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Oil palm adoption, household welfare and nutrition among smallholder farmers in Indonesia

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Johann-Friedrich-Blumenbach Institut für Zoologie und Anthropologie, Fakultät für Biologie und Psychologie

Abstract: The recent expansion of oil palm in Indonesia is largely smallholder-driven. However, its socio-economic implications are under-examined. Analyzing farm-household data from Jambi Province, Sumatra, oil palm adoption is found to have positive consumption and nutrition effects. However, these effects are largely due to farm size expansion that is associated with oil palm adoption. Potential heterogeneity of effects among oil palm adopters is examined using quantile regressions. While nutrition effects of oil palm adoption are found to be homogenous across quantiles, the effects on non-food expenditure are expressed more strongly at the upper end of the expenditure distribution.

Keywords: Non-food cash crops, oil palm expansion, smallholder livelihoods, quantile regression, Indonesia

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(Email: awansunito@gmail.com)

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OIL PALM ADOPTION, HOUSEHOLD WELFARE AND NUTRITION AMONG SMALLHOLDER FARMERS IN INDONESIA

Michael Euler[*1], Vijesh Krishna[*], Stefan Schwarze[*], Hermanto Siregar[**] and Matin Qaim[*]

[*]Department of Agricultural Economics and Rural Development, Georg-August-University of Goettingen, Platz der Goettinger Sieben 5, D-37073 Goettingen, Germany

[**]Faculty of Economics and Management, Bogor Agricultural University (IPB), Indonesia

ABSTRACT

The recent expansion of oil palm in Indonesia is largely smallholder-driven. However, its socio-economic implications are under-examined. Analyzing farm-household data from Jambi Province, Sumatra, oil palm adoption is found to have positive consumption and nutrition effects. However, these effects are largely due to farm size expansion that is associated with oil palm adoption. Potential heterogeneity of effects among oil palm adopters is examined using quantile regressions. While nutrition effects of oil palm adoption are found to be homogenous across quantiles, the effects on non-food expenditure are expressed more strongly at the upper end of the expenditure distribution.

KEY WORDS: Non-food cash crops; oil palm expansion; smallholder livelihoods; quantile regression; Indonesia

[1] Corresponding author. Tel.: +49551 3913623. E-mail address: meuler@gwdg.de.

1. INTRODUCTION

Oil palm has become one of the most rapidly expanding crops throughout the humid tropics, because of the rising demand for vegetable oils and biofuels, favorable government policies in producer countries, as well as its superior production potential and profitability compared to alternative land uses (Carrasco et al., 2014; Sayer et al., 2012; OECD and FAO, 2011; McCarthy and Cramb, 2009). Over the last two decades, the area under oil palm has more than doubled and its production quadrupled (FAOSTAT, 2014). Over 85% of the world´s palm oil production originates from Indonesia and Malaysia, which offer favorable agro-ecological growing conditions with relative abundance of cultivable land and agricultural labor (Basiron, 2007). The increasing product demand coupled with localized production of oil palm and related land use changes have significant environmental and socio-economic implications.

While the environmental consequences of associated land use changes have received considerable research focus (Carrasco et al., 2014; Margono et al., 2014; Koh and Lee, 2012; Wilcove and Koh, 2010; Buttler and Laurence, 2009; Danielsen et al., 2009), empirical studies on its socio-economic implications remain scarce. The human dimension of oil palm expansion deserves special attention, especially since the recent land use changes are largely driven by smallholder farmers. Smallholders account for 41% of the total oil palm area and for 36% of the total fresh fruit bunch (FFB) production in Indonesia, the world´s leading producer of palm oil (ISPOC, 2012). If the current trend continues, smallholders are expected to dominate the Indonesian palm oil sector in the near future (BPS, 2015). The outcome of oil palm adoption on farmers' livelihoods is a widely debated topic: While threats include an increasing vulnerability and economic marginalization of the rural population (McCarthy, 2010; Rist et al., 2010; Sheil et al., 2009), as well as unequally distributed benefits among oil palm adopters (Cramb and Curry, 2012; McCarthy, 2010), opportunities entail livelihood improvements through increased incomes, rural development and poverty reduction (Cahyadi and Waibel, 2013; Sayer et al., 2012; Feintrenie et al., 2010; Rist et al., 2010). Further, in a broad sense, farmer specialization in non-food cash crops like oil palm has been criticized for decreasing on farm production diversity, declining significance of subsistence food crops, greater farmer dependency on trade and markets to satisfy nutritional needs, and increased livelihood vulnerability to price shocks on international commodity markets

(Pellegrini and Tasciotti, 2014; Jones et al., 2014; World Bank, 2007; von Braun, 1995). For a society, however, the negative implications might be compensated by increased household incomes resulting from the adoption of non-food cash crops.

Surprisingly, there is only limited empirical evidence on the livelihood and nutritional implications of oil palm adoption (Cramb and Curry, 2012; Feintrenie et al., 2010; Rist et al., 2010). To the best of our knowledge, only Krishna et al. (2015), and Cahyadi and Waibel (2013) have analyzed the welfare implication of oil palm adoption empirically, building on econometric models. Krishna et al. (2015) employ endogenous switching regressions to model the impacts of oil palm adoption using total annual consumption expenditures as a proxy for household welfare. Cahyadi and Waibel (2013) focus on the effects of contract versus independent oil palm cultivation, however not including non-adopters in their analysis. We are not aware of any study that has analyzed the implications of oil palm adoption on the composition of household consumption expenditures, calorie consumption and dietary quality. Disentangling welfare implications of oil palm expansion on smallholders is of paramount importance, not only to understand how government strategies and trade policies affect smallholders, but also to foresee how these factors incentivize smallholders to expand their farming activities that may give rise to social challenges and significant ecological problems. Moreover, in an environment of widespread malnutrition and undernourishment it is crucial to assess the implications of the recent expansion of oil palm plantations on household nutrition and the prevalence of food security.[2]

The present study contributes to the literature by quantifying the implications of oil palm cultivation on smallholder livelihoods, using household survey data from Jambi province, Sumatra. Effects of oil palm adoption on consumption expenditure (food and non-food expenditure), calorie consumption and dietary quality are analyzed using econometric models. Unlike more traditional land uses (e.g. rubber plantations), the cultivation of oil palm requires farmers to adapt to a new set of agronomic management practices and to get accustomed to new input and output marketing channels. It is likely that smallholder respond differently to these emerging challenges. Thus, the benefits of oil palm adoption are expected

[2] In 2013, 37.2% of all Indonesian children were stunted and 11.4% of the Indonesian population lived below the poverty line (FAO et al., 2014).

to differ among the group of adopters. In order to account for possible heterogeneity of effects, we rely on a set of quantile regressions.

This paper is structured as follows. Section 2 lays out possible impact pathways of oil palm cultivation on household welfare and nutrition and introduces potential sources of impact heterogeneity. Section 3 describes the study area, data base and socio-economic characteristics of the sample and highlights differences in land use profitability between oil palm and rubber plantations. Section 4 introduces the analytical framework, the econometric approach and addresses the issue of endogeneity due to self-selection bias. Section 5 presents and discusses the results, while section 6 concludes.

2. Potential impact pathways of oil palm adoption

How does oil palm expansion affect household consumption expenditures and calorie consumption of smallholder farmers? It may be noted that the initial diffusion of oil palm in Jambi was mainly related to government supported smallholder schemes, in which farmers operated under contractual ties with large scale companies (Zen et al., 2006). More recently, smallholders took up oil palm independently and sporadically, without any government or private sector support (Euler et al., 2015; Gatto et al., 2014). Irrespective of whether the smallholder adoption was sporadic or supported, oil palm was a novel crop and a livelihood option in the context of smallholder agriculture. Smallholders either specialize in oil palm cultivation, or keep it supplementary to existing crops, especially rubber plantations (Euler et al., 2015; BPS, 2012). As management requirements between both crops differ widely, the adoption of oil palm will induce changes in the allocation of household resources (land, labor and capital) between and within farm and off-farm activities. In principle, there are two mayor pathways through which oil palm cultivation could affect household income, consumption expenditure and calorie consumption.

I. *Through increases in farm income*: Oil palm adoption might release household labor resources by demanding lower levels of labor input and thereby allow the expansion of farm area and the diversification of crop production. The reallocation of household resources might induce a change in on-farm production patterns and in the composition of farm income. Oil palm adoption may also directly affect household nutrition through a shift from food to non-food crop production.

II. *Through increases in off-farm income*: Household labor and capital resources might also be re-allocated between farm and off-farm activities. In particular, the amount of family labor invested in off-farm activities might increase and alter the composition of total household income and the relative importance of farm and off-farm income sources.

Are welfare effects of oil palm consistent across the poor and the rich? While average household incomes are expected to rise with oil palm adoption, the magnitude of observed increases would depend on the capacity of a given household to expand its farm size and diversify its income sources. These depend on a set of household and farm attributes that are not homogeneous across adopters. In particular, those adopters with better access to capital and land may find it easier to expand their farms, and those residing in proximity to commercial centers might have better off-farm income opportunities. Hence, it is unlikely that adopters are able to realize income and consumption expenditure surpluses in a similar magnitude. Some adopters, especially those with surplus family labor, might not even realize any income effect of oil palm.

We further expect to observe heterogeneous effects of oil palm adoption on consumption expenditure and calorie consumption, as adopters may have different income elasticities of demand. In particular, the effects of oil palm adoption are likely to depend on the household´s general consumption levels. Oil palm adoption might positively affect food expenditures and calorie consumption especially for those adopters at the lower tail of the distribution of total consumption expenditures. In turn, there might be no significant effect at the upper tail, as household are at saturation levels with respect to food intake. Moreover, adoption might positively affect dietary quality at the mid to upper tails of the total expenditure distribution as households have the economic means to not only meet their calorie needs but to also diversify their diets by consuming more nutritious but also more expensive food items. We further expect the effects of adoption on non-food expenditure to become larger while moving from the lower to the upper quantiles of the distribution of total consumption expenditure. In addition, the demand for non-food items is expected to be more elastic compared to food items. Knowing the effects of oil palm adoption at different points of the expenditure and calorie consumption distributions gives a more complete picture of its economic effects.

3. Data base, sample characteristics and land use profitability

3.1 Study area and data base

A comprehensive farm-household survey, conducted in Jambi province, Sumatra, provides the primary database for the present study. Jambi is one of the hotspots of recent oil palm expansion. Among all provinces in Indonesia, it ranks seventh in terms of cultivated oil palm area (over 0.72 million hectares) and sixth in terms of crude palm oil (CPO) production (around 1.70 million tons per year) (BPS, 2015). As previously indicated, this development largely involves smallholder farmers.

The prevalence of plantation agriculture might have significant impacts on farmer welfare in the study area. Only around 8% of Jambi´s total population lives below the poverty line of 270 thousand Indonesian Rupiah (IDR) per capita per month (around 28 US Dollar, exchange rate September 2012), which is considerably below the Indonesian average of 12% (BPS, 2014). Across Indonesia, Jambi is among the provinces with the highest average calorie consumption per capita (MPW et al., 2006) and the lowest vulnerability to food insecurity (DKP et al., 2009). Delineation of the causes of relative economic welfare of Jambi farmers has not been carried out.

In order to represent the major shares of oil palm farmers and cultivated oil palm area, we purposively selected five lowland regencies (Sarolangun, Batanghari, Muaro Jambi, Tebo, Bungo). To ensure spatial diversity within these regencies, we followed a multi-stage random sampling approach, stratifying on the regency, district and village level. Accordingly, four districts per regency, and two villages per district were selected randomly. As selected villages were found to differ significantly with respect to population size, households were selected proportionally according to village size, averaging 15 households per village. Details of the sampling methodology are included in Faust et al. (2013). An additional five villages in which supporting research activities were carried out were purposively selected. From these villages, 83 households were selected randomly, yielding a total of 683 household-level observations. For our statistical analysis, we excluded 19 observations.[3] Hence our final analysis is composed of 664 farmers, including 199 oil palm adopters and 465 non-adopters. We control for non-randomly selected villages in the statistical analysis. Data was collected between September and December 2012 through face to face interviews using structured questionnaires. Information on socio-economic household characteristics, farm endowments, agricultural activities, and off-farm income sources, as well as a detailed consumption expenditure module were gathered.

3.2 Sample characteristics

There is a significant difference in many socio-economic variables between adopters and non-adopters, as shown in Table 1. With respect to farm characteristics, adopters tend to have larger land endowments. This can mainly be attributed to the fact that a considerable share of adopters is also engaged in the cultivation of rubber, yet on a significantly smaller area than non-adopters. Rist et al. (2010) also report a preference of smallholders to cultivate both crops. Accordingly, farmers use oil palm to supplement rubber harvests during the rainy season, in which rubber yields are considerably lower. Cultivating both crops would also help to reduce price fluctuations in international markets. Lee et al. (2014) find oil palm farmers to derive around one fourth of their total household income through non-oil palm related activities. There is no difference across adopters and non-adopters with respect to the number of livestock units owned by a household. While agricultural income constitutes the main share of total household income for both groups, adopters derive a larger share of total household income through farm activities.

With respect to off-farm income sources, adopters are found to be engaged in employment activities to a lesser extent than non-adopters. Nonetheless, they are engaged more frequently in self-employment activities, such as trading, or managing a shop or restaurant. With respect to socio-economic characteristics, adopters do not differ from non-adopters in terms of age of the household head or the size of the household. Adopters are slightly better educated and many have migrated to the study villages with out-of-Sumatra origin. This is not surprising, as early oil palm diffusion was associated with government-

[3] These households showed large deviations (>3 standard deviations) from standardized means of total consumption expenditures, non-food expenditures, food expenditures and calorie consumption levels. They further differed significantly from the remaining households with respect to a set of socio-economic and farm characteristics.

supported trans-migration programs that brought a large number of Javanese migrants to Sumatra (Zen et al., 2006). Adopters tend to live closer to such market places where daily food- and non-food items are purchased.

Table 1. Descriptive statistics for oil palm adopters and non-adopters.

	Adopters (n=199)	Non-adopters (n=465)	% difference over non-adopters
Farm endowments and agricultural activities			
Cultivated area (ha)	4.6 (3.6)	3.1 (3.1)	48***
Productive oil palm area (ha)	1.9 (1.9)	0	--
Households cultivating rubber (%)	57	93	-39***
Productive rubber area (ha)	1.4 (2.2)	2.1 (2.6)	-33***
Livestock units (number owned by household)	0.8 (3.1)	0.7 (2.1)	14
Share of farm income in total income (%)	71.4 (44.8)	66.3 (50.0)	5.1***
Off-farm income activities			
Share of households with at least one member engaged in…			
Employed activities (%)	39	49	-20***
Self-employed activities (%)	23	18	28
Other socio-economic characteristics			
Age of household head (years)	46.0 (12.5)	45.6 (12.1)	1
Household size (number of AE)	3.0 (1.0)	3.0 (1.0)	0
Education (years of schooling)	7.7 (3.6)	7.3 (3.6)	5***
Household head migrated to place of residence (dummy)	71	46	54***
Household head originates from Sumatra (dummy)	37	58	-36***
Distance to nearest market place (km)	5.7 (7.2)	7.0 (7.5)	-12***

*Notes: Mean values are shown with standard deviations in parenthesis. Oil palm adoption only includes farmers cultivating productive oil palm plots. *** indicates that the differences are statistically significant at the 1% level. US Dollar = 9,387 IDR in 2012 (World Bank, 2015).*

3.3 LAND USE PROFITABILITY

The potential differences between oil palm and rubber plantations with respect to agronomic management practices as well as the levels of capital and labor use for cultivation were already mentioned in the previous section. Descriptive statistics suggest that oil palm adopters have larger farms and obtain a greater share of income from agriculture. Figure 1 and Table 2 explore such differences more comprehensively. Figure 1 shows realized gross margins (sales revenues less material input and hired labor costs) for oil palm and rubber plantations over the plantation life cycle. Thereafter, oil palm does not offer higher returns to land when compared to rubber plantations.

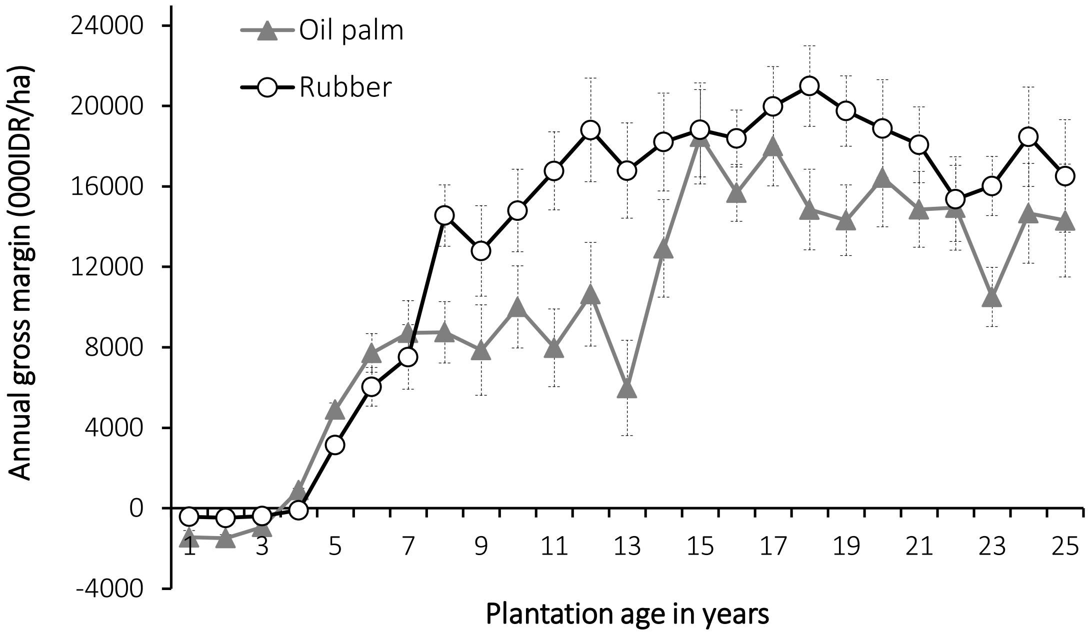

Figure 1. Annual gross margins for oil palm and rubber plantations over plantation age.
Gross margins are recorded in thousand Indonesian Rupiah (000 IDR). Bars indicate standard errors. 1US Dollar = 9,387 IDR in 2012 (World Bank, 2015). Source: Household survey, 2012.

However, oil palm requires considerably lower levels of labor input, which translates into significantly higher returns to labor throughout the entire productive plantation life (Table 2). These findings are also supported by Feintrenie et al. (2010) and Rist et al. (2010). Thus, it can be assumed that the adoption of oil palm generally enables households to obtain similar returns to land compared to rubber farming, while they are able to save a significant amount of family labor, which can be invested in alternative farm and off-farm activities.

Table 2. Annual labor use and returns to labor for oil palm and rubber plantations.

Plantation age (years)	Oil palm			Rubber		
	Number of plots	Annual labor use (days/ha)	Returns to labor (000 IDR/day)	Number of plots	Annual labor use (days/ha)	Returns to labor (000 IDR/day)
6-15	168	29 (17)	460 (450)	323	119*** (106)	105*** (198)
16-25	67	32 (14)	672 (481)	296	136*** (83)	164*** (128)
>25	2	29 (9)	427 (169)	158	120*** (72)	147*** (131)
Overall	363	25 (20)	289 (544)	947	106*** (94)	95*** (190)

*Notes: Mean values are presented along with standard deviations in parenthesis. *** indicates that differences are significant at the 1% level. 1 US Dollar = 9,387 IDR in 2012 (World Bank, 2015).*

4. ANALYTICAL FRAMEWORK

4.1 DEPENDENT VARIABLES

The present study involves an array of dependent variables, viz. annual food and non-food consumption expenditure, daily calorie consumption, and daily calorie consumption from nutritious foods. Household consumption expenditures are measured in thousand Indonesian Rupiah (000 IDR), calorie consumption in kilo calories (kcal). In order to enhance comparability across households, all variables were converted to per adult equivalents (AE), which was constructed following the OECD equivalent scale (OECD, 1982).

To record households´ food expenditure details, the household members in charge of food purchases (often female) were asked to recall the quantities and prices of 132 different food items consumed during the past seven days preceding the interview. Items were checked one by one. Food consumption included market purchases, home production and meals taken outside the household. If quantities were reported in local units, appropriate conversions to liter or kilograms were made. If a food item was consumed from home production, prices were imputed using average market prices as paid by other households residing in the same village.

Energy contents and nutritional composition of all food items were derived from national food composition tables as developed by the *Sustainable Micronutrient Interventions to Control Deficiencies and Improve Nutritional Status and General Health in Asia* (SMILING) project.[4] If a particular food item was not listed in the SMILING database, food composition tables from the database of *Food-standards*, a bi-national government agency based in Australia and New Zealand, or the United States Department of Agriculture were used.[5] Along with total energy consumption, we estimated the consumption of calories from highly nutritious foods. These items include seafood and animal products, fruits and vegetables, as well as pulses and legumes. In contrast to cereals and tubers, these items contain relatively more protein and micronutrients and are therefore used to reflect dietary quality of households (Babatunde and Qaim, 2010).

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[4] *Cf.* Berger et al. (2013) for details on the SMILING project. Food composition tables were retrieved on 20 November 2014 from http://www.nutrition-smiling.eu/content/view/full/48718.

[5] Food nutrient databases were retrieved on 20 November 2014 from http://www.foodstandards.gov.au/science/monitoringnutrients/ausnut/ausnutdatafiles/Pages/foodnutrient.aspx (Food-Standards), and http://ndb.nal.usda.gov/(USDA).

Non-food consumption expenditure was divided into 56 items, including items for basic needs such as housing, education, health related expenses, clothing, private and public transportation, etc. In addition, a number of luxurious consumption items such as electronic equipment, cosmetics, club membership fees, celebrations, and recreational expenses were covered. Expenditures were recorded based either on annual or on monthly recall, according to the frequency of consumption.

Table 3 presents details of dependent variables in the livelihood impact analysis along with a number of nutritional indicators. Total annual consumption expenditures are found to be well above the regional poverty line (3.24 million IDR per capita per year for 2012 for rural Jambi province; BPS, 2014).[6] These figures are in line with the Food Security and Vulnerability Atlas for Indonesia which reports the incidence of poverty to be below 10% in Bungo, Tebo and Muaro Jambi, and between 15-20% in Sarolangun and Batanghari (DKP et al., 2009). Average non-food expenditures are slightly larger than food expenditures. Consumption expenditures are significantly higher for oil palm adopters across all expenditure categories with non-food expenditures surpluses being relatively larger than surpluses in food expenditures. Arguably, additional income from oil palm adoption might be allocated to non-food consumption by farmer households.

The daily calorie consumption for sample households is higher compared to the national average, which was around 1,900 kcal per capita in 2012 (BPS, 2015).[7] Such figures are in line with findings from the Nutrition Map of Indonesia, which reports calorie consumption levels for Jambi province to be above the national average (MPW et al., 2006). Adopters are found consuming more total calories and more calories from nutritious foods. They also stand superior with respect to the food variety score (number of consumed food items) and the dietary diversity score (number of food groups from which food items are consumed).[8] Apparently, adopters do not only increase their calorie consumption, but also improve their diets by consuming more diverse and nutritious foods.

[6] The annual per capita consumption expenditure of sample households is 10.54 million IDR (12.09 for adopters and 9.87 million IDR for non-adopters).
[7] The daily per capita calorie consumption of sample households is 2,195 kcal (2,364 kcal for adopters and 2,124 kcal for non-adopters).
[8] The food variety score indicates the number of consumed food items; the dietary diversity score indicates the number of food groups from which food items are consumed (FAO, 2010).

Table 3. Descriptive statistics for household consumption expenditure and calorie consumption by adoption status.

	Oil palm adopters (n=199)	Non-adopters (n=465)	% difference over non-adopters
Consumption expenditure			
Total annual consumption expenditure (million IDR/AE)	16.72 (8.88)	13.40 (8.04)	25
Annual non-food expenditure (million IDR/AE)	9.52 (7.84)	7.08 (6.67)	34
Annual food expenditure (million IDR/AE)	7.21 (2.92)	6.32 (2.79)	14
Share of food expenditure (% of total expenditure)	48 (15)	51 (14)	-6
Calorie consumption and dietary quality			
Daily calorie consumption (kcal/AE)	3,257 (1,240)	2,889 (1,150)	13
Daily calorie consumption form nutritious foods (kcal/AE)	1,236 (719)	995 (612)	24
Share of calories from nutritious foods	37 (12)	33 (12)	12
Number of food items	29.4 (8.1)	26.2 (7.6)	12
Number of food groups	10.7 (1.1)	10.3 (1.4)	<1

Notes: Mean values are shown with standard deviations in parenthesis. Oil palm adoption only includes farmers cultivating productive oil palm plots. All differences are statistically different at the 1% level. 1 US Dollar = 9,387 IDR in 2012 (World Bank, 2015).

4.2 MODELING CONDITIONAL MEAN EFFECTS

In this section, we specify a set of OLS models to estimate the effects of oil palm adoption on household consumption expenditures and calorie consumption. Formally, we specify the following models:

$$Y_{ij} = \alpha + \gamma OP_{ij} + \sum_{l=1}^{L} \beta_l H_{ij} + \rho R_{ij} + \sigma V_i + \theta_j Z_j + \varepsilon_{ij} \qquad (1)$$

Here Y_{ij} is the respective dependent variable recorded for the ith household from the jth regency and OP_{ij} is a dummy indicating whether a farmer cultivates productive oil palm plantations. As indicated in the previous subsection, the set of dependent variables includes total annual consumption expenditure, annual non-food consumption expenditure, annual food consumption expenditure, daily calorie consumption and daily calorie consumption from nutritious foods. R_{ij} is the area under rubber plantations. The vector H_{ij} contains other L farm-household attributes including household size, the household head's age, education, migration status, ethnicity, distance from the market to the place of residence etc. V_i captures the type of village a household resides in through a set of dummy variables indicating whether the village was founded under the roof of the government resettlement program, founded naturally by the local population, or whether the village is a mixture of both forms (with naturally founded villages as reference). In addition we control for non-random village selection into the sample. In order to capture general differences in infrastructure and economic development, Z_j captures regency level fixed effects through a set of 4 regency dummies (with Sarolangun regency as the reference). Further, β_l, γ, ρ, σ and θ_j are the parameter vectors to be estimated and ε_{ij} is the random error term with zero mean and constant variance. If specified correctly, γ gives the conditional mean effect of oil palm adoption.

4.3 QUANTILE REGRESSIONS MODEL SPECIFICATION

The effects of oil palm adoption on consumption expenditure and calorie consumption might be heterogeneous among adopters due to differences in opportunities of farm size expansion and off-farm livelihood diversification. Simple OLS estimators cannot depict such nuances as they provide estimates of the effect of a given covariate on the conditional mean of the dependent variable.

One way of analyzing heterogeneity of effects is the specification of quantile regressions. Quantile regressions were first introduced by Koenker and Basset (1978) as a generalization of median regression to other quantiles. Quantiles of the conditional distribution of the response variable are expressed as functions of observed covariates (Koenker and Hallock, 2001). Instead of restricting covariate effects on conditional means, these regressions allow analyzing whether the effect of a given covariate changes over the conditional distribution of the dependent variable (Koenker and Hallock, 2001). Recent applications have used quantile regressions to model a range of heterogeneous effects from determinants of wages (Appleton et al., 2014), technology adoption (Sanglestsawai et al., 2014), social capital (Grootaert and Narayan, 2004) and CO_2 emissions (You et al., 2015) to impacts of economic inequality (Hassine, 2015; Nguyen et al., 2007). The conditional quantile function of y_i given x_i can be expressed as

$$Q_\tau(y_i|\, x_i) = x_i\beta_\tau \qquad (2)$$

With $Q_\tau(y_i|\, x_i)$ being the conditional quantile function at quantile τ, with $0 < \tau < 1$ and β_τ the respective unknown vector of parameters. Parameters are obtained by minimizing:

$$\min_{\beta_\tau} \frac{1}{N} \left\{ \sum_{i: y_i \geq x_i\beta_\tau} \tau |y_i - x_i\beta_\tau| + \sum_{i: y_i < x_i\beta_\tau} (1-\tau)|y_i - x_i\beta_\tau| \right\} \quad (3)$$

This equation is solved by linear programming methods (Buchinsky, 1998). Equation (3) implies that coefficients can be estimated at any point of the conditional distribution of the dependent variable by asymmetrical weighing of absolute values of the residuals. We specify a set of quantile regressions for each of the previously introduced dependent variables. Quantile functions are estimated simultaneously at five different levels of the conditional distribution of the respective dependent variable (τ = 0.10, 0.25, 0.50, 0.75, 0.90). As covariates, we use the same vector of household and farm attributes as in the OLS regressions (equation 1).

4.4 Addressing self-selection bias with oil palm adoption

In the specification of econometric models, we need to account for the fact that oil palm adoption may not be a random process. As households self-select into the groups of adopters and non-adopters, the set of determinants could include unobserved factors (e.g., motivation, risk aversion etc.) that affect the decision to adopt oil palm and the outcome variables of interest simultaneously. Such unobserved heterogeneity could potentially result in biased estimates. For instance, highly motivated farmers might take up oil palm faster. At the same time, irrespective of oil palm adoption, these farmers might achieve higher yields and farm incomes as compared to non-adopters. One common approach to overcome endogeneity bias with dichotomous adoption variables is the use of treatment effects models, which provide unbiased estimates in the presence of selection bias (Greene, 2008). However, obtaining reliable estimates using the treatment effect framework requires at least a unique instrumental variable that determines the adoption decision, but not the outcome variable directly.

Previous studies have shown that oil palm adoption at the household level is positively influenced by a set of village and regional level attributes (Euler et al., 2015; Budidarsono et al., 2013). The probability of individual oil palm adoption is higher when contractual ties between farmer group(s) and a private or public firm are active at the village level. Such contracts are typically negotiated between farmers or farmer cooperatives, but not necessarily include all farmers from a village. Nevertheless, the presence of contracts improves the overall access to technical extension services and output processing facilities at the village level (Gatto et al., 2014), thereby increasing the probability of non-contract farmers to adopt oil palm. Further, although most of the sample farmers (94%) started oil palm after 1992, the probability of adoption is found to be higher in villages where oil palm plantations have already been present in or before 1992 (Gatto et al., 2014). We therefore derive two instrumental variables –the presence of oil palm plantations in 1992 at the village level (recorded as dummy variable), and the presence of a farmer group-private investor contract at the village level. In order to enhance the variation among the sample households, we record the duration (number of years) for which a particular household was involved in farming while a village level contract was enacted (0 for villages with no contract) as the second instrument in the treatment effects models. Both of these variables are found strongly influencing the adoption decision.

The selected instruments were subjected to a falsification test to examine their validity that they are not directly correlated to the outcome variables. Following Di Falco et al. (2011), the outcome variables were regressed on the instruments in a reduced model, only for the sub-group of non-adopters. Coefficient estimates are insignificant in all models, indicating that there is no second pathway through which instruments affect the outcome variables other than through oil palm adoption (Table A1). The results show statistical non-significance in the outcome model for non-adopters and hence it can be concluded that these variables are valid as instruments. The full treatment effects model estimates are provided in Appendix A (Tables A2 and A3).

After controlling for covariates, the null hypothesis of no-correlation between error terms of the selection and outcome equations (*rho*) is not rejected by the Wald test in any of the treatment effects models. This seems plausible as oil palm adoption is largely determined by regional factors such as infrastructural development and connectivity to palm oil mills and industrial plantations (Euler et al., 2015; Gatto et al., 2014). Only in less than 40% of the sample villages, oil palm and rubber coexist over significantly large landscapes. In the remaining majority, large areas are devoted for monocultures of either oil palm or rubber. It is therefore possible that farmer heterogeneity plays only a minor role in the adoption decision. Against this background, we proceed the analysis with a set of OLS models.

5. RESULTS

5.1 EFFECTS OF OIL PALM ADOPTION ON HOUSEHOLD CONSUMPTION EXPENDITURE

Oil palm adopters have significantly higher non-food and food expenditures, and they consume more calories, as already observed in the descriptive statistics. However, we need to control for possible confounding factors before attributing the observed differences to oil palm cultivation. Table 4 presents estimation results for the model specification as outlined in equation (1).

We start with analyzing the effects of oil palm adoption on consumption expenditures which are given in the first three columns. The results suggest that oil palm cultivation significantly enhances total consumption expenditure (by around 3.4 million IDR), non-food expenditure (by around 2.6 million IDR) and food expenditure (by around 0.9 million IDR) of the household. In percentage terms this corresponds to around 25% over the total consumption expenditure of non-adopters, 37% over the non-food consumption expenditure, and 14% over the food consumption expenditure. Krishna et al. (2015) also find positive effects of oil palm adoption on total household consumption expenditure. If we assume that consumption expenditures are enhanced with rising farm income, these findings are in line with observations made by Rist et al. (2010) and Feintrenie et al. (2010) who reported positive income effects of oil palm cultivation mainly through increased labor productivity. Building on descriptive analysis, Budidarsono et al. (2012) also found household incomes to increase with oil palm cultivation.

Since we control for the total area under rubber plantations, the oil palm adoption dummy captures the effect of oil palm cultivation in addition to the mean cultivated rubber area. Recalling the reported levels of returns to land for oil palm and rubber plantations, the livelihood effect of oil palm adoption might partly be the scale effect stemming from farm size expansion. This notion is supported by additional regression results with alternative model specifications with respect to oil palm area and total farm size. If we insert the area under oil palm along with the area under rubber plantations, we find equal sized coefficients for both crops across all models, indicating that their effects on consumption expenditure are very similar (cf. Table A4).

However, oil palm demands significantly lower labor input, and therefore potentially enables farm size expansion and income diversification through the release of family labor. For example, if oil palm adoption is included alongside total farm size (cf. Table 5), the effects of oil palm adoption on total consumption expenditure and non-food expenditure are reduced by half, whereas the effect on food expenditure turns insignificant. Additionally controlling for annual household off-farm income and the number of owned livestock units, the positive effects of oil palm adoption on expenditures are further reduced with the coefficients for non-food expenditure and food-expenditure becoming insignificant (cf. Table A5). These results suggest that the main pathways through which oil palm adoption affects household consumption expenditures is via farm size expansion, diversification of on farm production (including livestock) and intensification of off-farm income activities. We find the effect of oil palm adoption to be more pronounced on non-food expenditures than on food expenditures. Potentially, adopters have reached saturation levels with respect to calorie intakes where further consumption of food items seems less valuable for them.

With respect to household nutrition, descriptive statistics have shown a surplus of total calorie consumption and a higher share of calories derived from nutritious foods for the group of oil palm adopters. The last two columns of Table 4 present the regression results with calorie consumption and calorie consumption from nutritious foods as dependent variables. Oil palm is found to significantly increase overall calorie consumption (by 364 kcal) as well as calorie consumption from nutritious foods (by 216 kcal). In percentage terms this corresponds to around 13% over the total calorie consumption of non-adopters, and to around 22% over the calorie consumption from nutritious foods. Thus, the estimated positive effect of oil palm adoption for food expenditure does not only translate into higher overall levels of calorie consumption, but also enhances a more nutritious diet among adopters. Apparently, non-food cash crop production is not associated with deteriorating household nutrition. Local food markets seem to be well developed and are able to supply an adequate amount and diversity of food items. Functioning food markets have been identified as critical condition allowing income surpluses to be translated into richer diets (Jones et al., 2014; von Braun, 1995).

As in the case of household consumption expenditure, positive effects of oil palm adoption are reduced in the alternative model specifications (Tables 5 and A5). However, coefficient estimates remain significant, even after controlling for total farm size and off-farm income. Since 57% of oil palm adopters also cultivate rubber, market risk faced by farmers might be spread, enabling a more stable consumption especially of food items.

Included covariates are found to have similar effects across all models. Thereafter, increasing the area under rubber cultivation by one additional hectare has positive effects on household expenditures and calorie consumption. This is not a surprise, as rubber plantations are also important sources of cash income (Rist et al. 2010; Feintrenie et. al, 2010). Larger households tend to have lower expenditure levels and tend to reduce both total calorie consumption and intake of energy from nutritious foods. This finding is consistent with other studies (Qaim and Kouser, 2013; Babatunde and Qaim, 2010). Most likely, economies of scale in the preparation and consumption of food are associated with lower levels of food wastage in larger families. Thus, lower energy availability might not necessarily mean lower calorie consumption (Babatunde and Qaim, 2010). Education levels are positively associated with consumption expenditures, calorie intakes and calorie intake from nutritious foods. Qaim and Kouser (2013) also find positive nutrition effects of rising education levels, while Babatunde and Qaim (2010) find negative effects. In the context of our study, better education might be correlated to higher farm incomes through better agronomic management practices. A larger distance between the place of residence and the next market place for food and non-food purchases has negative effects on consumption expenditure, total calorie consumption, but surprisingly not on calorie consumption from nutritious foods. Most likely, remoteness to commercial centers decreases the availability of consumption items. However, certain food items might be supplied from local production, especially fruits and certain vegetables. Households of Sumatran origin tend to spend less on food consumption, possibly due to of a higher share of subsistence production or heavier reliance on natural resources such as fish and fruits.

Table 4. Estimation results of OLS regressions for household consumption expenditure and calorie consumption.

	Total annual consumption expenditure (000 IDR/AE)	Annual non-food expenditure (000 IDR/AE)	Annual food expenditure (000 IDR/AE)	Daily calorie consumption (kcal/AE)	Daily calorie consumption from nutritious foods (kcal/AE)
Oil palm adoption (dummy)	3417.9***	2562.1***	855.8***	364.1***	215.5***
	(776.7)	(689.3)	(264.0)	(112.3)	(65.6)
Area under rubber (ha)	912.7***	642.5***	270.2***	77.0***	38.7***
	(161.2)	(149.6)	(48.2)	(19.8)	(10.2)
Age of household head (years)	-6.3	-23.2	16.9*	8.3**	3.5
	(26.7)	(22.6)	(9.9)	(4.0)	(2.3)
Household size (AE)	-1228.2***	-738.5***	-489.7***	-203.7***	-81.3***
	(298.7)	(248.6)	(104.8)	(45.2)	(24.5)
Education (years of schooling)	257.7**	155.2*	102.6***	30.2**	29.8***
	(106.3)	(93.6)	(33.8)	(13.2)	(8.1)
Household head migrated to the place of residence (dummy)	135.9	153.7	-17.9	-7.0	41.5
	(881.9)	(804.6)	(256.3)	(109.1)	(57.7)
Household head born in Sumatra (dummy)	-1393.5	-793.1	-600.3**	-146.6	-18.3
	(942.0)	(856.2)	(285.4)	(117.1)	(62.8)
Distance to nearest market place (km)	-90.2**	-61.0*	-29.2**	-11.5**	-2.6
	(38.5)	(34.3)	(11.9)	(4.7)	(2.8)
Household resides in trans-migrant village (dummy)	-619.9	-262.8	-357.1	-199.8	-102.8
	(1115.9)	(977.9)	(336.9)	(151.1)	(78.3)
Household resides in mixed village (dummy)	-283.9	129.9	-413.9	-179.3	-94.6
	(1153.4)	(980.2)	(508.7)	(207.0)	(124.1)
Random village (dummy)	1114.4	999.8	114.5	-2.8	-8.4
	(1133.7)	(982.0)	(402.2)	(171.1)	(89.0)
Model intercept	16318.0***	8949.7***	7368.2***	3471.6***	1083.3***
	(2344.7)	(2108.5)	(782.2)	(322.2)	(179.3)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes
No of observations	664	664	664	664	664
F	8.84	5.43	7.92	7.04	5.81
Adj. R^2	0.18	0.11	0.20	0.16	0.15

*Notes: Standard errors of estimates are shown in parenthesis. Oil palm adoption only includes farmers cultivating productive oil palm plots. Area under rubber only includes productive plots. *, **, *** indicate 10%, 5% and 1% level of significance.*

Table 5. Estimation results of OLS regressions for household consumption expenditure and calorie consumption with alternative model specifications.

	Total annual consumption expenditure (000 IDR/AE)	Annual non-food expenditure (000 IDR/AE)	Annual food expenditure (000 IDR/AE)	Daily calorie consumption (kcal/AE)	Daily calorie consumption from nutritious foods (kcal/AE)
Oil palm adoption (dummy)	1628.17** (773.09)	1256.19* (674.04)	372.02 (265.82)	225.65** (113.15)	154.95** (68.43)
Total farm size (ha)	737.79*** (114.57)	543.92*** (99.01)	193.87*** (41.28)	55.54*** (17.21)	23.12*** (8.19)
Model intercept	16663.10*** (2262.61)	9163.32*** (2045.16)	7499.71*** (769.15)	3508.74*** (319.47)	1107.77*** (178.65)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes
No. of observations	664	664	664	664	664
F	8.96	5.94	7.25	6.47	5.41
Adj. R^2	0.19	0.12	0.19	0.16	0.14

Notes: Standard errors are shown in parenthesis. Additional covariates used in the model correspond to the previous OLS models presented in Table 4. *, **, *** *indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

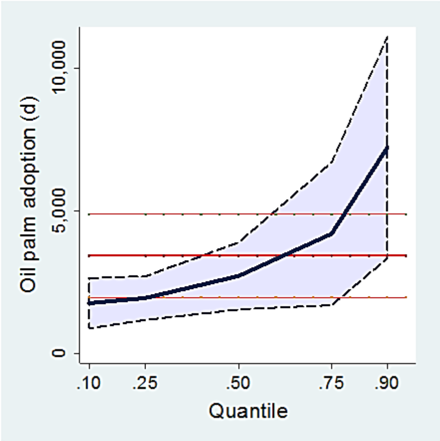
5.2 IMPACT HETEROGENEITY AMONG ADOPTERS

In this sub-section, we examine whether the effect of oil palm cultivation is homogeneous among adopters. OLS regression results suggest positive mean effects of oil palm adoption on consumption expenditure, calorie consumption and dietary quality. However, results also imply that effects are in part driven by the scale of agricultural operations, rather than by the adoption of oil palm *per se.* Thus, the net economic benefits associated with oil palm adoption depend on farm and household attributes such as the level of total plantation area which is likely to be higher at the upper quantiles of the conditional distributions of the set of dependent variables.

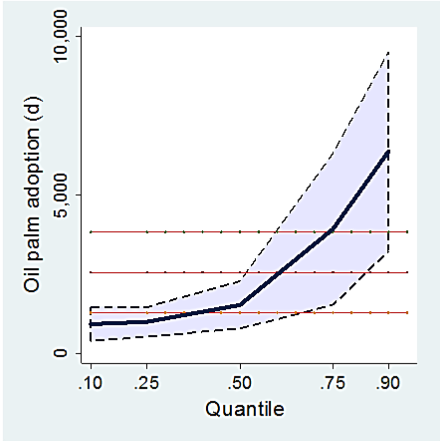
Quantile regressions allow to test whether the effect of oil palm cultivation differs between adopters at the conditional bottom quantile (τ=0.10) and adopters at the conditional top quantile (τ=0.90) of the distribution of the dependent variable. Results of quantile estimates are presented in Figures 2 (a) to (e). We restrict the presentation to the effect of oil palm adoption. Each Figure corresponds to the estimation results for one dependent variable. Table 6 provides the Wald test statistic for the test for equality of slope parameters for different pairs of quantiles. If the estimated coefficients differ across quantiles, it can be assumed that the effect of oil palm adoption is not constant across the distribution of the respective dependent variable (Koenker and Hallock, 2001). More detailed quantile estimates are included in Appendix A (cf. Tables A7 to A11).

Figures 2 (a) to (c) depict the conditional quantile effects of oil palm adoption on household consumption expenditure. Oil palm adoption is found to have positive effects on total consumption expenditure, non-food and food expenditure across all quantiles. However, adoption effects on non-food expenditure are distributed unevenly with oil palm adoption increasing the 0.90 quantile significantly stronger compared to the 0.10 quantile. Thus, oil palm adoption might enhance non-food expenditure disparities (cf. Table 6 and Table A7). Additional model specifications suggest that the effect of adoption and its heterogeneity are reduced across all quantiles if total farm size, total annual off-farm income and the number of livestock units owned by the household are controlled for (cf. Table A11). However, while the quantile estimate for oil palm adoption is smaller in magnitude it is still significantly larger at the 0.90 quantile compared to the 0.10 and 0.50 quantile. Most likely, some unobserved characteristics like farming ability seem to contribute to the observed heterogeneity of adoption effects. Quantile estimates for the effects on food expenditure are found to follow a similar pattern. In contrast to non-food expenditure, these effects do not differ across quantiles. Thus, oil palm adoption exerts a homogeneous effect on food expenditure along the entire distribution of food expenditures. Potentially, adopters at the 0.90 quantile are saturated with respect to food consumption and tend to invest additional expenditures for the consumption of non-food items more frequently.

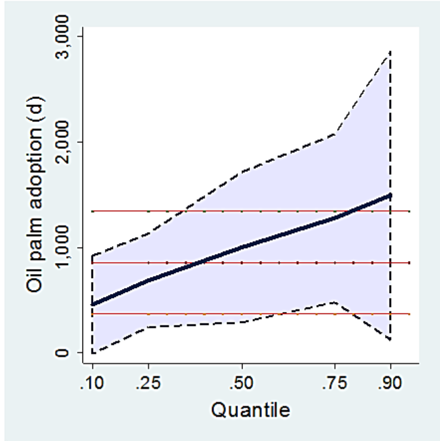
Figures 2 (d) and (e) present the effects of oil palm adoption on calorie consumption and calorie consumption from nutritious foods. The nutritional effects of oil palm adoption are positive and consistent across the group of adopters. However, oil palm adoption does not seem to contribute to disparities in calorie consumption and dietary quality (cf. Table 6, Table A9 and A10). This could be related to the relative high calorie consumption levels and the high share of nutritious food items that is consumed by all of our sample farmers. Moreover, heterogeneity in calorie consumption might not mainly be driven by income related variables, but rather by socio-economic household attributes such as education levels and levels of physical activity.



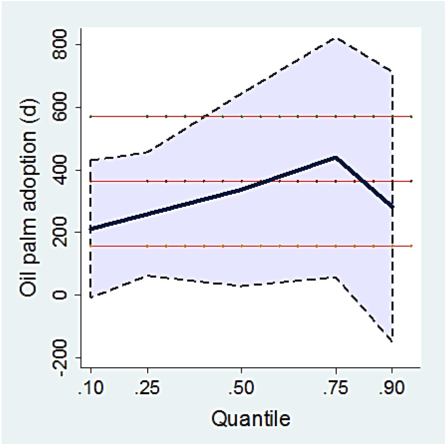
(a) Total consumption expenditure (000 IDR/AE)



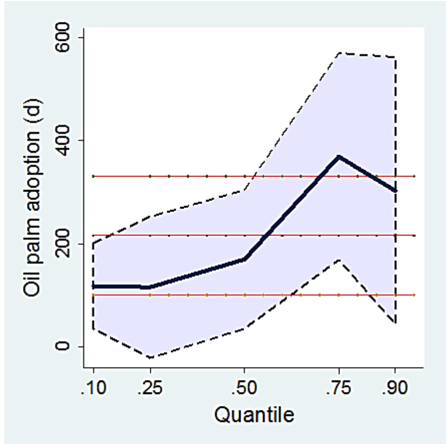
(b) Annual non-food expenditure (000 IDR/AE)



(c) Annual food expenditure (000 IDR/AE)



(d) Daily calorie consumption (kcal/AE)



(e) Daily calorie consumption from nutritiuos foods (kcal/AE)

Figure 2. Quantile regression estimates for household consumption expenditure and calorie consumption.

Notes: Quantile regression standard errors are bootstrapped. Conditional quantile estimates are presented by thick solid lines, with quantiles depicted on the x-axis. The magnitudes of the estimates are shown on the y-axis. Light horizontal lines indicate OLS estimates and corresponding confidence intervals. The shaded area indicates confidence intervals of conditional quantile estimates. Source: Household survey, 2012.

Table 6. Wald-test for equality of conditional slope parameters across quantiles.

	Wald test F statistic: τ=0.90 against…	
	τ=0.10	τ=0.50
Total consumption expenditure (000 IDR/AE)	5.08 (0.02)	1.72 (0.19)
Non-food expenditure (000 IDR/AE)	5.79 (0.02)	1.73 (0.19)
Food expenditure (000 IDR/AE)	2.40 (0.12)	2.54 (0.11)
Calorie consumption (kcal/AE)	0.08 (0.77)	0.74 (0.39)
Calorie consumption from nutritious foods (kcal/AE)	1.37 (0.24)	0.47 (0.49)

Notes: Corresponding p-values are given in parenthesis. Equality of marginal effects is tested for τ=0.10 and τ=0.50 against τ=0.90. The variance-covariance matrix for each quantile regression is obtained via bootstrapping (250 replications with replacement).

6. CONCLUSIONS

Oil palm is one of the most rapidly expanding crops throughout the humid tropics. Recent expansion of oil palm plantations is largely driven by smallholder farmers. Nevertheless, there has only been limited empirical evidence about the socio-economic implications of oil palm adoption and associated land use changes. The present study has contributed to the existing literature by analyzing the effects of oil palm cultivation on households´ economic welfare and nutritional status using household survey data from Jambi province, Indonesia. We have estimated average welfare and nutrition effects of oil palm cultivation for adopting smallholders. In addition, it was assessed whether observed effects are heterogeneous among oil palm adopters using quantile regressions. The analysis shows that oil palm is a financially lucrative land use option for smallholder farmers. Results suggest that its cultivation is associated with increases in household consumption expenditure, calorie consumption and dietary quality.

However, the observed effects can mainly be attributed to farm size expansions and off-farm income increases that are facilitated with the adoption of oil palm, and not to oil palm adoption *per se*. Due to the labor-saving and capital-intensive management of the crop, farmers are able to cultivate a relatively larger plantation area compared to traditional land uses at a given level of family labor. The net livelihood outcome of oil palm adoption therefore depends on smallholder household attributes which define their access to factor markets. Variation in these attributes is likely to cause livelihood outcomes to be distributed unequally among adopters. Although positive effects of oil palm adoption are present along the entire distribution of the set of dependent variables under study, the effects on household non-food expenditure are found to be significantly stronger at the upper tail of respective distributions.

There are two major policy implications that the present study addresses. First, the diffusion of oil palm among smallholder farmers may worsen social inequality. Among the group of oil palm adopters, those with better access to land and capital will realize significantly larger economic benefits compared to the resource constrained ones. From a rural development perspective, oil palm expansion might ultimately become a race for land, which might become a speculative object and a scare resource. Especially more traditional land use practices, such as slash and burn farming or rubber agro-forests, might gradually be replaced with the diffusion of oil palm plantations into smallholder agriculture. Thus, farmers who depend on more traditional livelihoods and who are not able (or willing) to make the transition to more intensive forms of smallholder agriculture are potential losers of this transformation process.

Second, the financial effects of oil palm cultivation forms a major element in the economic incentives that smallholders have to encroach forest land in Jambi and other parts of Indonesia. Due the positive livelihood outcomes associated with oil palm cultivation, an increasing number of smallholders is likely to include oil palm in their crop portfolio. Especially in regions that are still dominated by extensive land use practices, the land rent of agriculture relative to extensive agriculture (e.g., rubber agroforests) and forests could be increased (Krishna et al., 2014). *Ceteris paribus*, this might not only lead to increased deforestation but also adversely affect the long-term tenability of conservation incentives (Phelps et al., 2013). Imprecisely defined land rights further complicate the scenario and hamper foreseeing the exact social and environmental implications of oil palm expansion in Indonesia. Making land use transformation systems more sustainable and inclusive could be one of the most daunting challenges for policy makers and empirical researchers alike.

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APPENDIX

Table A1. Estimation results of reduced form OLS models with regression of dependent variables on instrumental variables for the group of non-adopters only.

	Total annual consumption expenditure (000 IDR/AE)	Annual non-food expenditure (000 IDR/AE)	Annual food expenditure (000 IDR/AE)	Daily calorie consumption (kcal/AE)	Daily calorie consumption nutritious (kcal/AE)
Years of farming in contract village	-21.2 (81.1)	-37.1 (63.1)	15.9 (29.9)	9.1 (13.0)	0.8 (6.7)
Village with oil palm in 1992 (dummy)	763.9 (1048.3)	348.2 (898.6)	415.8 (370.4)	79.6 (149.0)	-19-3 (76.3)
Model intercept	13319.4*** (435.4)	7092.7*** (361.3)	6226.6*** (148.7)	2862.0*** (62.5)	996.4*** (32.7)
No. of observations	465	465	465	465	465
F	0.29	0.24	0.73	0.35	0.04
Adj. R^2	<0.01	<0.01	<0.01	<0.01	<0.01

Notes: Standard errors are shown in parenthesis. *** *indicate 1% level of significance testing that intercept estimates are equal to zero.*

Table A2. Estimation results of endogenous treatment effects model.

	Total annual consumption expenditure (000 IDR/AE)		Annual non-food expenditure (000 IDR/AE)		Annual food expenditure (000 IDR/AE)	
	Selection equation	Outcome equation	Selection equation	Outcome equation	Selection equation	Outcome equation
Oil palm adoption (dummy)		5564.93 (3666.41)		4232.79 (3324.62)		1138.32* (679.50)
Area under rubber (ha)	-0.05* (0.03)	941.78*** (165.08)	-0.05* (0.03)	665.12*** (153.63)	-0.05* (0.03)	274.04*** (47.94)
Age of household head (years)	1E-03 (5E-03)	-9.06 (26.85)	1E-03 (5E-03)	-25.31 (22.44)	1E-03 (5E-03)	16.49* (9.88)
Education (years of schooling)	0.05*** (0.02)	235.22** (110.63)	0.05*** (0.02)	137.64 (96.35)	0.05*** (0.02)	99.62*** (34.86)
Household size (AE)	0.10 (0.06)	-1254.70*** (294.75)	0.10 (0.06)	-759.08*** (242.49)	0.10* (0.06)	-493.24*** (103.98)
Household head migrated to place of residence*(*dummy)	0.12 (0.16)	8.90 (927.34)	0.13 (0.16)	54.91 (844.18)	0.12 (0.16)	-34.59 (254.91)
Household head originates from Sumatra (dummy)	-0.10 (0.17)	-1441.91 (968.82)	-0.10 (0.18)	-830.82 (880.17)	-0.12 (0.16)	-606.72** (283.43)
Household resides in trans-migrant village (dummy)	0.20 (0.23)	-1301.92 (1793.53)	0.20 (0.23)	-793.50 (1630.29)	0.18 (0.22)	-446.83 (385.72)
Household resides in mixed village (dummy)	0.57** (0.27)	-898.93 (1621.31)	0.57** (0.27)	-348.64 (1392.78)	0.58** (0.27)	-494.88 (560.78)
Distance to nearest market place (km)	4E-03 (0.01)	-74.61* (45.31)	4E-03 (0.01)	-48.90 (40.34)	4E-03 (0.01)	-27.12** (11.82)
Random village (dummy)	-0.28 (0.23)	1590.08 (1493.84)	-0.28 (0.23)	1369.95 (1346.66)	-0.27 (0.22)	177.15 (419.47)
Household resides in…						
Batanghari (dummy)	-0.18 (0.19)	-3484.88*** (1103.31)	-0.18 (0.19)	-1726.45* (962.93)	-0.18 (0.19)	-1735.48*** (354.67)
Muaro Jambi (dummy)	-0.16 (0.27)	-2762.64** (1323.5)	-0.15 (0.27)	-1684.37 (1140.84)	-0.14 (0.26)	-1042.82** (503.18)
Tebo (dummy)	-0.86*** (0.26)	-2067.58 (1475.21)	-0.87*** (0.26)	-656.67 (1329.89)	-0.86*** (0.26)	-1440.52*** (389.39)
Bungo (dummy)	-0.76*** (0.23)	-3169.86*** (1231.63)	-0.75*** (0.23)	-1826.98* (1046.32)	-0.75*** (0.23)	-1351.89 (408.99)
Years of farming in contract village *(*no.)	0.07*** (0.01)		0.07*** (0.01)		0.07*** (0.01)	
Village with oil palm in 1992 (dummy)	0.67*** (0.16)		0.67*** (0.16)		0.67*** (0.16)	
Model intercept	-1.22*** (0.42)	15889.63*** (2528.97)	-1.24*** (0.42)	8616.44*** (2311.22)	-1.24*** (0.42)	1138.32*** (679.50)
σ_j	7690.91*** (496.86)		6739.92*** (521.33)		2562.85*** (98.80)	
ρ_j	-0.18 (0.32)		-0.16 (0.33)		-0.07 (0.16)	
Wald Chi^2	116.55		70.10		113.93	
Log Likelihood	-7177.38		-7090.75		-6451.70	
Wald test of independent eq. $\chi^2(1)$	0.32		0.23		0.22	

Notes: N=664. Standard errors are shown in parenthesis. *, **, *** *indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A3. Estimation results of endogenous treatment effects model.

	Daily calorie consumption (kcal/AE)		Daily calorie consumption from nutritious foods (kcal/AE)	
	Selection equation	Outcome equation	Selection equation	Outcome equation
Oil palm adoption		362.60		231.31**
(dummy)		(257.20)		(118.33)
Area under rubber	-0.05*	77.0***	-0.05*	38.92***
(ha)	(0.03)	(19.83)	(0.03)	(10.23)
Age of household head	1E-03	8.28**	1E-03	3.50
(years)	(5E-03)	(3.95)	(5E-03)	(2.31)
Education	0.05***	30.21**	0.05***	29.71***
(years of schooling)	(0.02)	(13.45)	(0.02)	(8.10)
Household size	0.10*	-203.71***	0.11*	-81.52***
(AE)	(0.06)	(44.76)	(0.06)	(24.31)
Household head migrated	0.12	-6.90	0.12	40.54
to place of residence (dummy)	(0.16)	(109.12)	(0.16)	(57.19)
Household head originates	-0.12	-146.52	-0.12	-18.63
from Sumatra (dummy)	(0.16)	(115.85)	(0.16)	(62.29)
Household resides in trans-	0.18	-199.33	0.18	-107.77
migrant village (dummy)	(0.22)	(165.10)	(0.22)	(83.98)
Household resides in mixed	0.58**	-178.93	0.58**	-99.16
village (dummy)	(0.27)	(220.46)	(0.27)	(126.83)
Distance to nearest market	4E-03	-11.50**	4E-03	-2.49
place (km)	(0.01)	(4.64)	(0.01)	(2.75)
Random village	-0.26	-3.1	-0.26	-4.90
(dummy)	(0.22)	(180.06)	(0.22)	(92.27)
Household resides in…				
Batanghari	-0.18	-757.16***	-0.18	-365.25***
(dummy)	(0.19)	(151.02)	(0.19)	(80.77)
Muaro Jambi	0.13	-487.46**	0.13	-179.69
(dummy)	(0.26)	(203.36)	(0.26)	(117.55)
Tebo	-0.86***	-618.63***	-0.86***	-385.75***
(dummy)	(0.26)	(169.14)	(0.26)	(89.42)
Bungo	-0.74*** (0.23)	-676.14***	-0.74***	-358.99***
(dummy)		(171.13)	(0.23)	(96.65)
Years of farming in contract	0.07***		0.07***	
village (no.)	(0.01)		(0.01)	
Village with oil palm in 1992	0.67***		0.67***	
(dummy)	(0.16)		(0.16)	
Model intercept	-1.25***	3471.86***	-1.25***	1080.20***
	(0.42)	(318.52)	(0.42)	(177.90)
σ_j	1089.76***		605.34***	
	(38.79)		(22.92)	
ρ_j	9E-04		-0.02	
	(0.14)		(0.11)	
Wald Chi^2	102.08		78.20	
Log Likelihood	-5884.66		-5494.24	
Wald test of independent eq. $\chi^2(1)$	<0.01		0.02	

Notes: N = 664. Standard errors are shown in parenthesis. *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.

Table A4. Estimation results of OLS regressions for household expenditure and calorie consumption with alternative model specifications.

	Total annual consumption expenditure (000 IDR/AE)	Annual non-food expenditure (000 IDR/AE)	Annual food expenditure (000 IDR/AE)	Daily calorie consumption (kcal/AE)	Daily calorie consumption nutritious foods (kcal/AE)
Oil palm area (ha)	948.9***	618.1***	330.8***	106.0***	61.3***
	(216.8)	(187.9)	(89.6)	(36.5)	(19.0)
Rubber area (ha)	900.7***	630.1***	270.6***	75.9***	38.0***
	(163.1)	(151.0)	(47.8)	(19.7)	(10.0)
Model intercept	17743.9***	9945.6***	7798.3***	3627.3***	1174.4***
	(2401.1)	(2154.7)	(789.1)	(330.6)	(184.1)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes
No. of observations	664	664	664	664	664
F	8.79	5.15	8.00	6.78	5.74
Adj. R^2	0.17	0.10	0.20	0.15	0.14

*Notes: Standard errors are shown in parenthesis. Oil palm adoption only includes farmers cultivating productive oil palm plots. Area under oil palm and rubber only includes productive plots. Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A5. Estimation results of OLS regressions for household expenditure patterns with alternative model specifications.

	Total annual consumption expenditure (000 IDR/AE)	Annual non-food expenditure (000 IDR/AE)	Annual food expenditure (000 IDR/AE)	Daily calorie consumption (kcal/AE)	Daily calorie consumption from nutritious foods (kcal/AE)
Oil palm adoption (dummy)	1242.53* (711.55)	925.82 (617.66)	316.75 (262.74)	209.47* (113.03)	144.94** (68.52)
Total farm size (ha)	682.43*** (105.67)	496.93*** (91.79)	185.50*** (40.64)	52.99*** (16.69)	21.56*** (7.88)
Off-farm income (million IDR/AE)	165.14*** (37.66)	148.28*** (31.47)	16.85 (11.92)	3.30 (4.91)	2.32 (2.70)
Livestock owned (number)	601.15 (240.50)	491.27** (250.72)	109.88*** (40.65)	37.87** (18.0)	22.50*** (8.98)
Model intercept	15959.72*** (2212.4)	8503.94*** (1997.33)	7455.71*** (777.22)	3509.47*** (322.31)	1105.89*** (180.53)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes
No. of observations	664	664	664	664	664
F	9.81	6.66	7.13	6.07	5.49
Adj. R^2	0.25	0.19	0.20	0.16	0.15

*Notes: Standard errors are shown in parenthesis. Oil palm adoption only includes farmers cultivating productive oil palm plots. Area under oil palm and rubber only includes productive plots. Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A6. Estimation results of quantile regression for total annual consumption expenditure.

	Total annual consumption expenditure (000 IDR/AE) Quantile					
Variables	OLS	0.10	0.25	0.50	0.75	0.90
Oil palm adoption (dummy)	3417.85***	1767.88***	1943.12***	2715.97***	4193.46***	7213.22***
	(776.67)	(475.09)	(493.43)	(689.94)	(1293.50)	(2416.71
Area under rubber (ha)	912.65***	463.47***	604.65***	664.06***	1094.72***	1411.97***
	(161.23)	(119.95)	(124.98)	(125.73)	(278.40)	(495.50)
Model intercept	16317.95***	6127.13***	11532.73***	13701.27***	14811.73***	20684.51***
	(2344.66)	(2046.30)	(1216.46)	(1554.97)	(3089.06)	(6783.04)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	664	664				
Adj. R^2/ Pseudo R^2	0.18	0.12	0.11	0.11	0.13	0.14
F	8.84					

*Notes: Standard errors are shown in parenthesis. OLS standard errors are robust. Quantile regression standard errors are bootstrapped (250 replications with replacement). Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *** indicates 1% level of significance testing that coefficients are equal to zero.*

Table A7. Estimation results of quantile regression for annual non-food expenditure.

		Annual non-food expenditure (000 IDR/AE) Quantile				
Variables	OLS	0.10	0.25	0.50	0.75	0.90
Oil palm adoption (dummy)	2562.13***	928.26***	1003.33***	1536.92***	3928.24***	6390.29***
	(689.26)	(277.35)	(280.70)	(466.86)	(1042.14)	(2293.64)
Area under rubber (ha)	642.46***	274.93***	257.19***	429.88***	663.07***	1309.0***
	(149.56)	(52.43)	(74.31)	(95.02)	(192.87)	(506.16)
Model intercept	8949.73***	1796.05**	3679.72***	6428.76***	6807.11***	16162.27***
	(2108.55)	(905.95)	(929.15)	(1241.64)	(1863.68)	(6451.22)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	664			664		
Adj. R^2/ Pseudo R^2	0.11	0.08	0.08	0.08	0.09	0.11
F	5.43					

*Notes: Standard errors are shown in parenthesis. OLS standard errors are robust. Quantile regression standard errors are bootstrapped (250 replications with replacement). Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A8. Estimation results of quantile regression for annual food expenditure.

	Annual food expenditure (000 IDR/AE)					
		Quantile				
Variables	OLS	0.10	0.25	0.50	0.75	0.90
Oil palm adoption (dummy)	855.77***	458.57*	689.90***	1003.24***	1278.71***	1497.15**
	(264.03)	(270.57)	(256.07)	(322.71)	(417.97)	(637.75)
Area under rubber (ha)	270.20***	147.96***	181.79***	292.51***	293.19***	365.92***
	(48.25)	(44.39)	(69.75)	(49.70)	(73.68)	(109.54)
Model intercept	7368.15***	4865.64***	5222.15***	6832.91***	8604.87***	11416.89***
	(782.19)	(782.67)	(711.93)	(727.55)	(1300.47)	(2465)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	664			664		
Adj. R^2/ Pseudo R^2	0.20	0.08	0.08	0.10	0.14	0.16
F	7.92					

*Notes: Standard errors are shown in parenthesis. OLS standard errors are robust. Quantile regression standard errors are bootstrapped (250 replications with replacement). Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A9. Estimation results of quantile regression for daily calorie consumption.

	Daily calorie consumption (kcal/AE)					
			Quantile			
Variables	OLS	0.10	0.25	0.50	0.75	0.90
Oil palm adoption (dummy)	364.06***	211.17*	259.30***	336.56***	440.44***	282.59
	(112.27)	(114.20)	(101.11)	(129.25)	(168.88)	(242.01)
Area under rubber (ha)	77.02***	47.60***	55.13**	88.45***	97.28***	78.73
	(19.78)	(15.01)	(25.01)	(24.73)	(29.03)	(48.82)
Model intercept	3471.57***	2134.90***	2505.85***	3181.75***	4546.68***	4608.17***
	(322.23)	(289.04)	(369.50)	(338.35)	(553.32)	(865.74)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	664			664		
Adj. R^2/ Pseudo R^2	0.16	0.07	0.07	0.09	0.13	0.16
F	7.04					

*Notes: Standard errors are shown in parenthesis. OLS standard errors are robust. Quantile regression standard errors are bootstrapped (250 replications with replacement). Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A10. Estimation results of quantile regression for daily calorie consumption from nutritious foods.

	Daily calorie consumption from nutritious foods (kcal/AE)					
		Quantile				
Variables	OLS	0.10	0.25	0.50	0.75	0.90
Oil palm adoption (dummy)	215.52***	117.64***	115.31*	169.65**	369.05***	302.83**
	(65.64)	(47.98)	(62.80)	(74.98)	(120.34)	(150.55)
Area under rubber (ha)	38.71***	26.80***	35.92	28.54**	41.29**	110.13***
	(10.18)	(9.72)	(7.54)	(11.72)	(19.44)	(40.92)
Model intercept	1083.35***	351.10**	682.46***	1129.11***	1513.11***	1315.99***
	(179.31)	(172.67)	(127.80)	(187.89)	(316.65)	(455.31)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	664			664		
Adj. R^2/ Pseudo R^2	0.15	0.07	0.06	0.07	0.09	0.17
F	5.81					

*Notes: Standard errors are shown in parenthesis. OLS standard errors are robust. Quantile regression standard errors are bootstrapped (250 replications with replacement). Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; *, **, *** indicate 10% , 5% and 1% level of significance testing that coefficients are equal to zero.*

Table A11. Estimation results of quantile regression for non-food expenditure with alternative model specifications.

	Annual non-food expenditure (000 IDR/AE)					
		Quantile				
Variables	OLS	0.10	0.25	0.50	0.75	0.90
Oil palm adoption (dummy)	925.82	528.16	443.84*	545.48	1333.60	3836.90**
	(617.66)	(338.23)	(269.88)	(455.84)	(842.25)	(1903.95)
Total farm size (ha)	496.93***	222.59***	250.67***	423.78***	470.57***	992.31***
	(91.79)	(37.03)	(47.57)	(57.58)	(182.83)	(240.61)
Model intercept	8503.94***	728.20	2938.83***	5861.53***	5495.20**	13206.79**
	(1997.33)	(847.36)	(845.44)	(1129.90)	(1766.0)	(5574.86)
Regency level fixed effects included	Yes	Yes	Yes	Yes	Yes	Yes
No. observations	664			664		
Adj. R^2/ Pseudo R^2	0.19	0.12	0.12	0.13	0.13	0.19
F	6.66					

*Notes: Standard errors are shown in parenthesis. OLS standard errors are robust. Quantile regression standard errors are bootstrapped (250 replications with replacement). Additional covariates used in the model are age, education level, ethnicity and migration background of the household head, household size, distance to the closest market place, village type and mode of village selection; annual off-farm income and number of livestock owned by the household; **, *** indicate 5% and 1% level of significance testing that coefficients are equal to zero. Wald test testing for equality of slope parameters of oil palm adoption for τ=0.90 against τ=0.10 and* τ=0.50 *indicate that quantile estimates are different at the 10% level (F=2.98 for* τ=0.90 vs. τ=0.10*; F=3.15 for* τ=0.90 vs. τ=0.50).