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Labor savings in agriculture and inequality at different spatial scales: The expansion of oil palm in Indonesia

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Keywords: tree-planting; oil palm; intentions; mediation; Asia

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Labor savings in agriculture and inequality at different spatial scales: The expansion of oil palm in Indonesia

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1 Introduction

Increasing agricultural productivity contributes to economic growth (McArthur & McCord 2017), poverty reduction (Christiaensen & Martin 2018) and reduced global pressure on forest land (Angelsen 2010; Villoria 2019). Productivity gains in agriculture are to a large extent the result of technical innovation. Historically, technical innovation in agriculture was often characterized by a decreasing labor intensity and an increasing capital intensity (Gallardo & Sauer 2018). The diffusion and effects of such labor-saving innovations are well documented in high-income countries such as the United States. While cropland in the US declined from 140 to 130 million hectares between 1920 and 1995, the agricultural labor force decreased much more rapidly during the same time period, from 26% to less than 3%. In contrast, agricultural production increased multifold (Sunding & Zilberman 2001). In low-income countries, technical change in agriculture and its structural effects are less well documented. Economic conditions in developing countries are likely to differ from the historical trajectories of industrialized countries. Nevertheless, labor-saving innovations through improved farm management, mechanization and the use of herbicides are often seen as key to increase agricultural productivity in low-income countries (Pingali 2007; Adu-Baffour et al. 2018).

It is widely acknowledged that labor savings in agriculture can have heterogeneous effects on different strata of rural societies (Pingali 2007; Haggblade et al. 2017). Increasing labor productivity can directly boost profits at the farm level. At larger scales, such as village or district level, the potential effects are more ambiguous. Higher labor productivity can translate into higher incomes for farmers and agricultural laborers. Moreover, if sufficient income is generated in the agricultural sector, local demand effects can increase employment rates and wages across other sectors as well. Conversely, a labor-saving innovation will reduce labor demand if wages and output stay constant. A lower labor demand in agriculture, or an oversupply of labor in the non-agricultural sector through farm households reallocating saved labor time, can displace individuals with limited access to production factors or lower labor productivity. Empirical evidence on such mechanisms is scarce in low-income countries (Binswanger 1986; Benin 2015; Fischer et al. 2018). First, the spread of labor-saving innovations is often difficult to measure at larger scales. Second, the adoption of labor-saving innovations is often limited to large agricultural companies or a relatively small group of larger farms.

In this study, we address this research gap by using the expansion of the oil palm crop in Indonesia as an empirical example. Oil palm is a labor-saving innovation in the sense that it requires much less labor per unit of land than alternative crops, such as rubber or rice. The differences in labor intensity and productivity between oil palm and alternative cash crops were recently found to increase the living standard of oil palm adopters and agricultural laborers (Edwards 2017; Euler et al. 2017; Bou Dib et al. 2018; Kubitza & Gehrke 2018). Oil palm is interesting also because it is not only grown by large companies but also by smallholder farmers. We analyze the welfare and equity effects of oil palm as a labor-saving innovation in the small farm sector, addressing farm-level effects as well as implications at higher spatial scales, such as village and regency levels.[1]

The second contribution of our paper is to examine the role of land expansion and land scarcity in relation to labor-saving innovations. If the initial labor supply is limited, labor savings in agriculture allow for land expansion and increases in output. Land expansion could mitigate the initial drop in demand for agricultural labor per unit area. Furthermore, the growth in agricultural output and income could lead to growth also in other rural sectors due to local demand effects. Such aspects have rarely been considered in existing empiric research on the effects of labor-saving innovations. They may play an important role in the case of Indonesia, as oil palm cultivation is often linked to cropland expansion, deforestation and degradation of natural ecosystems (Butler & Laurance 2009; Koh et al. 2011; Carlson et al. 2018). We focus on two major options for farm households to reallocate the labor time saved through oil palm adoption, which may have differential welfare and equity effects. First, the saved time may be reallocated to the non-agricultural sector (Janvry & Sadoulet 2002; Minten & Barrett 2008). Second, more labor is employed on farm to cultivate additional land.[2]

The main research question addressed here is: How does a labor-saving innovation such as oil palm affect welfare and inequality in the rural labor market? Unlike the body of literature that exists on the long-run structural effects of labor-saving innovation in agriculture (Clark 1940; Lewis 1954; Lagakos & Waugh, 2013; Bustos et al. 2016; McArthur & McCord 2017), we focus on short- and medium-term impacts, namely those related to the displacement of labor. To address our research question we use local household data collected during several surveys as well as

[1] Oil palm is a cash crop that is traded internationally, so that increases in local output do not lead to falling prices. For non-tradable commodities, higher productivity would lower output prices leading to different effects (Collier & Dercon 2014).

[2] Increasing labor intensity per unit area is hardly an option, since labor requirements in oil palm cultivation are relatively fixed with the given production technology.

representative national survey data reaching from 2001 to 2015. In addition, we supplement our survey data with data derived from satellite imagery.

The rest of the paper is structured as follows: In section 2, we provide background information on the expansion of oil palm in Indonesia and the factor productivity in comparison to the main alternative crops in oil palm growing regions. In section 3, we present our conceptual framework on labor savings in agriculture and its linkages with agricultural employment, the non-agricultural sector and land expansion. In section 4, we present the different data sources used. In section 5, we discuss our estimation strategies. Results are presented in section 6. A discussion of the results is given in section 7, while section 8 concludes.

2 Background: Oil palm expansion in Indonesia

The global expansion of oil palm over the last few decades led to land-use changes rarely observed before in agricultural history in terms of speed and magnitude. Global production of palm oil rose by around 600% between 1990 and 2016 (Byerlee et al. 2017; US Department of Agriculture 2017). The main production growth was highly concentrated in only two countries - Indonesia and Malaysia. In Indonesia, now the largest producer worldwide, the oil palm area increased from 1 million hectares in 1990 to 12 million hectares in 2016 (Ministry of Agriculture 2017). Several factors led to this rapid increase: First, global consumption of vegetable oils increased by approximately 5% annually between 1993 and 2012. Second, non-food consumption of palm oil derivatives increased rapidly (Byerlee et al. 2017) and lastly, since the early 2000s, new policies in different parts of the world incentivized the use and production of biodiesel (OECD-FAO 2015). The high market demand contributed to the high financial profitability of palm oil production (Clough et al. 2016; Byerlee et al. 2017). Palm oil production thus became an essential part of Indonesia's economic development strategy. In particular during the new order regime oil palm expansion was combined with resettlement programs (the so-called transmigrant program) to balance the divergent population density of Java and the outer islands and to foster economic development in remote regions (Adhiati & Bobsien 2001).

While the literature emphasizes the detrimental effects of oil palm expansion on forest conservation and various ecosystem functions (Clough et al. 2016; Dislich et al. 2017), oil palm cultivation also sustains millions of livelihoods in Indonesia.[3] Smallholder farm households cultivate more than 40 percent of the national oil palm area (Gatto et al. 2015; Euler et al. 2016), and non-farm households in rural areas also derive substantial income from working on oil palm farms and plantations (Bou Dib et al. 2018). While the literature is rather critical on the potential welfare effects of large-scale plantations due to land conflicts and exploitative labor relations (Li 2015; Cramb & McCarthy 2016), recent research shows substantial positive effects of oil palm cultivation on farm households' living standards (Euler et al. 2017; Kubitza et al. 2018b).

Recent papers point out that the positive welfare effects are driven in parts by a lower labor intensity in oil palm cultivation compared to competing cash crops such as rubber and rice (Rist et al. 2010; Euler et al. 2017).[4] Table A1 illustrates the differences between oil palm and rubber based on plot data. Labor productivity is significantly higher in oil palm compared to rubber which is driven by a lower labor intensity. Male labor hours per year per hectare are 72.19% lower for oil palm compared to rubber cultivation. For women the labor hours decrease even more drastically by 91.79%. This difference can be explained by the considerable additional physical strength needed to harvest oil palm compared to rubber. We further observe that women receive lower wages in oil palm than men. Although we cannot calculate gender differences in agricultural productivity due to joint management of plots, we interpret the changes in working hours and wages as an indication that relative labor productivity is lower for women compared to men. Data from other studies also indicate that labor productivity in oil palm is significantly higher compared to rice cultivation due to lower labor intensity but also higher profits per hectare (Rist et al. 2010). Kubitza & Gehrke (2018) provide further evidence on labor savings introduced by oil palm adoption.

In line with the general critique on labor savings in agriculture, some research already underlined the potential inequality effects of oil palm expansion for landless population groups or other groups of society such as women (Obidzinski et al. 2012; Cramb & Curry 2012).

[3] Large-scale plantations of oil palm are frequently associated with deforestation. Smallholders are typically assumed to contribute to a lesser extent to deforestation. Yet, also smallholders are frequently found to encroach forest land to gain additional land for cultivation (Kubitza et al. 2018a).

[4] PODES data shows that rubber and rice are the main competing crops of oil palm at village level (Kubitza & Gehrke 2018).

3 Conceptual framework

In this section, we first outline the effects of a labor-saving innovation at the farm scale before assessing general welfare effects, focusing on interactions with agricultural employment, the non-agricultural sector and land expansion at different scales.[5] We assume that once the necessary infrastructure such as palm oil mills and roads are in place, the decision to adopt oil palm is mainly based on individual preferences and constraints of farm households.[6] Local evidence and recent literature shows that starting around 1995, oil palm was largely adopted by independent farmers (Euler et al. 2016).[7] We assume further that oil palm is only adopted if it increases income at household level.[8] Our data and other studies suggest that oil palm has a lower land productivity compared to competing crops such as rubber (Rist et al. 2010; Euler et al. 2017). We can hence assume that part of the income effect is running via reallocation of labor to additional land or to the non-agricultural sector (Krishna et al. 2017a).[9] We furthermore assume that labor can move freely between sectors, since non-agricultural employment opportunities are widely available in Indonesia and we assume that gender differences in access to the non-agricultural sector are not affected by oil palm expansion. We further do not assume that sectoral linkages between oil palm plantations and palm oil mills and other downstream industries play an essential role, since the labor demand generated by palm oil mills is limited to villages in close proximity.

3.1 Farm scale

We first develop a simplified income function at the farm household level (Goodwin & Holt 2002). Since farm households are the central decision-maker, our analysis focuses on smallholder production systems. We assume that these households maximize their income subject to the following constraint:

[5] We do not focus on the welfare effects of changes in prices for agricultural products. In 2015, consumption data for a representative sample of farm households (Kubitza et al. 2018b) showed that expenditures for palm oil amount only to 2% of total consumption expenditure.

[6] We assume that oil palm is not skill-biased (Acemoglu 2002). Although oil palm is more physically demanding, we assume that the level of general skills needed does not vary compared to other crops.

[7] Initially smallholder oil palm farmers were supported through specific government programs. However, after these programs were phased out, farmers started to establish and manage their plantations independently, in particular after the decline of the new order regime in 1998.

[8] We assume that the households maximize consumption and not leisure.

[9] We assume hence some elasticity of the final demand which is reasonable since palm oil is a highly demanded export product.

$$I + rX = AP\{T_{F,M}, T_{F,W}, X\} + w_M T_{OF,M} + w_W T_{OF,W}$$

where I is income, X is a vector of farm inputs and r the respective price vector. A refers to farm size in unit areas. The revenue is generated according to the production function P per unit area using labor input T and other farm inputs X. T_F presents labor hours of family labor deployed on farm. T_{OF} depicts labor hours deployed off-farm.[10] The subscript W denotes the labor allocation of women and M of men. w is the respective wage for off-farm work.

Our data (see table A1 in the Appendix) and additional evidence from literature suggest that the labor productivity in oil palm is significantly higher compared to competing crops such as rubber or rice at low levels of labor input, thus $\frac{\partial P(OP)}{\partial T_F} > \frac{\partial P}{\partial T_F}$. Moreover, with the adoption of oil palm the relative labor productivity of men increases compared to women since oil palm cultivation needs more physical strength: $\frac{\partial P(OP)}{\partial T_{F,M}} / \frac{\partial P}{\partial T_{F,M}} > \frac{\partial P(OP)}{\partial T_{F,W}} / \frac{\partial P}{\partial T_{F,W}}$. However, such a labor-augmenting technical change also reduces the amount of land per unit of labor in efficiency units, which entails that the marginal product of labor in oil palm falls more rapidly with increasing number of hours worked per unit area compared to competing crops (Bustos et al. 2016). Oil palm can be hence characterized as a labor-saving innovation (Kubitza & Gehrke 2018).

In the following paragraphs, we outline the possible effects of oil palm adoption first at the farm scale both for land scarce and land abundant settings, and then at the village and regency scale. If land is scarce (A is fixed) or not all farm households have access to land (Krishna et al. 2017b), we assume that $T_{F,W}$ and $T_{F,M}$ decrease with oil palm adoption and that $T_{F,W}$ decreases more drastically. Farm households can increase their income via allocating their freed labor to the off-farm sector, thus increasing T_{OF}. We assume that labor can move freely between sectors, which implies that in the long run $w_M = \frac{\partial P}{\partial T_{F,M}}$ and $w_F = \frac{\partial P}{\partial T_{F,W}}$. Since relative labor productivity of women in farming is declining, we expect that women in particular opt to work in the non-agricultural sector, hence $T_{OF,W}$ increases.

In a land-abundant setting, labor can be reallocated to new farm land, hence A increases, potentially offsetting the initial decrease in T_F. This will be in particular the case if in the short run $\frac{\partial P(OP)}{\partial T_F} > w$, which is more likely for men with higher relative labor productivity in oil palm,

[10] Note that T is constrained by the available family labor. We define off-farm work as including agricultural employment, non-agricultural employment and self-employment in non-agriculture, thus everything excluding own-farm work.

even though this could also apply to women. Based on these considerations we make the following predictions.

Prediction 1. If land is scarce:

1.1 Oil palm adoption increases income of farm households via off-farm employment.

1.2 Oil palm adoption increases off-farm employment in farm households, in particular for women. Men and women shift out of agriculture.

Prediction 2. If land is abundant:

2.1 Oil palm adoption increases income of farm households via land expansion.

2.2 Oil palm adoption has only limited impact on off-farm employment in farm households. Sectoral shifts between men and women may occur.

3.2 Aggregate scale

At higher spatial scales, welfare effects are expected to be heterogeneous depending on the abundance of land. We expect that the oil palm expansion affects welfare via four different transmission mechanisms. First, since more labor-intensive crops are converted to oil palm, we assume that the demand for agricultural labor T_F decreases in particular for women due to their relatively lower labor productivity (*labor demand effect*). Second, since oil palm adoption increases labor productivity in the agricultural sector, $\frac{\partial P(OP)}{\partial T_F} > \frac{\partial P}{\partial T_F}$, we expect that a higher labor productivity increases wages in agricultural employment, especially for men (*productivity effect*). Third, if oil palm adoption leads to higher incomes due to higher labor productivity and land expansion, we expect that higher income increases demand for other local goods and services (Klasen et al. 2013; Emerick 2018). Aggregated consumption demand is a positive function of income, hence wages in the non-agricultural and agricultural sector could increase (*local demand effect*).

Forth, in a scenario with land scarcity, we assume that the major part of the freed labor in the farm sector is allocated to the non-agricultural sector, hence T_{OF} increases. We expect that the additional supply of labor to the non-agricultural sector decreases wage rates in that sector (ceteris paribus). In addition, lower labor demand in agriculture could decrease agricultural wages (*labor supply effect*). The labor demand and labor supply effect could counterbalance the productivity effect and the local demand effect, which depends eventually on the newly generated consumption demand and thus on the magnitude of the income increase through oil palm adoption.[11] Overall, at a higher scale an oversupply of non-agricultural labor and decreasing labor demand in agriculture could hence theoretically depress wages and employment opportunities. In a scenario with abundant land, we assume that the labor savings of oil palm adoption would also be reallocated to new farming land, A. If the additionally cultivated land absorbs freed labor (hence no labor supply and no labor demand effect), we would expect that oil palm expansion is positively affecting agricultural employment and the non-agricultural sector via local demand linkages and increases in agricultural labor productivity. However, even under land abundance oil palm increases the relative labor productivity of men, which could still lead to a redistribution of labor activities. Based on these considerations, the following impacts are possible in the case of land scarcity or land abundance.

Prediction 3: If land is scarce:

3.1 Employment in agriculture decreases, especially for women. If the non-agricultural sector does not absorb all freed labor, employment rates are likely to drop.

3.2 The effect on non-agricultural wages is ambiguous, but wages will fall if the labor supply effect dominates the local demand effect.

Prediction 4: If land is abundant:

4.1 Demand for agricultural labor will not decrease or even rise, especially for men. Due to changes in relative labor productivity, women are likely to shift to the non-agricultural sector.

4.2 Agricultural and non-agricultural wages increase (based on 4.1).

4 Data

The analysis is based on diverse datasets. We employ data from different administrative levels such as local household data and national datasets as well as from different sources such as survey data and satellite data. Our local household data provide details on agricultural input and output for rubber and oil palm at the plot level as well as employment data for oil palm adopters and non-adopters both at the household and individual level. These data were collected by us in a specific region (see details below), as they are not available in national surveys. However, national surveys have larger sample sizes and provide regency-level panel data reaching several years back in time.

[11] Partly also depends on the amount of consumption which is satisfied by local markets versus foreign markets, we assume, however, that this ratio stays constant.

Having panel data allows for more sophisticated identification strategies and the detection of oil palm expansion effects at higher scales. Table A2 in the Appendix lists the different datasets.

Local household data were gathered in the framework of an interdisciplinary project located in Jambi, Sumatra. In Jambi, cash crops such as rubber (*Hevea brasiliensis*) and oil palm (*Elaeis guineensis*) dominate local agriculture. Jambi ranks sixth place in national palm oil production compared to other provinces (Kubitza et al. 2018b). Data were collected through several surveys. A farm-household survey was conducted in 2015 (*survey I*). Sampling was based on a multi-stage framework and included 683 randomly selected farm households in 45 villages. Sampling details are explained in Kubitza et al. (2018b). In addition to the farm household survey, 24 (of the 45) villages were randomly chosen for a labor household survey (*survey II*), including 432 labor households. The sampling strategy for the labor household survey is detailed in Bou Dib et al. (2018). Since *survey I* and *survey II* were partly overlapping in their definition of farm and labor households, we merged both datasets and drew a threshold at one hectare, referring to all households above this threshold as farm households.[12] Additional data from a sample of only oil palm farmers (*survey III*) was analyzed for robustness checks.[13] We also analyzed data on agricultural traders (*survey IV*) that employ a considerable share of non-farm labor in the villages (Kopp & Brümmer 2017). For spatial data, land-use maps for 2013 were derived from Landsat imagery with 30 m spatial resolution (Melati et al. 2014). Land-use types were identified through spectral and textural differences. An overall accuracy of 80% was obtained using 200 ground control points. As indicator for oil palm expansion at village level, we use oil palm area per household.[14]

Several national datasets were complied. We only included regencies (*kapubaten*) into our analysis and exclude cities (*kotas*), as oil palm cultivation happens primarily in rural areas.[15] The SAKERNAS dataset, the national labor survey of Indonesia, provides data on the sectoral shares of men or women as well as wages in the agricultural and non-agricultural sector. We compiled a

[12] For simplicity we keep on referring to the farm household survey as *survey I* although households were resampled based on the threshold of one hectare.

[13] The data is drawn from a sample of 738 independent oil palm farmers from 36 villages in Jambi Province. These villages covered five regencies in this province (Muaro Jambi, Tebo, Sarolangun, Batanghari and Bungo). From a national village census, we randomly selected 27 villages with more than 70% of households engaged in oil palm and 9 villages with at least 30%. In each village, we randomly selected 22 to 24 farmers from a household list.

[14] Maps with administrative village boundaries are publically available. Number of households per village was elicited during a short interview with the village head, conducted alongside the farm household survey (*survey I*).

[15] In Indonesia provinces are the highest level of local government. Provinces are further divided into regencies (kabupaten) and city districts (kotas). Regencies in Aceh, Papua and the Maluku islands were not included since data in these regions are not available for some years.

regency-level panel from 2001 to 2015. Tree Crops Statistics provide data on yearly oil palm expansion at regency level. For additional robustness checks we use PODES (Indonesian village survey) for infrastructure data and a subsample of the Indonesian census for migration data. The GAEZ (global agro-ecological zones) database provides spatial data on the maximum attainable yield of oil palm across Indonesia. The GAEZ dataset is based on agronomic models which use agro-climatic conditions to predict the agro-climatically attainable yields for different crops under specific levels of input and management conditions. Spatial data on forest cover are derived from Margono et al. (2014). Data are available for 2000, 2005, 2010 and 2012. The maps are based on the global forest cover change maps of Hansen et al. (2013) and are additionally adjusted for the presence of plantation crops in Indonesia.

5 Estimation strategy

5.1 Farm-scale models

We start with testing our predictions at the farm scale. To test if additional income from oil palm adoption is either generated via land expansion or the allocation of freed labor to the off-farm sector (*i.e.* agricultural wage employment or the non-agricultural sector), we regress total household income on the share of farm land dedicated to oil palm (*predictions 1.1 and 2.1*). We then stepwise add farm size and employment dummies as additional control variables. This household-level model is specified as follows:

$$TI_k = \beta_0 + \beta_1 OP_k + \beta_2 A_k + \beta_3 OF_k + \beta_4 X_k + \varepsilon_k \quad (1)$$

where TI_k is total income of a household k (in log terms). OP_k is the share of farm land planted with oil palm. A_k is the total farm size, and OF_k includes dummies for off-farm employment. X_k includes additional control variables such as age, education and migration background.

To test if farm-household members are more likely to work or to take up work in the off-farm sector (*predictions 1.2 and 2.2*), we regress employment indicators on the share of farmers' landholding planted with oil palm. We restrict the sample to working age individuals between 15-65 years. Our reduced-form model of labor supply is specified as follows:

$$OF_{ik} = \beta_0 + \beta_1 OP_k + \beta_2 K_{ik} + \varepsilon_{ik} \quad (2)$$

where OF_{ik} is a dummy for different types of work such as employment and self-employment dummies of individual i in household k. K_{ik} includes additional controls. We split the sample by gender.

Equations (1) and (2) are likely to be subject to endogeneity bias due to omitted variables and reverse causality. Omitted variables such as farmers' general ability could determine both oil palm adoption as well as off-farm self-employment. In addition, while oil palm adoption can increase the likelihood of off-farm self-employment, self-employment can also increase the available capital of farm households. This can in turn facilitate large investments such as planting oil palm.

To address potential endogeneity, we employ an instrumental variable (IV) approach. We use the distance of farm households' dwellings to the closest palm oil mill to instrument the share of farmers' landholding planted with oil palm. We assume that the distance to the closest palm oil mill is significantly correlated with oil palm adoption, since fresh fruit bunches have to be processed within two days to ensure high quality oil (Edwards 2017).[16] Having no palm oil mill in proximity substantially increases transaction costs. Considering the exogeneity of our instrument, we assume that the decision to establish palm oil mills is not affected by individual characteristics of farmers or villages but by the location of large-scale oil palm plantations. The location of large-scale plantations is typically set by local or central government bodies. A wide array of literature documents that plantation projects were implemented regardless of the specific demands of local population groups or the overall environmental and economic conditions (Zen et al. 2006; Cramb & McCarthy 2016; Gatto et al. 2017). Yet, if palm oil mills correlate with large oil palm plantations, the direct vicinity of such plantations could influence employment opportunities and income generation.[17] Additionally, the presence of such plantations might spark land conflicts and influence tenure security which in turn influences farmers' investment decisions. We therefore also control for village level variables such as bordering large-scale plantations as well as the number of land conflicts and the prevalence of secure land titles. Since farmers willing to plant oil palm could just migrate into the proximity of palm oil mills, we control for household migration status in all regressions. Since some regencies were more suitable for oil palm than others, and highly populated areas also did not lend themselves for oil palm plantations, we control for these and other regional characteristics in the later regression analysis through regency dummies and distance variables.

To measure the distance of palm oil mills to farm households we use the GPS location of households' dwelling as well as GPS data from Global Forest Watch, which registered palm oil

[16] Pearson correlation coefficient for our dataset: -0.284 (p-value: 0.000).

[17] Palm oil mills operate mostly within large-scale plantations rather than as independent entities. By controlling for direct vicinity of large-scale plantations, we also control for employment effects of palm oil mills on local labor markets.

mills for the whole of Indonesia. It is possible that the database did not register all palm oil mills in the region. In 2015, the distance from the closest palm oil mill to the village center was elicited through a personal interview with the villages' administrative staff. However, in 11 out of 45 villages the village heads were not able to estimate the distance as palm oil mills were too far away. For the available data, the Pearson correlation coefficient between the survey-based variable and the variable based on geocoded data is 0.218 (p-value: 0.000). The relatively small correlation coefficient can be explained by three factors. First, the distance between village centers and farmers' homestead can be quite substantial. Second, the estimates from the village questionnaire are likely to get very imprecise for larger distances. Third, missing data in the global forest watch dataset.[18] While geocoded data are more precise in general, missing palm oil mills close to the villages would significantly affect data accuracy. To address this issue we opted to correct the distance based on geocoded data through the survey-based data if the survey-based distance was smaller than the distance based on the geocoded data.

5.2 Aggregate-scale models

To test if oil palm expansion affected employment opportunities of labor households, we regress employment indicators of labor households on the oil palm area at village level per household (*predictions 3.1 and 4.1*). We use the following model:

$$OF_{ik} = \beta_0 + \beta_1 VOP_v + \beta_2 X_{ik} + \varepsilon_{ik} \quad (3)$$

where again OF_{ik} is a dummy for different types of employment such as wage or self-employment of individual i in household k. VOP_v is the area of oil palm based on satellite imagery per household in village v. X_{ik} includes additional control variables. We split the sample by gender.

Model (3) may still be subject to endogeneity bias. Moreover, agricultural and non-agricultural labor is not only supplied by labor households but also by farm households. To address these caveats and to extend the analysis at a larger scale, we use national data at regency level. We regress the share of a regency's area planted with oil palm by smallholders on employment rates, sectoral shares (*predictions 3.1 and 4.1)* and wages (*predictions 3.2 and 4.2)*. We split our sample again by gender using a panel spanning from 2001 to 2015, which allows us to apply regency-level fixed effects.

[18] Some of the estimates of the village heads exceed 100km, which is highly unlikely in the context of Jambi and refuted by geocoded data.

Since reverse causality and time-variant unobserved factors could still be a concern, we apply an IV approach. Our instrument consists of two components. The cross-sectional component of our instrument is derived from FAO's Global Agro-Ecological Zones (GAEZ) database (Fischer et al. 2012). The database provides a geo-spatial dataset with the maximum attainable yield of oil palm across the whole of Indonesia.[19] We then interact the cross-sectional variation in the oil palm suitability index (max. attainable yields) across regencies with the national expansion of oil palm over time, which is similar to the approach by Duflo & Pande (2007). This provides a prediction of how much the oil palm area in a regency should have changed solely based on its suitability for oil palm cultivation. Our instrument correlates highly with the actual expansion.[20] Concerning exogeneity, we see no reason why the necessary ecological and climatic conditions for oil palm cultivation should affect the development of sectoral shares and wages over time other than through oil palm expansion. We further assume that the national expansion of oil palm is driven by world market prices and the policies of the central government and not by idiosyncratic regional developments. The instrument was developed by Kubitza & Gehrke (2018) who provide a more detailed discussion and further robustness checks. Since the main islands are spatially segregated, which could lead to potentially different development paths, we additionally control for regional time trends.[21]

Our first stage is as follows:

$$OP_{rt} = \beta_o + \beta_1 AY_r * OPA_t + \beta_2 OPA_t + \beta_3\, X_{rt} + \beta_4\, y_t * p_p + y_t + \mu_r + \varepsilon_{rt} \qquad (4)$$

where OP_{rt} is the share of smallholder oil palm area of total regency area. AY_r is the average max. attainable yield for oil palm in each regency *r*, and OPA_t is the national oil palm area in hectare in year t. X_{rt} includes additional controls such as average age. y_t is a time trend, p_p are region dummies, and μ_r are regency fixed effects.

The second stage of our fixed effects IV model is as follows:

$$Y_{rt} = \beta_o + \beta_1 \widehat{OP}_{rt} + \beta_2 OPA_t + \beta_3 X_{rt} + \beta_4\, y_t * p_p + y_t + \mu_r + \varepsilon_{rt} \qquad (5)$$

Y_{rt} represents sectoral shares and wage levels. The other variables are the same as in equation (4).

[19] Maximum attainable yield of oil palm is mostly affected by differences in climatic conditions such as the level and variation in temperature, radiation and rainfall (Pirker et al. 2016). These conditions are captured by the GAEZ at pixel-level.

[20] Pearson correlation coefficient: 0.305 (p-value: 0.000).

[21] We define five regions including the main islands Sumatra, Kalimantan, Java, Sulawesi with their adjacent smaller islands and a fifth category including all other islands.

We designed models to test if changes in the labor market due to oil palm expansion indicate any labor displacement. As outlined in the conceptual framework these effects depend on the availability of land. It is challenging to define if a household, a village or a regency is land scarce or land abundant and our samples are not large enough to detect interaction effects between land scarcity and oil palm expansion. While we observe that the positive income effect of oil palm is related to land expansion, we do not know if farmers expanded agricultural land (*i.e.* deforestation) or solely converted other crops. To address these challenges we compiled data on regencies' forest cover over time based on satellite imagery. This allows us to test if the expansion of smallholder oil palm is decreasing forest cover, which would indicate an expansion of agricultural land. In addition, we test if infrastructure development and migration could be confounding transmission channels. We use the same IV approach as described in equation (4).

6 Results

6.1 Descriptive results

Table A3 in the Appendix provides an overview and a description of all variables used for analysis. Figure 1 illustrates Indonesia's oil palm expansion disaggregated by producer type. The data show a clear increase over time of the importance of smallholders, who cultivated around 40% of the total oil palm area in 2017. Table A4 in the Appendix reports descriptive statistics for our local household surveys. Table A5 in the Appendix reports descriptive statistics for the national data. Figure 2 is derived from SAKERNAS 2001 and 2015 and shows employment rates and sectoral shares of men (Panel A) and women (Panel B) split by regencies with and without smallholder oil palm in 2015. The bar chart shows that employment rates did not drop more rapidly for men and women in regencies with oil palm than elsewhere. However, agricultural wage employment rose in regencies with oil palm. Furthermore, the shift of women into the non-agricultural sector is more pronounced in regencies with oil palm. Descriptive evidence thus suggests that oil palm did not decrease employment rates but that women and men shifted sectors.

6.2 Regression results - farm scale

Table 1 reports the effect of oil palm cultivation on farm households' total income. Columns (1) to (3) show OLS estimates, while columns (4) to (6) show IV estimates.[22] Additional control variables at household and village level are reported in Table A6 in the Appendix. We add for both estimation approaches stepwise total farm size and dummies for off-farm employment to test if the income effect is running via land expansion or involvement in the off-farm sector. We observe for all models a positive effect of oil palm cultivation on total income.[23] We further observe that if total farm size is included the significant positive effect decreases strongly from column (1) to column (2) for OLS estimates and from column (4) to column (5) for IV estimates. This indicates that part of the positive income effect is running via land expansion. These results are also supported by other studies that used propensity score matching and panel data models (Euler et al. 2017; Kubitza et al. 2018b). We do not observe strong evidence that the income effect is driven by off-farm employment. We find our results to be consistent with prediction 2.1 that under land abundance oil palm adoption increases households' income partly via land expansion.

Table 2 shows the effect of oil palm adoption on individual employment indicators in farm households using IV and probit models. Additional control variables at individual, household and village level are reported in Tables A7 and A8 in the Appendix. We observe that neither women nor men significantly decrease their overall labor supply (columns 1 and 2). But women are significantly less likely to work on their own farm (column 4) both in the IV and probit models. The decreasing labor supply of women in own-farm work matches our plot-level results, which show a strong decrease of women's working hours in oil palm compared to rubber (see Table A1). In addition, we find a positive effect on the likelihood of women to work in non-agricultural self-employment (column 8). We also find a significant positive effect of oil palm on the men working in the off-farm sector, however, only in the probit models.[24] Since we only find limited effects of oil palm adoption on men working in agriculture and general employment rates, our results are more consistent with our prediction 2.2.

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[22] For the IV estimation we only used the data from *survey I* where we had data available for distance to palm oil mills based on the village questionnaire. Our instrument passes all the necessary tests such as the underidentification and weak identification test.

[23] Effect size is larger in the IV models than in the OLS models. Since the Kleibergen F-Stat is sufficiently high we find no indication that this is due to a weak instrument problem. Other reasons could include local average treatment effect and endogeneity bias in the OLS estimates. In general, rubber prices were extremely low in 2015 which may have added to the high effect magnitude (Kubitza et al. 2018b).

[24] To further validate our results, we use a sample including only oil palm adopters but with varying degree of the share of oil palm of total land holding. We also do not find that employment rate and off-farm working changed due to expanding oil palm (see Table A9).

6.3 Regression results - aggregate scale

Table 3 reports probit and OLS results for labor households (*predictions 3.1 and 4.1*). Columns (1) and (2) show that a larger oil palm area per household in a village is not associated with decreasing female and male employment rates. We also do not find any evidence that men and women significantly decrease their labor supply to the agricultural sector. Yet, we find that men increase their working hours in agricultural wage employment due to oil palm expansion at the village level. This provides some support for prediction 4.1 that in a land-abundant setting labor demand in agriculture may not necessarily diminish. Moreover, in Table A11 we observe that a higher share of oil palm farmers in the village is not associated with any changes in income or working hours for agricultural traders, who are likely to have large impact on labor demand outside the farm sector.

Tables 4-6 report the results from the regency panel for the whole of Indonesia. We use the IV approach described in chapter 5.2. The results in Tables 4 and 5 show that neither men nor women significantly altered their overall work force participation as a result of oil palm expansion (column 1), confirming the findings from the household-level analysis and prediction 4.1. We observe, however, that women shift from the agricultural sector to the non-agricultural sector (Table 4, column 2). Women shift into non-agricultural employment, not into self-employment (Table 4, column 6). This differs from the household-level results. But the regency analysis might also capture the effect of migration from rural to urban areas. Laborers may potentially be leaving smaller villages in order to take up non-agricultural jobs in more urban areas. For men, we observe a shift into agricultural wage labor (Table 5, column 4), which is in line with the farm-scale results and confirms prediction 4.1.[25] Table 6 reports the results for wages. Wages in the non-agricultural sector in particular increased due to oil palm expansion for both women and men (Table 6, columns 2 and 5). We further find that wages for men increased significantly in the agricultural sector (Table 6, column 6), which we interpret as a productivity effect of oil palm expansion. These results lend some support to prediction 4.2.

6.4 Regression results - transmission channels

We found consistent evidence that the expansion of oil palm did not lead to significant displacements of male and female rural laborers. Based on our conceptual framework, this would

[25] We also tested the effect of oil palm expansion on working hours (see Tables A12 and A13 in the Appendix). The effect, however, seems to be rather at the extensive margin than at the intensive margin of labor supply.

occur if oil palm expansion is associated with a general expansion of agricultural land and thus deforestation. In Table 7, we estimate how smallholder oil palm expansion is associated with forest cover at the regency level, using data from 2001 to 2012. The negative estimation coefficient suggests that oil palm expansion has contributed to deforestation. The coefficient magnitude of 0.77 is relative high and indicates that a one unit area increase in smallholder oil palm cultivation is associated with a loss of 0.77 units of forest cover. However, we caution that this estimate is a local average treatment effect and might present an upper boundary. While several studies confirm that oil palm expansion increased deforestation (Koh et al. 2011; Vijay et al. 2016; Carlson et al. 2018), oil palm also replaced other agricultural crops and fallow land to some extent (Gatto et al. 2015).

A few possible confounding mechanisms are discussed in the following. One concern may be that the observed effects may be driven by general investments in infrastructure that are associated with oil palm expansion. However, we do not observe that all population groups enter the non-agricultural sector. Men enter agricultural wage labor and only women switch into non-agriculture, which is in line with the gendered productivity differentials between oil palm and alternative crops and does not support a story of general infrastructure development. In an additional robustness check, we also control for several infrastructure variables, such as roads, schools and electricity at the regency level, using the PODES dataset. To merge the different datasets, we had to restrict the timespan to 2001-2011 with 3-year differences. Table A14 in the Appendix shows the results for this time period without controlling for infrastructure. These results do hardly differ from the earlier ones shown in Tables 4 and 5 for the full timespan. Table A15 in the Appendix includes the infrastructure variables as additional controls. We do not find any significant changes to the estimates in Table A14, which supports our argument that the results are not primarily due to general infrastructure development.

One further concern is that oil palm expansion could be correlated with migration flows. The Indonesian government supported migration movements from the densely populated main island (Java) to the outer islands to obtain laborers for large-scale plantations. These migration movements altered the cultural and socio-demographic composition of the labor force. It is not unreasonable to assume that migrants are more open to innovation and hence more likely to adopt oil palm and also to take up non-agricultural employment. However, we control for migration status in all farm and village-scale regressions. Moreover, controlling for the share of migrants at the regency level does not alter the effect of oil palm expansion on sectoral shares, as additional robustness checks indicate (Tables A16 and A17 in the Appendix).[26]

7 Discussion

How do the labor savings per unit area in agriculture induced by oil palm expansion affect inequality in the labor market and welfare of rural farm and labor households? Overall, our results suggest that smallholder oil palm expansion has contributed to rising human welfare in rural Indonesia. Average incomes and wages increased which is supported by the local household data as well as the national data. We did not find any evidence that oil palm expansion of smallholders increased inequality in the labor market through displacing vulnerable groups such as women or rural laborer household more generally.

Conceptually, if wages and output are fixed, a labor-saving innovation such as oil palm can decrease labor demand, affecting less productive population groups and groups with limited access to land and capital. But in Indonesia, output was not fixed and further cropland expansion was possible. Our results show that, at the farm level, a considerable share of the positive income effects of oil palm cultivation is running via land expansion. This was confirmed at the regency level, where we found that oil palm expansion significantly increased deforestation.

The increase in agricultural land has increased the demand for agricultural labor, especially for men who have a higher labor productivity in oil palm cultivation than women. Indeed, the labor household data suggest that men in villages with more oil palm also supply more agricultural labor. This is confirmed at the regency scale, where we find clear evidence that men reallocate part of their time to agricultural wage labor. Our results further show that men's agricultural wages increased due to oil palm expansion, which is in line with their increasing labor productivity in oil palm. Oil palm expansion hence does not seem to have decreased access to agricultural labor.

We also find no evidence that the likelihood of women working decreased with the expansion of oil palm in the small farm sector. At the farm scale, our results show that women increased their involvement in off-farm business activities, which might be a measure to counteract the lower

[26] We use a census subsample to obtain data on migration. Census data is only available in 5 year differences between 2001 and 2011. We hence run our regressions with 5-year differences. The baseline results again confirm our results from Table 4 and 5.

labor demand on farm. At the regency level, we also find clear evidence that women left agriculture and entered the non-agricultural sector. Women are particularly engaged in non-agricultural employment, and less in self-employed activities. Because of their increasing involvement in the non-agricultural sector, women's overall access to employment has not decreased. We further find that wages in the non-agricultural sector increased significantly as a result of oil palm expansion, which we attribute to local demand effects.

Our study involves a few limitations. First, we focus on oil palm affecting rural labor markets by pushing certain groups out of agriculture. However, besides these push factors, various pull factors such increasing rural or urban wages could determine the outcomes. While the gender-differentiated outcomes match well with our conceptual framework, we caution that there might be additional factors at play. Second, our data are limited in some areas. For farm households, we do not have data on individual labor hours. At the regency level, we do not have consistent information on private large-scale plantations. Third, it would have been ideal to compare the effect of oil palm expansion in land-abundant versus land-scarce regencies or villages. However, having a limited number of observations, using an instrumental variable approach and coarse indices of land scarcity did not allow us to delineate interaction effects between oil palm expansion and land scarcity.

8 Conclusion

We conclude that inequality in the labor market was not amplified by the expansion of oil palm as a labor-saving innovation in Indonesia. The main reason for not observing labor-displacing effects is the expansion of agricultural land, which increased the demand for agricultural labor, especially for men. Furthermore, oil palm contributed to broader income growth, leading to local demand effects and a boost to the non-agricultural sector, which absorbed female labor that was freed from agriculture. Local demand and productivity effects clearly overcompensated the potential decreases in labor demand through the labor-saving innovation itself.

However, our results suggest that the positive economic and social effects worked largely at the expense of natural ecosystems, in particular forest land. Direct countermeasures to avoid deforestation could include increasing labor intensity per unit of land, which would be however unprofitable due to rapidly decreasing marginal returns to labor. Alternatively, restricting further forest encroachment would force new oil palm adopters to reallocate some of their saved labor to the non-agricultural sector. Our study suggests that by incentivizing farm households to reallocate their labor to the off-farm sector rather than to expand agricultural land, rural laborers – and women in particular – might be pushed out of the labor market. This presents a fundamental trade-off for policymakers. To address this trade-off, forest conservation policies have to be accompanied by improvements in access to non-agricultural employment. Our results suggest that to manage the negative externalities of a labor-saving innovation, such as oil palm, having secure property rights for agricultural land and forest as well as access to the non-agricultural sector might have to go hand-in-hand, while isolated interventions might entail undesirable social effects. Future policy interventions should address these issues.

In general, our results underline that the economic, social and environmental effects of a labor-saving innovation have to be closely interpreted against the backdrop of land abundance. While the Indonesian case, or also historical data from the agricultural expansion in the US, show that labor-savings innovations can be economically beneficial, this may not be the case in settings with scarce land resources or limited access to the non-agricultural sector. Moreover, the implementation of labor-saving innovations in settings with weak land regulations has to be conducted with caution in order to inhibit a further degradation of our natural ecosystems.

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TABLES

Table 1: Effect of oil palm cultivation on farm household income

	OLS			IV		
	(1) Total income (log)	(2) Total income (log)	(3) Total income (log)	(4) Total income (log)	(5) Total income (log)	(6) Total income (log)
Share of oil palm (0-1)	0.282**	0.151	0.144	1.065**	0.585	0.517
	(0.113)	(0.098)	(0.096)	(0.484)	(0.435)	(0.439)
Total farm size (ha)		0.090***	0.085***		0.086***	0.082***
		(0.009)	(0.008)		(0.009)	(0.009)
Employed household members (=1)			-0.176**			-0.201**
			(0.075)			(0.079)
Self-employed household members (=1)			0.197***			0.167**
			(0.067)			(0.075)
F-Stat	16.144	23.101	24.935	16.399	25.619	26.806
Kleibergen F-Stat				29.119	26.839	24.920
Observations	635	635	635	635	635	635

Notes: Farm-household data (survey I). Instrument is based on log distance to the closest palm oil mill. Additional covariates included in estimation are reported in Table A4. Due to taking the log eight observations with zero or negative income were dropped. Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Effect of oil palm cultivation on employment status of individuals in farm households

	(1) Working (=1) (Men)	(2) Working (=1) (Women)	(3) Working on-farm (=1) (Men)	(4) Working on-farm (=1) (Women)	(5) Working off-farm (=1) (Men)	(6) Working off-farm (=1) (Women)	(7) Self employed off-farm (=1) (Men)	(8) Self employed off-farm (=1) (Women)
				IV				
Share of oil palm (0-1)	0.071	0.076	0.027	-0.603*	0.183	0.098	-0.107	0.328
	(0.131)	(0.317)	(0.204)	(0.324)	(0.261)	(0.295)	(0.222)	(0.218)
F-Stat	115.892	21.512	158.193	14.592	30.950	6.017	2.851	2.262
Kleibergen F-Stat	21.901	17.621	21.901	17.621	21.901	17.621	21.901	17.621
Observations	961	901	961	901	961	901	961	901
				Probit				
Share of oil palm (0-1)	-0.005	-0.060	0.007	-0.138***	0.098**	0.022	0.036	0.064***
	(0.020)	(0.046)	(0.031)	(0.047)	(0.043)	(0.040)	(0.045)	(0.022)
Chi2	569.705	377.687	577.946	391.507	913.610	459.128	119.381	179.322
Observations	961	901	961	901	961	901	961	901

Notes: Farm-household data (survey I). Instrument is based on log distance to the closest palm oil mill. Additional covariates included in estimation are reported in Table A6 for IV models and n Table A7 for probit models. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Effect of oil palm expansion on employment status of individuals in labor households

	(1) Working (=1) (Men)	(2) Working (=1) (Women)	(3) Employed in agriculture (=1) (Men)	(4) Employed in agriculture (=1) (Women)	(5) Hours working in agricultural wage labor (Men)	(6) Hours working in agricultural wage labor (Women)
Oil palm area (km2) per HH in village	0.234	0.947	0.0708	0.810	2.591*	3.751
	(0.402)	(0.791)	(0.758)	(0.570)	(1.437)	(3.877)
Chi2/R2	160.3	111.2	201.2	64.55	0.100	0.489
Observations	598	568	564	546	310	48

Notes: Labor-household data (survey II). Marginal effects are reported based on probit models (columns 1-4) and OLS models (columns 5-6). For columns (3) and (4) we have missing data. For column (5) and (6) we do not have data for the complete sample due to merging data with survey I. Additional covariates included in estimation are reported in Table A8. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Regency-level effects of oil palm expansion on sectoral shares of women (2001-2015)

	(1) Share of women working	(2) Share of women in non-agricultural sector	(3) Share of women in agricultural family labor	(4) Share of women in agricultural wage labor	(5) Share of women in non-agricultural self-employment	(6) Share of women in non-agricultural wage labor
Share of smallholder oil palm area in regency (0-1)	-2.550	4.573**	-3.204*	-0.384	0.886	3.251**
	(1.706)	(1.948)	(1.930)	(0.765)	(0.949)	(1.368)
F-stat	14.146	34.069	26.080	8.515	8.123	42.288
Kleibergen F-Stat	13.095	13.095	13.095	13.095	13.095	13.095
Observations	2911	2911	2911	2911	2911	2911

Notes: SAKERNAS and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of working age women, national oil palm expansion, regency fixed-effects, year dummies and region trends. Outcome variables are shares ranging between 0 and 1. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Regency-level effects of oil palm expansion on sectoral shares of men (2001-2015)

	(1) Share of men working	(2) Share of men in non-agricultural sector	(3) Share of men in agricultural family labor	(4) Share of men in agricultural wage labor	(5) Share of men in non-agricultural self-employment	(6) Share of men in non-agricultural wage labor
Share of smallholder oil palm area in regency (0-1)	-0.735	-1.026	-0.448	2.157***	-1.225	0.230
	(0.825)	(0.995)	(0.637)	(0.776)	(0.899)	(0.870)
F-Stat	27.642	51.499	26.403	8.153	16.473	87.967
Kleibergen F-Stat	13.238	13.238	13.238	13.238	13.238	13.238
Observations	2911	2911	2911	2911	2911	2911

Notes: SAKERNAS and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of working age men, national oil palm expansion, regency fixed-effects, year dummies and region trends. Outcome variables are shares ranging between 0 and 1. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Regency-level effects of oil palm expansion on women's and men's wages (2001-2015)

	(1) Wage of women	(2) Wage of women in non-agriculture	(3) Wage of women in agricultural wage work	(4) Wage of men	(5) Wage of men in non-agriculture	(6) Wage of men in agricultural wage work
Share of smallholder oil palm area in regency (0-1)	8.591**	8.714**	11.655	5.126	6.818*	10.434*
	(4.254)	(4.379)	(7.160)	(3.499)	(3.676)	(5.760)
F-Stat	39.231	22.055	30.309	49.277	36.057	23.122
Kleibergen F-Stat	13.095	12.999	11.900	13.238	13.238	13.274
Observations	2910	2903	2638	2911	2911	2786

Notes: SAKERNAS and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of male or female working age population respectively, national oil palm expansion, regency fixed-effects, year dummies and region trends. Columns (1) to (2) and (4) to (5) include income from self-employment. Outcome variables are log hourly wages. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

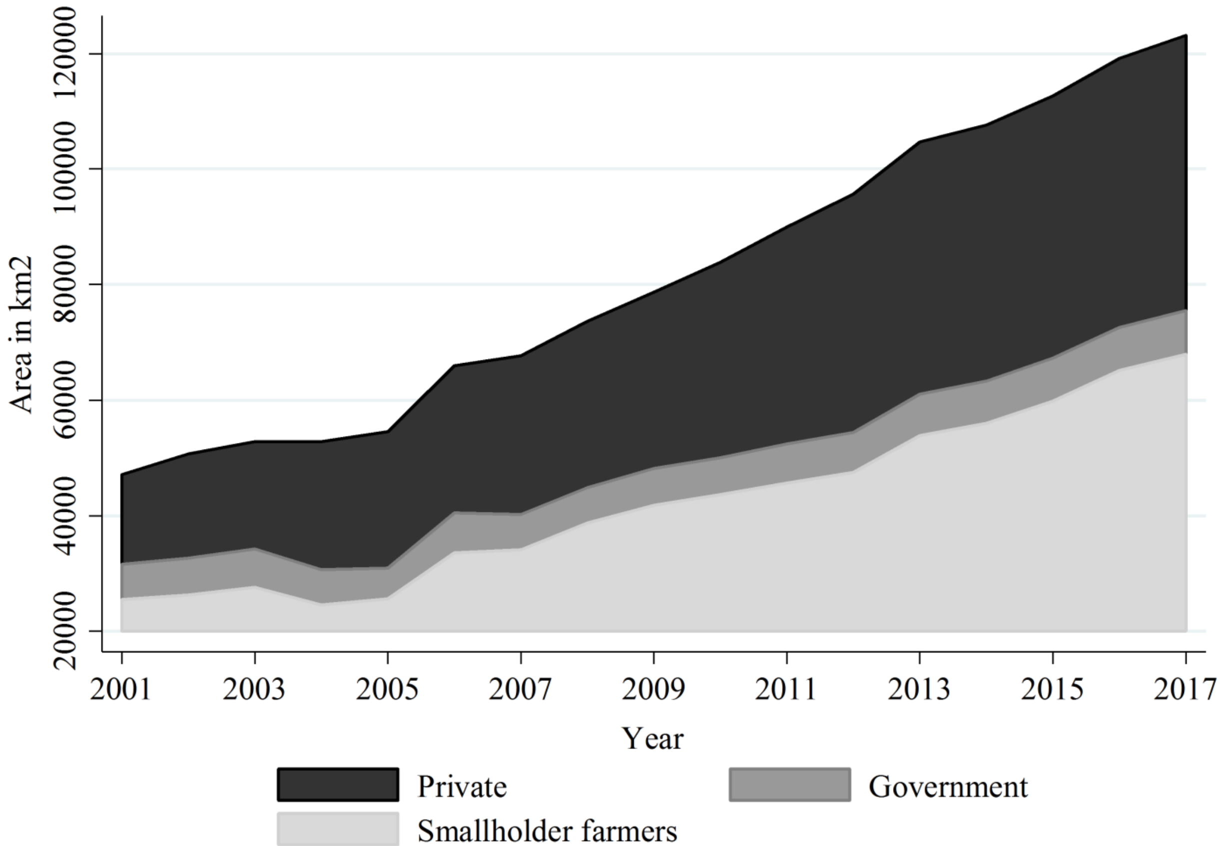
Table 7: Regency-level effects of oil palm expansion on forest cover

	(1)
	Share of forest cover (0-1)
Share of smallholder oil palm area in regency (0-1)	-0.777**
	(0.330)
F-Stat	21.122
Kleibergen F-Stat	11.168
Observations	855

Notes: Margono and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. Only data for 2001, 2005, 2010 and 2012. We control for national oil palm expansion, regency fixed-effects, year dummies and region trends. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

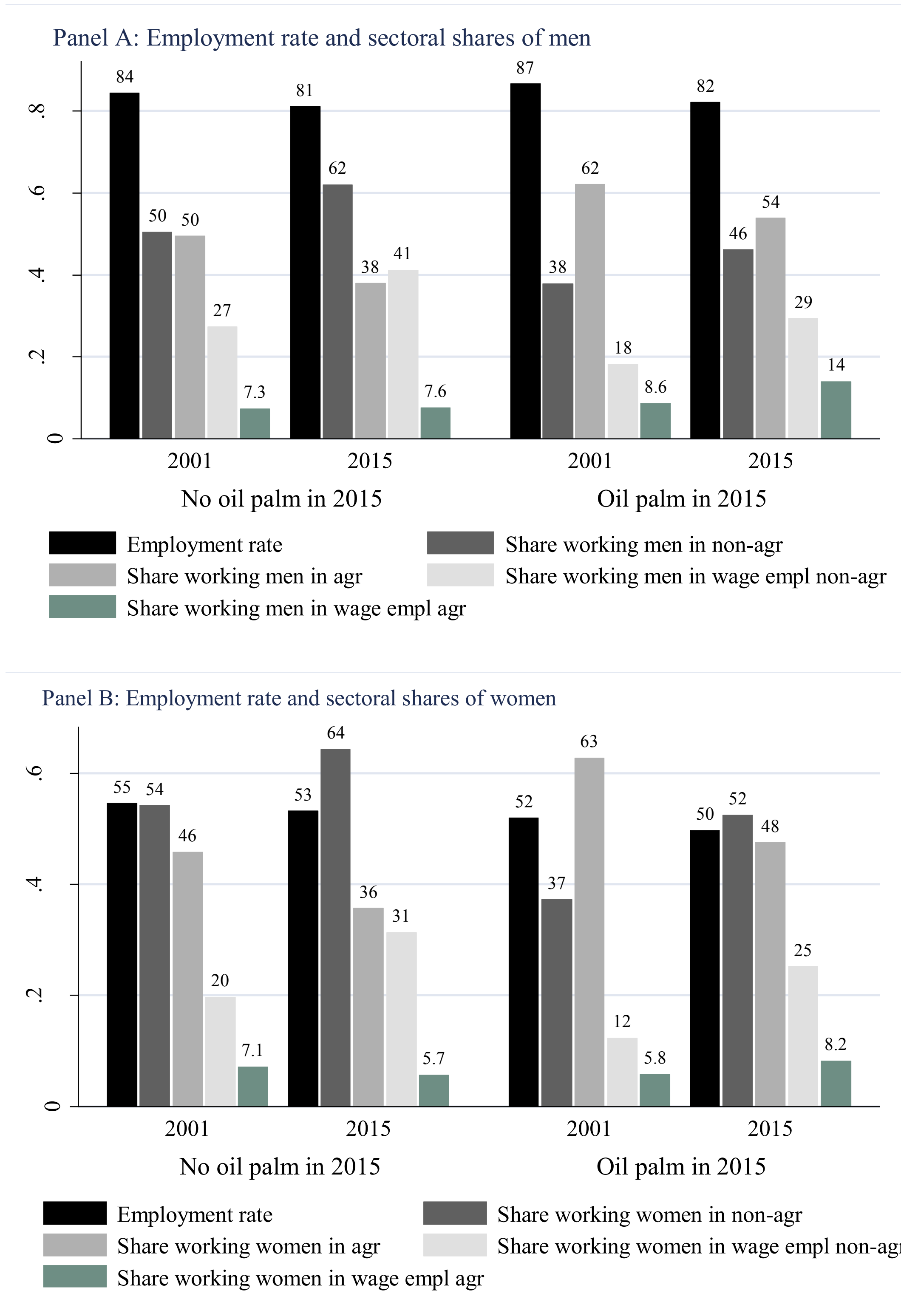
FIGURES

Figure 1: Expansion of oil palm in Indonesia by producer type



Source: Tree crop statistics.

Figure 2: Gendered employment rates at the regency level in Indonesia



Notes: 208 regencies are included. In 2015, smallholders cultivated oil palm in 86 regencies (41%).

APPENDIX

Table A1: Labor and land productivity of oil palm and rubber

	Oil palm		Rubber	
	#Obs.	Mean (Std. dev.)	#Obs.	Mean (Std. dev.)
Plot size [ha]	437	1.84	973	1.90
		(1.50)		(1.59)
Land productivity [‘000 IDR/ha /year]	437	11714.02***	967	15419.47
		(10396.00)		(11549.01)
Female labor employed [Hours/ha/year]	439	25.76***	973	313.76
		(65.35)		(471.62)
Male labor employed [Hours/ha/year]	439	237.70***	973	854.69
		(211.09)		(997.98)
Labor productivity[‘000 IDR/hour]	437	65.40***	967	18.43
		(93.94)		(18.17)
Female wage rate [‘000 IDR/hour]	17	12.44	27	10.44
		(11.35)		(1.75)
Male wage rate [‘000 IDR/hour]	167	18.23***	319	14.41
		(17.22)		(15.58)

Notes: Farm-household data (survey I). Unproductive plots were excluded and tree age restricted to productive age from 5 to 25 years (except for wage data). For the male-wage data two outliers were excluded. Hours worked includes family as well wage labor. Monetary values from 2012 were inflation-adjusted. T-tests were applied to test for statistically significant differences. Adjusted based on data from (Kubitza & Gehrke 2018).

Table A2: Datasets

Datasets	Year of survey/observation	Source
Local surveys		
Farm households (n = 701)	2015	Primary data collected by authors
Oil palm farm households (n = 780)	2016	
Labor households (n = 432)	2015	
Trader households (n = 315)	2012	
Remote sensing data		
Land cover in Jambi province	2013	Landsat data
Hansen forest data	2000-2012	Margono et al. 2014
National surveys		
National village survey (PODES)	2001, 2003, 2006, 2008, 2011	Badan Pusat Statistik (BPS)
National labor force survey (SAKERNAS)	2001-2015	
Indonesian census	2000, 2006, 2011	IPUMS International database
Tree Crops Statistics	2001-2015	Ministry of Agriculture

Table A3: Variable descriptions

Variable name	Variable description
Individual level	
Age	Age of individual household member in years
Age squared	Squared age of individual household member in years
Education level	Educational degree of individual household member. (Educational degrees range from 1 for never attended to 6 for university level)
Student	Student status of individual household member. (1=student; 0=otherwise)
Household level	
Share of oil palm	Share of total farm land of household planted with oil palms. (share ranges from 0 to 1)
Age of household head (Years)	Age of household head in years
Female headed household (=1)	Household is headed by female member. (1=female household head; 0=otherwise)
Education of household head (degree)	Educational degree of household head. (Educational degrees range from 1 for never attended to 6 for university level)
Migrant household (=1)	Household head migrated to village. (1=household head migrated to village, 0=household head born in village)
Number of household members	Number of current household members.
Number of adults	Number of adult household members (older than 16 years).
Distance to Jambi City (km)	Geodesic distance from households' dwelling to Jambi city in kilometers.
Productive farm (=1)	Household cultivates a productive farm, hence planation trees are old enough to be harvested and household is active in farming. (1=farm land is productive; 0=no production)
Total farm size (ha)	Total farm size in hectares, which includes all land owned by the household either formal or informal.
Employed household members (=1)	At least one of the household members is employed either in the agricultural or non-agricultural sector. (1=employed; 0=otherwise)
Self-employed household members (=1)	At least one of the household members is self-employed apart from own farming. (1=self-employed; 0=otherwise)
Village level	
Transmigrant village (=1)	Village was founded as part of the transmigrant program.
Oil palm area (km2) per HH in village	Oil palm area per village derived from satellite data in km2 divided by number of households residing in village derived from village survey data.
Share of land with systematic land titles	Share of village land with systematic land titles. Data derived from village survey. (share ranges from 0 to 1)
Share of land with sporadic land titles	Share of village land with sporadic land titles. Data derived from village survey. (share ranges from 0 to 1)
Number of conflicts between farmers and companies in the last 10 years.	Number of conflicts between farmers and companies in the last 10 years derived from village survey.
Village bordering with large-scale oil palm plantations (=1)	Villages shares a direct boarder with a large-scale oil palm plantation either privately managed or by government. (1=direct boarder; 0=otherwise)
Share of oil palm farmers in village	Share of sampled farmers in household survey who cultivate oil palm. (share ranges from 0 to 1)

Regency level	
Share of smallholder oil palm area in regency (0-1)	Share of oil palm area managed by smallholders as reported by tree crop statistics divided by total regency area. (share ranges from 0 to 1)
Share of women/men working (0-1)	Share of women or men between 15 and 65 years reporting either working in last week or having a job but not working in last week. Data from SAKERNAS. (share ranges from 0 to 1)
Share of women/men in non-agricultural sector (0-1)	Share of working women or men between 15 and 65 years reporting working in the non-agricultural sector in last week. Data from SAKERNAS. (share ranges from 0 to 1)
Share of women/men in agricultural family labor (0-1)	Share of working women or men between 15 and 65 years reporting working in the agricultural sector for own family (unpaid) in last week. Data from SAKERNAS. (share ranges from 0 to 1)
Share of women/men in agricultural wage labor (0-1)	Share of working women or men between 15 and 65 years reporting working in the agricultural sector for wage income in last week. Data from SAKERNAS. (share ranges from 0 to 1)
Share of women/men in non-agricultural self-employment (0-1)	Share of working women or men between 15 and 65 years reporting working self-employed in the non-agricultural sector in last week. Data from SAKERNAS. (share ranges from 0 to 1)
Share of women/men in non-agricultural wage labor (0-1)	Share of working women or men between 15 and 65 years reporting working in the non-agricultural sector for wage income in last week. Data from SAKERNAS. (share ranges from 0 to 1)
Wage of women/men	Wage of women or men per hour in IDR which includes income from self-employment and wage employment. Data from SAKERNAS.
Wage of women/men in non-agriculture	Wage of women or men per hour in IDR which includes income from self-employment and wage employment in the non-agricultural sector. Data from SAKERNAS.
Wage of women/men in agricultural wage work	Wage of women or men per hour in IDR which includes income from wage employment in the agricultural sector. Data from SAKERNAS.
Share of forest cover (0-1)	Share of land cover in regency with primary degraded and intact forest as derived from Margono satellite dataset. (share ranges from 0 to 1)
Share of villages with asphalt roads (0-1)	Share of villages with asphalted main road based on PODES data. (share ranges from 0 to 1)
Share of households with electricity (0-1)	Share of households connected to the electric grid. (share ranges from 0 to 1)
Share of villages with junior high school (0-1)	Share of villages with junior high school. (share ranges from 0 to 1)
Share of migrants (0-1)	Share of respondents which ever migrated to their current place of residence based on a subsample of the Indonesian census. (share ranges from 0 to 1)
Total working hours	Average total working hours in specific sector.

Table A4: Descriptive statistics for local household surveys

	Farm households (Survey I)			Labor households (Survey II)		
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
Individual-scale						
Age [year]	1870	36.781	13.467	1221	35.004	12.695
Women [=1; otherwise 0]	1870	0.483	0.500	1221	0.486	0.500
Education level [scale]	1862	3.834	1.520	1220	3.416	1.376
Student [=1; otherwise 0]	1870	0.089	0.285	1221	0.047	0.211
Working [=1; otherwise 0]	1870	0.692	0.462	1221	0.608	0.488
Working off-farm [=1; otherwise 0]	1870	0.394	0.489	1221	0.499	0.500
Working on farm [=1; otherwise 0]	1870	0.513	0.500	1221	0.231	0.422
Self-employed off-farm [=1; otherwise 0]	1870	0.124	0.330	1221	0.075	0.263
Employed [=1; otherwise 0]	1870	0.286	0.452	1221	0.450	0.498
Employed in non-agr. sector [=1 otherwise 0]]	1870	0.125	0.330	1221	0.084	0.277
Employed in agricultural sector [=1 otherwise 0]]	1870	0.161	0.368	1221	0.366	0.482
Household-scale						
Migrant household [=1; otherwise 0]	645	0.557	0.497	468	0.628	0.484
Household size [number of members]	645	4.144	1.509	468	3.895	1.359
Number of adults	645	3.099	1.174	468	2.739	1.014
Total income per year [‘000IDR]	645	36968.06	64041.14	466	18636.70	15875.77
Total farm size [ha]	645	4.454	4.688	468	0.352	0.423
Share of oil palm [0-1; share of total farm size]	645	0.273	0.385			
Productive farm (=1)	645	0.913	0.282	468	0.502	0.501
Distance to nearest palm oil mill [km]	644	17.826	10.868			
Distance to province capital [km]	645	96.172	55.678	468	95.154	55.764
Village-scale						
Transmigrant village [=1]	44	0.295	0.462	25	0.280	0.458
Oil palm area (km2) per HH in village	44	0.021	0.032	25	0.020	0.032
Share of land with systematic land titles [0-1]	44	0.399	0.373	25	0.362	0.367
Share of land with sporadic land titles [0-1]	44	0.246	0.306	25	0.459	0.345
Number of conflicts between farmers and companies in the last 10 years	44	0.227	0.803	25	0.520	1.046
Village bordering with large oil palm plantations (=1)	44	0.636	0.487	25	0.840	0.374
Share of oil palm farmers in village [0-1]	44	0.350	0.301	25	0.383	0.269

Notes: Educational attainments range from 1 (never attended) to 6 (university level first stage). One village contains soley households with less than 1 ha farm land which reduces the number of villages with farm household from 45 to 44.

Table A5: Descriptive statistics for national surveys

	2001			2015		
SAKERNAS						
Women	Obs.	Mean	SD	Obs.	Mean	SD
Employment rate [0-1]	209	0.563	0.142	209	0.518	0.113
Share in non-agr. sector [0-1]	209	0.471	0.207	209	0.593	0.183
Share in agr. family labor [0-1]	209	0.354	0.186	209	0.250	0.149
Share in agr. wage employment [0-1]	209	0.066	0.069	209	0.067	0.051
Share in non-agr. self-employment [0-1]	209	0.207	0.110	209	0.216	0.069
Share in non-agr. wage employment [0-1]	209	0.166	0.128	209	0.287	0.131
Wage (IDR/hour)	209	7308.763	3039.426	209	9289.494	2869.812
Wage in non-agr. (IDR/hour)	207	8216.641	3585.307	209	10114.239	3241.482
Wage in agr. (IDR/hour)	193	4776.408	3099.871	209	5999.040	2307.705
Total working hours	209	32.688	5.401	209	34.269	4.519
Total working hours in agr	208	25.703	6.454	209	25.259	3.862
Total working hours in non-agr	208	39.891	5.530	209	40.180	3.378
Total working hours in family agr.	206	23.825	6.246	209	23.981	4.279
Total working hours in wage agr.	160	33.448	10.471	207	31.414	6.948
Total working hours in wage non-agr.	202	40.310	6.901	209	38.502	3.759
Total working hours in self-employment agr.	197	25.318	8.207	208	23.452	4.828
Men						
Employment rate [0-1]	209	0.883	0.046	209	0.816	0.038
Share in non-agr. sector [0-1]	209	0.452	0.177	209	0.554	0.171
Share in agr. family labor [0-1]	209	0.089	0.068	209	0.063	0.053
Share in agr. wage employment [0-1]	209	0.078	0.066	209	0.102	0.071
Share in non-agr. self-employment [0-1]	209	0.198	0.084	209	0.174	0.050
Share in non-agr. wage employment [0-1]	209	0.235	0.128	209	0.362	0.135
Wage (IDR/hour)	209	9442.456	2958.225	209	10599.590	2627.762
Wage in non-agr. (IDR/hour)	209	10470.427	3438.182	209	11473.207	3045.539
Wage in agr. (IDR/hour)	206	6979.675	3411.456	209	8209.082	3053.200
Total working hours	209	39.385	3.986	209	38.766	4.170
Total working hours in agr	209	34.493	4.900	209	33.012	4.335
Total working hours in non-agr	209	44.605	3.982	209	43.429	2.829
Total working hours in family agr.	204	28.841	7.759	208	27.363	6.615
Total working hours in wage agr.	190	40.494	8.815	208	39.131	5.713
Total working hours in wage non-agr.	208	44.040	4.483	209	43.268	2.884
Total working hours in self-employment agr.	209	34.383	5.695	209	31.703	4.465

	2001			2011		
PODES						
Share of villages with asphalt roads [0-1]	207	0.640	0.199	203	0.771	0.185
Share of households with electricity [0-1]	208	0.584	0.199	203	0.875	0.137
Share of villages with junior high school [0-1]	208	0.440	0.156	203	0.563	0.155
CENSUS						
Share of migrants [0-1]	209	0.087	0.118	209	0.094	0.119

Notes: SAKERNAS data. Wage, working hours and PODES data missing for some regency. Wage data is inflated to 2015 values.

Table A6: Effect of oil palm cultivation on farm household income

	OLS			IV		
	(1) Total income (log)	(2) Total income (log)	(3) Total income (log)	(4) Total income (log)	(5) Total income (log)	(6) Total income (log)
Share of oil palm (0-1)	0.282**	0.151	0.144	1.065**	0.585	0.517
	(0.113)	(0.098)	(0.096)	(0.484)	(0.435)	(0.439)
Age of household head	0.001	-0.003	-0.004	0.001	-0.003	-0.004
(Years)	(0.004)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)
Female headed household	-0.369**	-0.270	-0.186	-0.263	-0.216	-0.138
(=1)	(0.166)	(0.173)	(0.168)	(0.172)	(0.169)	(0.165)
Education level of	0.047	0.018	0.024	0.038	0.014	0.022
household head (degree)	(0.031)	(0.028)	(0.028)	(0.032)	(0.028)	(0.028)
Migrant household (=1)	0.020	0.046	0.065	-0.006	0.031	0.053
	(0.085)	(0.076)	(0.076)	(0.090)	(0.077)	(0.075)
Number of household	-0.067	-0.039	-0.029	-0.090**	-0.053	-0.039
members	(0.041)	(0.038)	(0.038)	(0.044)	(0.040)	(0.040)
Number of adults	0.114**	0.077	0.077	0.156**	0.101*	0.099*
	(0.055)	(0.049)	(0.050)	(0.061)	(0.055)	(0.057)
Productive farm (=1)	2.279***	2.157***	2.137***	2.206***	2.122***	2.098***
	(0.164)	(0.161)	(0.154)	(0.163)	(0.157)	(0.157)
Distance to Jambi City	-0.001	-0.002**	-0.002**	-0.001	-0.001	-0.001
(km)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Total farm size (ha)		0.090***	0.085***		0.086***	0.082***
		(0.009)	(0.008)		(0.009)	(0.009)
Employed household			-0.176**			-0.201**
members (=1)			(0.075)			(0.079)
Self-employed household			0.197***			0.167**
members (=1)			(0.067)			(0.075)
F-Stat	16.144	23.101	24.935	16.399	25.619	26.806
Kleibergen F-Stat				29.119	26.839	24.920
Observations	635	635	635	635	635	635

Notes: Farm-household data (survey I). Instrument is based on log distance to the closest palm oil mill. Regency and survey dummies are included. At village level, we control for the share of land with systematic or sporadic land titles, bordering large-scale plantations, transmigrant village and the number of conflicts between farmers and companies in the last 10 years. Due to taking the log eight observations with zero or negative income were dropped. Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A7: Effect of oil palm cultivation on employment status of individuals in farm households (IV models)

	(1) Working (=1) (Men)	(2) Working (=1) (Women)	(3) Working on-farm (=1) (Men)	(4) Working on-farm (=1) (Women)	(5) Working off-farm (=1) (Men)	(6) Working off-farm (=1) (Women)	(7) Self employed off-farm (=1) (Men)	(8) Self employed off-farm (=1) (Women)
Share of oil palm (0-1)	0.071	0.076	0.027	-0.603*	0.183	0.098	-0.107	0.328
	(0.131)	(0.317)	(0.204)	(0.324)	(0.261)	(0.295)	(0.222)	(0.218)
Age	0.032***	0.059***	0.050***	0.045***	0.045***	0.031***	0.006	0.018***
	(0.005)	(0.008)	(0.006)	(0.007)	(0.008)	(0.007)	(0.006)	(0.004)
Age squared	-3.6e-04**	-0.001***	-4.74e-04***	-0.001	-0.001	-3.84e-04***	-6.5e-05	-2.28e-04***
	(6.31e-05)	(1.03e-04)	(7.4e-05)	(8.81e-05)	(1.03e-04)	(8.63e-05)	(7.08e-05)	(5.36e-05)
Education level (degree)	8.62e-07	0.011	-0.049***	-0.048***	0.025*	0.046***	-0.015	-0.003
	(0.008)	(0.016)	(0.012)	(0.014)	(0.014)	(0.016)	(0.012)	(0.008)
Student (=1)	-0.660***	-0.173***	-0.147***	0.117**	-0.347***	-0.206***	-0.020	0.009
	(0.054)	(0.061)	(0.051)	(0.049)	(0.066)	(0.060)	(0.053)	(0.035)
Migrant household (=1)	0.014	0.038	0.006	0.060	0.031	-0.011	-0.020	-0.035
	(0.017)	(0.039)	(0.027)	(0.039)	(0.036)	(0.037)	(0.032)	(0.027)
Total farm size (ha)	4.1e-04	-0.009***	0.001	-0.005	-0.005	-0.008**	0.012**	-0.001
	(0.002)	(0.003)	(0.003)	(0.003)	(0.005)	(0.003)	(0.005)	(0.002)
Number of household members	0.016	-0.016	0.036**	0.002	0.053***	-0.009	0.021	-0.015
	(0.011)	(0.019)	(0.016)	(0.020)	(0.020)	(0.018)	(0.017)	(0.012)
Number of adults	-0.019	0.005	-0.087***	-0.044	-0.067**	0.015	-0.045*	0.016
	(0.014)	(0.028)	(0.020)	(0.027)	(0.026)	(0.026)	(0.023)	(0.019)
Productive farm (=1)	-0.022	-0.059	0.111**	-0.010	-0.153***	-0.103*	0.001	0.002
	(0.026)	(0.061)	(0.049)	(0.063)	(0.048)	(0.062)	(0.044)	(0.048)
Distance to Jambi City (km)	4.05e-04	0.001	0.001	-0.002	-2.2e-04	0.001	-0.001	0.001
	(4.49e-04)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
F-Stat	115.892	21.51	158.193	14.592	30.950	6.017	2.851	2.262
Kleibergen F-Stat	21.901	17.69	21.901	17.621	21.901	17.621	21.901	17.621
Observations	961	901	961	901	961	901	961	901

Notes: Farm-household data (survey I). IV estimates are reported. Instrument is based on log distance to the closest palm oil mill. Regency and survey dummies are included. At village level, we control for the share of land with systematic or sporadic land titles, bordering large-scale plantations, transmigrant village and the number of conflicts between farmers and companies in the last 10 years. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A8: Effect of oil palm cultivation on employment status of individuals in farm-households (Probit models)

	(1) Working (=1) (Men)	(2) Working (=1) (Women)	(3) Working on farm (=1) (Men)	(4) Working on farm (=1) (Women)	(5) Working off-farm (=1) (Men)	(6) Working off-farm (=1) (Women)	(7) Self employed off-farm (=1) (Men)	(8) Self employed off-farm (=1) (Women)
Share of oil palm (0-1)	-0.005	-0.060	0.007	-0.138***	0.098**	0.022	0.036	0.064***
	(0.020)	(0.046)	(0.031)	(0.047)	(0.043)	(0.040)	(0.045)	(0.022)
Age	0.023***	0.057***	0.037***	0.056***	0.042***	0.035***	0.007	0.024***
	(0.004)	(0.007)	(0.005)	(0.008)	(0.008)	(0.006)	(0.005)	(0.004)
Age squared	-2.55e-04***	-0.001***	-0.001***	-6.21e-04***	-5.26e-04***	-0.001***	-7.87e-05	-3.0e-04***
	(5.04e-05)	(8.62e-05)	(7.01e-05)	(1.0e-04)	(1.03e-04)	(7.60e-05)	(6.23e-05)	(5.15e-05)
Education level (degree)	0.001	0.014	-0.055***	-0.054***	0.025*	0.049***	-0.017	-0.001
	(0.008)	(0.014)	(0.009)	(0.013)	(0.013)	(0.014)	(0.012)	(0.008)
Student (=1)	-0.218***	-0.300***			-0.462***	-0.275***	-0.048	
	(0.032)	(0.071)			(0.096)	(0.063)	(0.082)	
Migrant household (=1)	0.017	0.038	0.006	0.032	0.032	-0.009	-0.024	-0.025
	(0.017)	(0.031)	(0.025)	(0.031)	(0.036)	(0.029)	(0.029)	(0.022)
Total farm size (ha)	3.78e-04	-0.010***	0.002	-0.008**	-0.004	-0.009**	0.008***	0.001
	(0.002)	(0.004)	(0.002)	(0.003)	(0.004)	(0.004)	(0.002)	(0.002)
Number of household members	0.021***	-0.012	0.025*	0.002	0.055***	-0.009	0.018	-0.011
	(0.008)	(0.019)	(0.014)	(0.018)	(0.013)	(0.018)	(0.014)	(0.011)
Number of adults	-0.032***	-0.002	-0.069***	-0.033	-0.070***	0.015	-0.039**	0.004
	(0.009)	(0.025)	(0.015)	(0.022)	(0.019)	(0.023)	(0.016)	(0.013)
Productive farm (=1)	-0.016	-0.059	0.085*	0.003	-0.164**	-0.087*	0.001	-0.004
	(0.033)	(0.053)	(0.046)	(0.047)	(0.078)	(0.049)	(0.039)	(0.041)
Distance to Jambi City (km)	1.94e-04	0.001	-0.001	0.001	0.001*	6.73e-04	-0.001	4.23e-04
	(2.01e-04)	(4.66e-04)	(4.02e-04)	(0.001)	(4.34e-04)	(5.14e-04)	(4.49e-04)	(2.78e-04)
Chi2	569.705	377.687	577.946	391.507	913.610	459.128	119.381	179.322
Observations	961	901	961	901	961	901	961	901

Notes: Farm-household data (survey I). Marginal effects are reported. Regency and survey dummies are included. At village level, we control for the share of land with systematic or sporadic land titles, bordering large-scale plantations, transmigrant village and the number of conflicts between farmers and companies in the last 10 years. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A9: Effect of oil palm cultivation on employment status of individuals in farm-households (oil palm farm households)

	(1)	(2)	(3)	(4)	(5)	(6)
	Working (=1) (Men)	Working (=1) (Women)	Working off-farm (=1) (Men)	Working off-farm (=1) (Women)	Self employed off-farm (=1) (Men)	Self employed off-farm (=1) (Women)
Share of oil palm (0-1)	0.408	0.976	-1.245	0.010	0.513	0.222
	(0.426)	(0.711)	(0.794)	(0.518)	(0.544)	(0.398)
Age	0.032***	0.003	0.051***	0.005	0.026***	0.006
	(0.005)	(0.008)	(0.009)	(0.007)	(0.006)	(0.005)
Age squared	-3.25e-04***	-3.05e-05	-0.001***	-4.86e-05	-2.95e-04***	-8.12e-05
	(5.91e-05)	(9.87e-05)	(1.07e-04)	(8.62e-05)	(7.40e-05)	(6.75e-05)
Education level	-0.013	0.016	0.081***	0.083***	0.002	-0.001
	(0.013)	(0.020)	(0.020)	(0.015)	(0.013)	(0.011)
Student (=1)	-0.621***	-0.214**	-0.417***	-0.386***	-0.008	-0.047
	(0.049)	(0.083)	(0.076)	(0.068)	(0.050)	(0.036)
Migrant household (=1)	-0.086	-0.138	0.134	0.075	-0.072	0.013
	(0.056)	(0.109)	(0.110)	(0.076)	(0.071)	(0.061)
Total farm size (ha)	0.002	0.003	-0.005	-0.001	0.009***	0.001
	(0.002)	(0.004)	(0.005)	(0.002)	(0.004)	(0.002)
Number of HH members	-0.011	-0.035*	-0.001	-0.018	-0.007	-0.011
	(0.011)	(0.019)	(0.023)	(0.015)	(0.016)	(0.010)
Number of adults	0.003	0.043*	-0.016	0.012	0.008	-0.001
	(0.017)	(0.026)	(0.033)	(0.020)	(0.024)	(0.015)
Productive farm (=1)	-0.067	-0.057	0.121	-0.053	-0.024	-0.032
	(0.060)	(0.100)	(0.149)	(0.082)	(0.080)	(0.055)
Distance to Jambi City (km)	4.01e-04	0.002	-0.003	-0.001	0.001	-6.41e-05
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
F-Stat	540.2	3.643	16.12	6.470	4.822	4.125
Kleibergen F-Stat	9.505	10.58	9.505	10.58	9.505	10.58
Observations	1126	1006	1126	1006	1126	1006

Notes: Oil palm farmer data (survey III). IV estimates are reported. Instrument is based on log distance to the closest palm oil mill. Regency and survey dummies are included. At village level, we control for transmigrant village. Marginal effects based on probit models are reported. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, $^{**}p < 0.05$, *** $p < 0.01$.

Table A10: Effect of oil palm expansion on employment status of individuals in labor households

	(1)	(2)	(3)	(4)	(5)	(6)
	Working (=1) (Men)	Working (=1) (Women)	Employed in agriculture (=1) (Men)	Employed in agriculture (=1) (Women)	Hours working in agricultural wage labor (Men)	Hours working in agricultural wage labor (Women)
Oil palm area (km2)	0.234	0.947	0.071	0.810	2.591*	3.751
per HH in village	(0.402)	(0.791)	(0.758)	(0.570)	(1.437)	(3.877)
Age	0.029***	0.034***	0.050***	0.027***	-0.004	0.028
	(0.004)	(0.008)	(0.006)	(0.007)	(0.018)	(0.048)
Age squared	-3.25e-04***	-3.51e-04***	-0.001***	-3.07e-04***	4.56e-05	-0.001
	(5.12e-05)	(1.02e-04)	(8.51e-05)	(8.89e-05)	(2.27e-04)	(0.001)
Education level	-0.002	0.008	-0.020	-0.039***	-0.024	-0.112
(degree)	(0.010)	(0.018)	(0.014)	(0.012)	(0.029)	(0.119)
Student (=1)	-0.264***	-0.309*				
	(0.065)	(0.171)				
Migrant household	-4.15e-04	-0.013	-0.057	-0.011	0.113*	0.110
(=1)	(0.019)	(0.041)	(0.038)	(0.028)	(0.066)	(0.219)
Total farm size (ha)	0.012	0.092*	0.001	-0.045	-0.019	0.077
	(0.027)	(0.050)	(0.052)	(0.037)	(0.092)	(0.275)
Number of	-0.020*	-0.030	-0.006	0.004	0.040	-0.093
household members	(0.012)	(0.019)	(0.020)	(0.015)	(0.037)	(0.122)
Number of adults	0.006	0.012	-0.037	0.002	-0.028	0.261*
	(0.016)	(0.028)	(0.025)	(0.021)	(0.053)	(0.143)
Distance to Jambi	-1.03e-04	0.001	-0.001**	0.001	0.004	2.83e-04
City (km)	(2.82e-04)	(0.001)	(4.84e-04)	(3.64e-04)	(0.003)	(0.007)
Chi2/R2	160.264	111.169	201.176	64.548	0.10	0.49
Observations	598	568	564	546	310	48

Notes: Labor-household data (survey II). Marginal effects are reported based on probit models (columns 1-4) and OLS (columns 5-6) models. For columns (3) and (4) we have missing data. For column (5) and (6) we do not have data for the complete sample due merging data with survey I. Regency and survey dummies are included. At village level, we control for the share of land with systematic or sporadic land titles, bordering large-scale plantations, transmigrant village and the number of conflicts between farmers and companies in the last 10 years. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A11: Effect of oil palm expansion on income and labor hours of trader households

	(1) Income per month (log)	(2) Income per hour (log)	(3) Working hours in trading agricultural products	(4) Total working hours
Oil palm area (km2) per HH in village	4.069	3.587	-112.963	53.429
	(3.244)	(5.155)	(72.691)	(175.827)
Age	-0.017**	-0.001	-0.163	-0.949**
	(0.008)	(0.011)	(0.325)	(0.433)
Education	-0.002	-0.023	2.154	0.120
	(0.053)	(0.070)	(1.972)	(3.244)
Women (=1)	0.549**	0.706**	-5.885	-1.143
	(0.261)	(0.328)	(8.058)	(16.848)
Farm size (ha)	0.001	0.002	-0.060*	-0.095**
	(0.001)	(0.002)	(0.030)	(0.043)
Transmigrant household (=1)	-0.280	-0.750**	3.251	20.235
	(0.218)	(0.279)	(7.245)	(15.255)
Number of household members	0.071**	0.034	1.492	1.613
	(0.033)	(0.040)	(1.186)	(2.956)
Distance to Jambi city	0.002	-0.005	-0.174	0.733**
	(0.004)	(0.006)	(0.115)	(0.280)
Melayu (=1)	-0.436*	-0.302	13.515	-11.880
	(0.252)	(0.341)	(9.762)	(15.125)
Javanese (=1)	0.053	0.344	10.847	-27.409*
	(0.218)	(0.305)	(8.067)	(14.153)
Constant	15.758***	11.946***	12.615	157.696***
	(1.065)	(1.330)	(29.258)	(40.530)
F-Stat	6.603	5.122	10.974	4.536
Observations	294	294	298	298

Notes: Trader-household data (survey IV). OLS estimates are reported. Regency and survey dummies are included. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A12: Effect of oil palm expansion on working hours - Men

	(1) Total working hours	(2) Total working hours in agricultural sector	(3) Total working hours in non-agricultural sector	(4) Total working hours in agricultural family labor	(5) Total working hours in agricultural wage labor	(6) Total working hours in non-agricultural wage labor	(7) Total working hours in agricultural self-employment
Share of smallholder oil palm area in regency (0-1)	21.225	63.999	-7.099	70.565	-11.383	-15.863	-7.511
	(46.483)	(69.186)	(48.589)	(90.085)	(85.249)	(46.842)	(73.318)
F-Stat	24.045	17.047	34.163	7.156	8.804	22.457	21.916
Kleibergen F-Stat	13.238	13.238	13.238	13.371	13.254	13.218	13.238
Observations	2911	2910	2911	2858	2790	2908	2910

Notes: SAKERNAS and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of working age men, national oil palm expansion, regency fixed-effects, year dummies and region trends. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A13: Effect of oil palm expansion on working hours - Women

	(1) Total working hours	(2) Total working hours in agricultural sector	(3) Total working hours in non-agricultural sector	(4) Total working hours in agricultural family labor	(5) Total working hours in agricultural wage labor	(6) Total working hours in non-agricultural wage labor	(7) Total working hours in agricultural self-employment
Share of smallholder oil palm area in regency (0-1)	97.924	67.353	18.383	141.539	-36.243	-97.857	13.998
	(61.170)	(75.306)	(63.298)	(87.220)	(135.794)	(68.708)	(82.037)
F-Stat	19.606	11.763	24.834	13.752	5.728	23.919	12.476
Kleibergen F-Stat	13.095	13.164	13.017	13.161	12.140	12.842	13.404
Observations	2911	2908	2907	2863	2645	2888	2874

Notes: SAKERNAS and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of working age women, national oil palm expansion, regency fixed-effects, year dummies and region trends. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A14: Effect of oil palm expansion on sectoral shares (2001-2003-2006-2011)

	(1) Share of women working	(2) Share of women in non-agricultural sector	(3) Share of women in agricultural family labor	(4) Share of women in agricultural wage labor	(5) Share of women in non-agricultural self-employment	(6) Share of women in non-agricultural wage labor	(7) Share of men working	(8) Share of men in non-agricultural sector	(9) Share of men in agricultural family labor	(10) Share of men in agricultural wage labor	(11) Share of men in non-agricultural self-employment	(12) Share of men in non-agricultural wage labor
Share of smallholder oil palm area in regency (0-1)	-1.991	6.476**	-4.258	-0.339	0.283	5.148**	-1.644	1.578	0.019	2.162*	0.821	0.989
	(2.106)	(3.119)	(2.858)	(1.121)	(1.452)	(2.083)	(1.091)	(1.876)	(1.056)	(1.211)	(1.170)	(1.310)
F-Stat	9.106	13.340	11.226	4.703	10.275	23.794	14.831	32.752	5.646	4.135	5.315	53.199
Kleibergen F-Stat	11.003	11.003	11.003	11.003	11.003	11.003	11.215	11.215	11.215	11.215	11.215	11.215
Observations	834	834	834	834	834	834	834	834	834	834	834	834

Notes: SAKERNAS, PODES and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of working age men or women respectively, national oil palm expansion, regency fixed-effects, year dummies and region trends. Outcome variables are shares ranging between 0 and 1. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A15: Effect of oil palm expansion and infrastructure on sectoral shares (2001-2003-2006-2011)

	(1) Share of women working	(2) Share of women in non-agricultural sector	(3) Share of women in agricultural family labor	(4) Share of women in agricultural wage labor	(5) Share of women in non-agricultural self-employment	(6) Share of women in non-agricultural wage labor	(7) Share of men working	(8) Share of men in non-agricultural sector	(9) Share of men in agricultural family labor	(10) Share of men in agricultural wage labor	(11) Share of men in non-agricultural self-employment	(12) Share of men in non-agricultural wage labor
Share of smallholder oil palm area in regency (0-1)	-1.585	7.369**	-5.079	-0.273	0.208	5.946**	-1.774	2.121	0.014	2.201*	1.001	1.374
	(2.230)	(3.495)	(3.180)	(1.216)	(1.614)	(2.425)	(1.203)	(2.108)	(1.155)	(1.300)	(1.254)	(1.525)
Share of villages with asphalt roads (0-1)	0.040	0.061	-0.029	-0.026	0.010	0.042	0.001	0.032	0.013	-0.021	0.028	0.012
	(0.042)	(0.068)	(0.055)	(0.025)	(0.033)	(0.046)	(0.024)	(0.045)	(0.021)	(0.024)	(0.024)	(0.034)
Share of households with electricity (0-1)	-0.023	0.011	0.010	-0.018	0.028	-0.043	0.002	-0.022	0.006	0.008	0.003	-0.025
	(0.039)	(0.059)	(0.055)	(0.020)	(0.031)	(0.039)	(0.020)	(0.039)	(0.018)	(0.023)	(0.023)	(0.029)
Share of villages with junior high school (0-1)	0.045	-0.098	0.068	0.006	-0.013	-0.046	-0.016	-0.086*	0.060***	0.035	-0.066***	-0.009
	(0.039)	(0.072)	(0.056)	(0.022)	(0.031)	(0.043)	(0.025)	(0.047)	(0.019)	(0.030)	(0.024)	(0.032)
F-Stat	6.670	10.044	8.091	3.832	6.927	18.151	11.229	24.656	5.297	3.670	4.655	37.458
Kleibergen F-Stat	9.616	9.616	9.616	9.616	9.616	9.616	9.722	9.722	9.722	9.722	9.722	9.722
Observations	825	825	825	825	825	825	825	825	825	825	825	825

Notes: SAKERNAS, PODES and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. No data for 2008. We control for mean age of working age men or women respectively, national oil palm expansion, regency fixed-effects, year dummies and region trends. Outcome variables are shares ranging between 0 and 1. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A16: Effect of oil palm expansion on sectoral shares (2001-2006-2011)

	(1) Share of women working	(2) Share of women in non-agricultural sector	(3) Share of women in agricultural family labor	(4) Share of women in agricultural wage labor	(5) Share of women in non-agricultural self-employment	(6) Share of women in non-agricultural wage labor	(7) Share of men working	(8) Share of men in non-agricultural sector	(9) Share of men in agricultural family labor	(10) Share of men in agricultural wage labor	(11) Share of men in non-agricultural self-employment	(12) Share of men in non-agricultural wage labor
Share of smallholder oil palm area in regency (0-1)	-2.972	6.395*	-6.317*	-0.112	-0.160	4.779**	-1.124	0.912	0.171	2.115	0.647	0.761
	(2.248)	(3.676)	(3.551)	(1.322)	(1.740)	(2.155)	(1.037)	(2.216)	(1.185)	(1.298)	(1.398)	(1.489)
F-Stat	8.766	6.515	3.170	3.328	4.649	18.042	13.086	18.396	3.357	2.586	2.381	32.404
Kleibergen F-Stat	10.659	10.659	10.659	10.659	10.659	10.659	10.868	10.868	10.868	10.868	10.868	10.868
Observations	625	625	625	625	625	625	625	625	625	625	625	625

Notes: SAKERNAS, Census and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. We control for mean age of working age men or women respectively, national oil palm expansion, regency fixed-effects, year dummies and region trends. Outcome variables are shares ranging between 0 and 1. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A17: Effect of oil palm expansion and migration on sectoral shares (2001-2006-2011)

	(1) Share of women working	(2) Share of women in non-agricultural sector	(3) Share of women in agricultural family labor	(4) Share of women in agricultural wage labor	(5) Share of women in non-agricultural self-employment	(6) Share of women in non-agricultural wage labor	(7) Share of men working	(8) Share of men in non-agricultural sector	(9) Share of men in agricultural family labor	(10) Share of men in agricultural wage labor	(11) Share of men in non-agricultural self-employment	(12) Share of men in non-agricultural wage labor
Share of smallholder oil palm area in regency (0-1)	-2.848	6.350*	-6.253*	-0.086	-0.239	4.833**	-1.070	0.965	0.167	2.091	0.657	0.806
	(2.166)	(3.650)	(3.524)	(1.321)	(1.757)	(2.155)	(1.013)	(2.189)	(1.176)	(1.286)	(1.394)	(1.487)
Share of migrants (0-1)	0.475*	-0.194	0.245	0.097	-0.297*	0.187	0.228**	0.206	-0.022	-0.101	0.033	0.183
	(0.253)	(0.374)	(0.401)	(0.118)	(0.171)	(0.261)	(0.092)	(0.181)	(0.129)	(0.150)	(0.121)	(0.141)
F-Stat	7.853	5.852	2.856	3.019	4.110	16.450	12.977	17.650	2.974	2.418	2.145	29.443
Kleibergen F-Stat	10.732	10.732	10.732	10.732	10.732	10.732	10.955	10.955	10.955	10.955	10.955	10.955
Observations	624	624	624	624	624	624	624	624	624	624	624	624

Notes: SAKERNAS, Census and Tree crop statistics data. IV estimates are reported. Instrument is based on max. attainable oil palm yield per regency interacted with national oil palm expansion over time. We control for mean age of working age men or women respectively, national oil palm expansion, regency fixed-effects, year dummies and region trends. Outcome variables are shares ranging between 0 and 1. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.