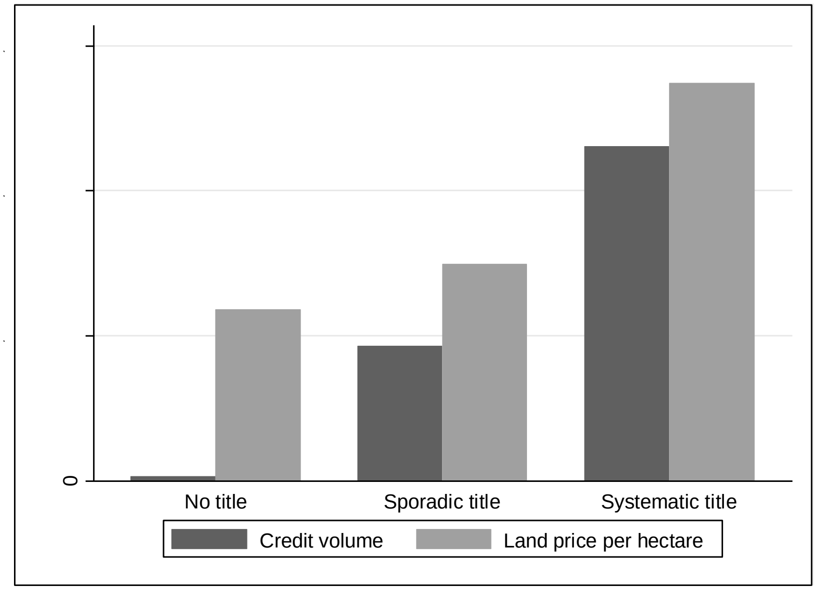
Notes: Map 1 & 2 depict Jambi Province in 1990 and 2013. Land-use classification is based on the automatic classification. Map 3 is from Harapan Rainforest region in 1990, including eight sample villages. The red circles indicate the 2km radii around sample households' residence, which were used to calculate the share of forest land.

Figure 2: Land titling and deforestation activities by farmers over time



Notes: Based on farmer recall data from 902 plots. Graph displays number of deforestation and land titling activities for each year, derived employing locally-weighted time series smoothing. *Source*: Household survey data .

Figure 3: Credit volume and land price for different title status



Notes: Mean values are reported. Number of observations for no titles, sporadic and systematic title are for credit volume 522, 472 and 545 respectively; for land prices 496, 547 and 581 respectively.

TABLES

Table 1: Summary statistics

Surveys	2012			2015		
	Number of obs.	Mean	Std. deviation	Number of obs.	Mean	Std. deviation
Plot survey (Rubber plantations)						
Output per year per hectare (kg)	643	1144.683	1083.612	466	1489.196	1086.691
Material input per year per hectare (000 IDR)	643	322.521	672.179	466	141.655	419.497
Labor input per year per hectare (hours)	643	692.655	630.828	466	1057.674	1122.030
Systematic land title (=1)	645	0.074		690	0.100	
Sporadic land title (=1)	645	0.180		690	0.222	
Plot size (ha)	645	2.242	1.948	690	2.084	1.809
Age of trees (years)	645	14.763	10.647	689	17.026	10.479
Employing sharecropping tenants (=1)	645	0.143		690	0.223	
Distance from residence (km)	645	4.802	8.226	689	4.902	12.791
Distance from road (km)	645	1.170	1.757	689	0.885	1.410
Household survey						
Age of household head (years)	471	44.996	12.213	473	47.072	11.408
Female headed household (=1)	471	0.059		473	0.080	
Education of household head (years in school)	471	7.476	3.620	473	7.150	3.742
Migrated to village (=1)	471	0.255		473	0.256	
Number of adults in household	471	2.975	1.243	473	2.987	1.190
Total farm size (ha)	471	4.200	4.642	473	4.134	4.615
Productive rubber size (ha)	406	2.684	3.037	406	2.968	3.167
Oil palm farmer (=1)	471	0.285		473	0.309	
Rubber farmer (=1)	471	0.866		473	0.860	
Rubber farmer using fertilizer/pesticide (=1)	408	0.519		406	0.345	
Oil palm farmer using fertilizer/pesticide (=1)	134	0.819		146	0.818	
Formal credit (=1)	471	0.166		473	0.288	
Informal credit (=1)	471	0.193		473	0.173	
Own business (=1)	471	0.200		473	0.277	
Share of land with systematic land title	471	0.060		473	0.089	
Share of land with sporadic land title	471	0.167		473	0.189	
Village survey						
Number of households per village				34	735.118	973.537
Share of Melayu households				34	0.696	0.308
Conflicts over land ownership (=1)						
1 Year ago				34	0.235	
5 Years ago				34	0.242	
10 Years ago				33	0.206	

Notes: All observations for unbalanced data. In 2015 plot level output and input data was taken for a random subsample of plots. The difference between output in 2012 and 2015 is due to the increasing age of trees and changing labor input. Due to a price drop of about 50% for rubber between 2012 and 2015, farmers invested considerable more labor into their rubber plantations in 2015 to counteract the price drop with a higher production. Model estimations in Table 3 column (6) show that after controlling for all these factors that there is no significant difference between 2012 and 2015 anymore.

Table 2: Agricultural productivity and land titles

	Household-level models				Plot-level models				Plot-level models with soil controls	
Log of yield per hectare	(1) Fixed effects	(2) Random effects: Full sample	(3) Random effects: Migrants	(4) Random effects: Non-migrants	(5) Fixed effects	(6) Random effects: Full sample	(7) Random effects: Migrants	(8) Random effects: Non-Migrants	(9) Random effects: Perceived soil quality	(10) OLS: Soil quality measurement
Share of land with govn. title	0.352	0.351***	0.586***	0.328***	0.025	0.152**	0.370***	0.095	0.182***	0.697**
	(0.298)	(0.085)	(0.107)	(0.098)	(0.269)	(0.063)	(0.098)	(0.070)	(0.071)	(0.265)
Share of land with sporadic title	-0.098	0.019	0.111	-0.038	0.070	-0.017	0.039	-0.070	-0.036	-0.131
	(0.199)	(0.071)	(0.090)	(0.123)	(0.203)	(0.071)	(0.073)	(0.106)	(0.079)	(0.254)
Total farm size (ha)	0.049	-0.025	-0.007	-0.020	0.014	-0.020*	0.021	-0.023*	-0.018	-0.123**
	(0.033)	(0.022)	(0.038)	(0.026)	(0.029)	(0.012)	(0.021)	(0.013)	(0.016)	(0.054)
Size of rubber area (ha)	-0.064***	-0.030*	-0.006	-0.040**	-0.138***	-0.086***	-0.132***	-0.080***	-0.088***	-0.097*
	(0.023)	(0.016)	(0.028)	(0.018)	(0.049)	(0.017)	(0.029)	(0.018)	(0.022)	(0.049)
Wealth index (quintiles)	-0.006	0.011	-0.023	0.021	0.015	0.031**	0.021	0.042*	0.034*	0.134***
	(0.040)	(0.017)	(0.031)	(0.022)	(0.038)	(0.015)	(0.021)	(0.022)	(0.019)	(0.049)
Number of adults	0.036	-0.007	0.128	-0.062	-0.003	0.019	-0.014	0.021	0.005	0.011
	(0.044)	(0.065)	(0.095)	(0.081)	(0.046)	(0.021)	(0.029)	(0.024)	(0.022)	(0.059)
Own business (=1)	0.033	0.019	0.001	0.024	0.026	-0.045	0.126	-0.118*	-0.026	-0.351*
	(0.099)	(0.024)	(0.041)	(0.029)	(0.096)	(0.056)	(0.085)	(0.070)	(0.065)	(0.195)
Wave 2012 (=1)	-0.107**	-0.075	-0.126	-0.062	-0.138***	-0.114**	-0.080	-0.132***	-0.117**	
	(0.051)	(0.049)	(0.136)	(0.050)	(0.050)	(0.046)	(0.100)	(0.049)	(0.048)	
Age of household head (years)		-0.001	0.002	-0.002		-2.E-4	0.004	-0.003	-0.001	-0.024***
		(0.003)	(0.004)	(0.003)		(0.003)	(0.005)	(0.003)	(0.003)	(0.009)
Female headed household (=1)		-0.227**	-0.480***	-0.141		-0.196*	-0.472***	-0.056	-0.192	0.055
		(0.113)	(0.140)	(0.130)		(0.105)	(0.178)	(0.098)	(0.126)	(0.362)
Education (years of schooling)		0.010	0.004	0.012		0.017*	0.008	0.021**	0.016*	0.015
		(0.010)	(0.012)	(0.011)		(0.009)	(0.011)	(0.010)	(0.010)	(0.020)
Farm size squared (ha)		0.001***	0.000	0.001**		0.001***	7.E-5	0.001***	0.001**	0.008***
		(0.001)	(0.001)	(0.001)		(4.E-4)	(0.001)	(5.E-4)	(0.001)	(0.003)
Non-random village (=1)		-0.165**	-0.215***	-0.126		-0.191***	-0.227**	-0.137**	-0.167**	
		(0.068)	(0.072)	(0.078)		(0.067)	(0.099)	(0.056)	(0.066)	
Migrant (=1)		0.056				0.040			0.019	-0.115
		(0.065)				(0.066)			(0.067)	(0.200)
Age of trees (years)						0.017*	0.028	0.013	0.023**	-0.004
						(0.009)	(0.017)	(0.010)	(0.009)	(0.038)
Age of trees (years squared)						-4.E-4*	-0.001	-3.E-4*	-0.001***	1.E-06
						(-2.E-4)	(0.000)	(-2.E-4)	(2.E-4)	(0.001)
Employing sharecroppers (=1)						0.118*	0.171	0.098	0.077	0.360**
						(0.064)	(0.110)	(0.069)	(0.062)	(0.178)
Distance from residence (km)						-0.002	-0.025***	0.003	-0.003	-0.012
						(0.003)	(0.008)	(0.004)	(0.006)	(0.013)
Distance from road (km)						0.005	0.055**	-0.007	0.009	0.013
						(0.016)	(0.026)	(0.019)	(0.017)	(0.066)
Altitude of residence (m)									-2.E-4	
									(0.001)	
Medium fertile soils (=1)									0.012	
(*Ref.=Low fertile)*									(0.122)	
Highly fertile soils (=1)									-0.042	
(*Ref.=Low fertile)*									(0.112)	

	Household-level models				Plot-level models				Plot-level models with soil controls	
Log of yield per hectare	(1) Fixed effects	(2) Random effects: Full sample	(3) Random effects: Migrants	(4) Random effects: Non-migrants	(5) Fixed effects	(6) Random effects: Full sample	(7) Random effects: Migrants	(8) Random effects: Non-Migrants	(9) Random effects: Perceived soil quality	(10) OLS: Soil quality measurement
Bulk density										-0.600
										(0.456)
Carbon content										-0.088
										(0.099)
Carbon content (squared)										0.003
										(0.003)
C/N ratio										0.032
										(0.037)
Constant	7.105***	7.233***	7.188***	7.279***	7.494***	7.126***	6.967***	7.220***	7.163***	8.760***
	(0.211)	(0.150)	(0.244)	(0.171)	(0.234)	(0.199)	(0.347)	(0.237)	(0.256)	(0.852)
F & chi2	1.986***	297.453***	232.371***	123.891***	1.89**	312.312***	2332.550***	550.142***	482.379***	3.634***
Number of observations	564	665	174	491	516	851	231	620	741	92

Notes: Robust and clustered standard errors in parentheses. Hausman test-statistic for household-level models: chi2= 2.24, (p-value = 0.945). Hausman test-statistic for plot-level models: chi2=4.67, (p-value = 0.792). The share of land titled is 1 if plot is titled and 0 if not on the plot-level. The percentage effect of a dummy variable in a semi-logarithmic regression equation can be calculated by $\hat{p}=100(\exp(\hat{c}-0.5\hat{V}(\hat{c}))-1)$ where $\hat{c}$ is the estimated coefficient and $\hat{V}(\hat{c})$ the variance of the estimate (van Garderen & Shah 2002). * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.

Table 3: Agricultural intensity and land titles

	Plot-level models					
	(1) Random effects tobit: Material input (‘000 IDR) Full sample	(2) Random effects tobit: Material input (‘000 IDR): Migrants	(3) Random effects: Log of labor input (hours) Full sample	(4) Random effects: Log of labor input (hours): Migrants	(5) Random effects: Log of yield per hectare (kg): Full Sample	(6) Random effects: Log of yield per hectare (kg): Full Sample
Systematic land title (=1)	114.148**	204.127**	0.125*	0.122	0.141**	0.145**
	(48.649)	(97.340)	(0.070)	(0.104)	(0.062)	(0.062)
Sporadic land title (=1)	-9.365	26.157	0.055	0.198*	-0.015	-0.026
	(36.395)	(61.016)	(0.056)	(0.105)	(0.073)	(0.062)
Total farm size (ha)	14.887**	23.495	-0.035*	0.006	-0.022**	-0.002
	(7.195)	(17.456)	(0.018)	(0.035)	(0.011)	(0.010)
Farm size squared (ha)	-0.241	-0.285	0.001*	-0.001	0.001***	0.001**
	(0.231)	(0.659)	(0.001)	(0.001)	(0.000)	(0.000)
Wealth index (quintiles)	38.959***	9.467	-0.007	-0.011	0.029*	0.027*
	(11.018)	(22.878)	(0.023)	(0.042)	(0.015)	(0.014)
Own business (=1)	-11.332	102.631	0.023	0.073	-0.047	-0.068
	(33.826)	(65.527)	(0.056)	(0.117)	(0.054)	(0.057)
Number of adults	-4.377	-0.566	0.031	0.045	0.019	0.007
	(12.091)	(27.882)	(0.028)	(0.053)	(0.020)	(0.018)
Age of household head (years)	-0.414	1.233	0.003	0.004	-0.000	-0.002
	(1.451)	(3.207)	(0.004)	(0.007)	(0.003)	(0.002)
Female headed household (=1)	-181.132**	-324.205	-0.246	-0.707*	-0.186*	-0.068
	(76.972)	(225.738)	(0.197)	(0.406)	(0.103)	(0.092)
Education (years of schooling)	2.652	26.751***	-0.011	-0.022	0.017*	0.020**
	(4.375)	(9.153)	(0.010)	(0.021)	(0.009)	(0.009)
Migrant (=1)	113.687***		-0.061		0.027	0.060
	(32.706)		(0.056)		(0.067)	(0.064)
Plot size (ha)	-7.491	-14.137	-0.104***	-0.063	-0.084***	-0.053***
	(9.024)	(21.056)	(0.021)	(0.038)	(0.017)	(0.014)
Age of trees (years)	-32.052***	-33.473***	-0.014	-0.028	0.020**	0.011
	(5.586)	(10.745)	(0.009)	(0.018)	(0.010)	(0.009)
Age of trees (years squared)	0.542***	0.560**	0.000	0.001	-0.000*	-0.000
	(0.123)	(0.235)	(0.000)	(0.000)	(0.000)	(0.000)
Plot producitve (=1)	191.446***	392.696***	3.393***	3.417***		
	(45.729)	(91.030)	(0.127)	(0.211)		
Employing sharecroppers (=1)	-62.861	-45.360	-0.077	-0.202	0.121**	0.136**
	(42.254)	(82.972)	(0.087)	(0.209)	(0.062)	(0.062)
Distance from residence (km)	-0.083	-0.308	0.002	-0.002	-0.001	-0.001
	(1.071)	(42.252)	(0.001)	(0.086)	(0.061)	(0.061)
Distance from road (km)	-20.854**	-2.569	0.029	0.074	0.005	0.002
	(9.577)	(21.924)	(0.024)	(0.054)	(0.016)	(0.014)
Wave 2012 (=1)	121.727***	178.450***	-0.170***	-0.222**	-0.124***	-0.071
	(27.185)	(51.524)	(0.060)	(0.102)	(0.046)	(0.047)
Non-random village (=1)	-67.208*	-261.588***	0.067	0.236**	-0.185***	-0.198***
	(36.386)	(67.676)	(0.080)	(0.114)	(0.065)	(0.058)
Material input (million IDR per ha)					0.000***	
					(0.000)	
Log of labor input (hours)						0.334***
						(0.034)
Constant			3.784***	3.487***	7.096***	4.873***
			(0.291)	(0.539)	(0.199)	(0.287)
chi2	139.889***	82.550***	4202.748***	482.462***	357.550***	1033.791***
Number of observations	1101	286	1015	269	850	846

Notes: For column (1) and (2), marginal effects for the unconditional expected value of y are reported with standard errors in parentheses. The outcome variables in columns (3) to (6) are logarithmized, hence only plots with positive labor input or production are included, respectively. Robust and clustered standard errors are reported in parentheses. * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.

Table 4: Forest cover, farm size and land titling

	Probit model at plot level					Spatial lag model at household level			
Systematic land title (=1)	(1) at 2 km radius	(2) at 5 km radius	(3) at 10 km radius	(4) All plots	*Log of total farm size (ha)*	(5) at 2 km radius	6) at 5 km radius	(7) at 10 km radius	(8) All plots
Share of forested area in 1990	-0.180***	-0.128**	-0.180***			0.268*	0.337**	0.453**	
	(0.057)	(0.050)	(0.065)			(0.146)	(0.155)	(0.198)	
Direct forest encorachment (=1)				-0.060**					0.258***
				(0.028)					(0.086)
Age of household head (years)	-0.002	-0.001	-0.001	-0.001		0.011**	0.011**	0.011**	0.009*
	(0.002)	(0.002)	(0.001)	(0.001)		(0.005)	(0.005)	(0.005)	(0.005)
Education (years of schooling)	0.004	1.E-4	-0.001	-0.003		0.038***	0.037***	0.037***	0.039***
	(0.005)	(0.004)	(0.004)	(0.004)		(0.012)	(0.012)	(0.012)	(0.012)
Migrant (=1)	-0.042	-0.020	0.009	-0.014		0.137	0.135	0.132	0.148
	(0.035)	(0.030)	(0.025)	(0.029)		(0.101)	(0.101)	(0.101)	(0.101)
Wealth Index (initial, quintiles)	0.003	0.009	0.018*	0.029**		0.142***	0.144***	0.146***	0.140***
	(0.015)	(0.012)	(0.010)	(0.011)		(0.034)	(0.034)	(0.034)	(0.034)
Non-random village (=1)	-0.030	-0.041	0.005	-0.008		0.169	0.144	0.105	0.177
	(0.054)	(0.048)	(0.044)	(0.051)		(0.137)	(0.136)	(0.137)	(0.136)
Share of migrants in village (%)	0.212***	0.197***	0.149**	0.184**		0.585***	0.596***	0.590***	0.578***
	(0.074)	(0.069)	(0.061)	(0.075)		(0.192)	(0.192)	(0.192)	(0.191)
Village wealth index (initial, quintiles)	-0.017	-0.004	-3.E-5	0.001		-0.105***	-0.107***	-0.111***	-0.104***
	(0.013)	(0.013)	(0.013)	(0.012)		(0.033)	(0.033)	(0.033)	(0.033)
Rubber plot (=1)	-0.059	-0.101***	-0.081***	-0.097***					
	(0.038)	(0.025)	(0.025)	(0.033)					
Duration of plot ownership (years)	0.005***	0.005***	0.004***	0.006***					
	(0.002)	(0.002)	(0.001)	(0.001)					
Distance from road (km)	-0.095**	-0.042**	-0.025**	-0.023**					
	(0.041)	(0.017)	(0.011)	(0.011)					
Age of household (years)						0.009*	0.009*	0.009*	0.008*
						(0.005)	(0.005)	(0.005)	(0.005)
Constant						-0.544*	-0.554*	-0.585*	-0.514*
						(0.301)	(0.300)	(0.301)	(0.298)
Regency dummies	*Yes*	*Yes*	*Yes*	*Yes*		*Yes*	*Yes*	*Yes*	*Yes*
Wald chi2 & Squared correlation	74.830***	95.021***	77.205***	75.126***		0.208	0.210	0.211	0.217
Number of observations	433	660	750	594		462	462	462	462

Notes: In models (1) to (4) average marginal effects are reported with clustered standard errors in parentheses. In models (5) to (8) the spatial lag coefficient p is ranging from 2.310 to 2.400 significant at $p \leq 0.01$. Standard errors are reported in parentheses. Goodness of fit measure is squared correlation for column (5) to (8). * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$.