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The Economics Behind an Ecological Crisis: Livelihood Effects of Oil Palm Expansion in Sumatra, Indonesia

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Abstract
While the negative ecological effects of the rapid expansion of oil palm in Southeast Asia are far-reaching and relatively widely studied, the socioeconomic consequences have received much less attention in the literature. We examine whether local farmers in Indonesia benefit from cultivating oil palm. We also look at the impact dynamics and possible spillover effects on other farmers. Our analysis builds on panel data collected from 680 farm households in Jambi Province, Sumatra. We show that oil palm cultivation has significant positive effects on farmers' livelihoods. The economic gains allow farm households to increase their consumption. Oil palm has lower labor requirements than alternative crops. Hence, oil palm farmers can cultivate larger areas and also reallocate saved labor time to non-farm economic activities, which contributes to additional secondary gains. Policies aimed at regulating further oil palm area expansion will have to account for the economic benefits of this crop for the local population.

Keywords Farmer welfare · Land-use changes · Farm household survey · Spatial modeling · Jambi Province, Sumatra · Indonesia

Introduction

The negative environmental effects associated with oil palm (*Elaeis guineensis* Jacq.) monocultures in Southeast Asia have received much attention over the last two decades. Studies have shown that oil palm expansion contributed to deforestation and conversion of peat swamps (Abood *et al*. 2015; Stibig *et al.* 2014; Wilcove *et al.* 2013; Carlson *et al.* 2012; Koh *et al.* 2011) causing biodiversity loss and disruptions in other ecosystem services (Ganser *et al.* 2017; Guillaume *et al*. 2015; Konopik *et al.* 2015; Barnes *et al*. 2014; Lucey and Hill 2012; Azhar *et al.* 2011; Gibbs *et al*. 2010; Swarna Nantha and Tisdell 2009; Fitzherbert *et al*. 2008). In spite of mounting evidence about the negative environmental effects, oil palm expansion has continued in the tropics during the last two decades at a rate unparalleled for any crop in the more recent history of agriculture (Cramb and McCarthy 2016; Vijay *et al*. 2016; FAOSTAT 2014; Wicke *et al*. 2011). The main reason for this unprecedented expansion is the increase in global demand for vegetable oil due to population and income growth. Increasing demand results in high economic profitability in the palm oil sector (Clough *et al*. 2016; Drescher *et al*. 2016; Wilcove and Koh 2010).

Much of oil palm cultivation is carried out by large companies (Euler *et al*. 2016a). However, smallholder farmers are also increasingly involved (Rist *et al*. 2010; Bourke and Harwood 2009). Recent studies have estimated that smallholder farmers account for about 40% of total global palm oil supply with a further rising trend (Byerlee *et al*. 2017; Euler *et al*. 2017). Unlike large company plantations, smallholder-driven land-use changes are more difficult to monitor and regulate (Kubitza *et al*. 2018). Hence, policies

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aimed at more sustainable land-use systems have to build on a thorough understanding of the economic incentives for smallholder farmers.

Our study was conducted in Indonesia, the world's leading palm oil producer. Similar to the global pattern, more than 40% of the oil palm area is cultivated by smallholder farmers (Euler *et al*. 2016b; Gatto *et al*. 2015; Susanti and Budidarsono 2014). Several studies have shown that oil palm has a higher labor productivity than alternative cash crops, such as rubber (Clough *et al*. 2016; Budidarsono *et al.* 2012; Bourke and Harwood 2009). However, very few have explicitly analyzed the economic and social effects of oil palm cultivation among smallholder farmers. Extrapolating productivity data from large company plantations is of limited value because the average yields achieved by smallholders are significantly lower than those on large oil palm plantations (Hoffmann *et al.* 2017; Woittiez *et al*. 2017; Cramb and McCarthy 2016; Euler *et al.* 2016a). We are aware of only two recent studies that analyzed the livelihood effects of oil palm cultivation in the small-farm sector (Euler *et al*. 2017; Krishna *et al*. 2017a). Using cross-sectional data, both studies suggested that cultivating oil palm has a positive effect on household living standards on average. Both also showed that the magnitude of the effect varies depending on the farms' endowment of land, labor, and capital.

While these recent studies are an important step towards better understanding the economics of smallholder oil palm cultivation, we identify two major limitations that are addressed in this article. First, existing studies used cross-sectional data so that the results only provide a snapshot of effects under static conditions. The benefits of cash crop cultivation for farmers critically depend on fluctuating market prices and can hence change over time. Here, we use data from 2012 and 2015 to analyze possible dynamics. In 2012, the international price of palm oil was relatively low compared to the main competing crop – natural rubber (*Hevea brasiliensis* Muell-Arg.). In subsequent years, the international rubber price declined (von Agris 2017), thus adding to the relative profitability of oil palm as an alternative cash crop such that we expect to observe an increase in the benefits of oil palm cultivation between 2012 and 2015.

The second limitation of existing studies is that they did not look at possible spillover effects that the cultivation of oil palm by some farmers may have on others in the local context. Spillovers could occur through various mechanisms. For instance, oil palm is less labor-intensive than rubber (Euler *et al.* 2017; Gatto *et al*. 2015), which could reduce the local demand for labor and increase the market price of cultivable land and thus may affect employment and other economic opportunities for households in the community. On the other hand, the expansion of oil palm is often associated with new public or private sector infrastructure investments that may also be beneficial for local households not directly involved in the palm oil sector. The analysis of spillover effects is possible through the use of spatially explicit regression models, a relatively recent trend in the empirical economics literature (Wollni and Andersson 2014; Lewis *et al*. 2011). We are not aware of previous studies that have analyzed economic spillover effects of oil palm cultivation or related land-use changes.

Methodology

Study Area

This study was conducted in the lowlands of Jambi Province on the island of Sumatra, Indonesia. The region has a tropical humid climate with average temperature of 26.7 ± 0.2 °C and annual precipitation of 2235 ± 381 mm during the 1991–2011 period (Drescher *et al*. 2016). Lowland rainforests largely disappeared and agroforestry systems were significantly downsized in Jambi over the last 30–40 years. The land thus gained was used primarily for rubber and oil palm monocultures (Krishna *et al*. 2017b; Clough *et al*. 2016; Luskin *et al*. 2014).

Oil palm cultivation was introduced in Jambi on large state plantations, and its diffusion among smallholder farmers started during the late-1980s and early-1990s. During the early stages, smallholder participation was promoted by the Indonesian government through subsidized contract schemes (Gatto *et al.* 2017; Rist *et al*. 2010). While subsidized government interventions declined after 1999, smallholder farmers continued to adopt and cultivate oil palm, often independently without any company contracts (Susanti and Budidarsono 2014). Yet, independent adoption is more often observed in villages where company contracts existed in the past, which is likely due to better access to technical information and to output markets in these settings (Euler *et al*. 2016b). Official statistics show that around 200,000 households are involved in oil palm cultivation in Jambi, which ranks sixth among Indonesian provinces in terms of crude palm oil production with an estimated oil palm area of over 700,000 ha (Badan Pusat Statistik 2012). At the same time, the province is also known for its forest and biodiversity resources; the national parks of Jambi support a number of threatened wildlife species (Luskin *et al.* 2014).

Data

The main unit of observation in our study is the farm household. Survey data were collected from 683 farm households in two rounds, 2012 and 2015, as part of a larger interdisciplinary research project (for details see Drescher *et al.* 2016). The households were selected for interview following a multi-stage random sampling procedure. Five regencies of Jambi that comprise most of the lowland, non-peat smallholder systems were chosen for the study (Sarolangun, Bungo, Tebo, Batanghari, Muaro Jambi). The survey was carried out in 45 rural villages from these five regencies (40 randomly selected villages and 5 purposively selected ones to facilitate interdisciplinary overlaps) (Fig. 1). From each of the selected villages, depending on size, between 6 and 24 farm households were randomly sampled using complete lists of all farm households in 2012. The same households were revisited in 2015. Some sample attrition occurred due to outmigration or deceased household heads, among other reasons, but the attrition rate of 6% is relatively low. Further randomly selected households in the same villages replaced households that were unavailable in 2015. Using a structured questionnaire, details of all cropping and livestock activities of households during the past 12 months were elicited in both survey rounds. Most farm households in the sample grow either rubber or oil palm or both. Socio-demographic characteristics, details of off-farm income activities, asset endowment, and consumption expenditures on food and non-food goods and services were additionally recorded.

Measuring Livelihoods

The value of household consumption (i.e., consumption expenditure) is used as an indicator of household livelihoods (living standards). Being less volatile and less influenced by measurement errors, consumption is considered a better indicator of household living standards than income (Blundell and Preston 1998). Household consumption expenditure was calculated by summing up the value of all food items and non-food goods and services consumed by all household members. The expenses on food items were elicited through a seven-day recall, non-food expenditures were captured through monthly or annual recall, depending on the particular goods and services. To make consumption values comparable across households of different size, we calculated annual household expenditures per adult equivalent. The 2012 data were adjusted for inflation to enable comparison with the 2015 data.

In addition to total consumption expenditures, we also look at food and non-food consumption separately. The cultivation of oil palm (and other non-food cash crops) can affect food consumption in farm households through the subsistence pathway (possibly less food) and through the income pathway (possibly more food) (Sibhatu et al. 2015). A breakdown by type of expenditure can help better understand the various facets of household livelihoods.

Estimating Effects of Oil Palm Cultivation

We estimate the effects of oil palm cultivation on household livelihoods by using a standard random-effects model (sometimes also called random-intercepts model). To account for possible non-linearity, consumption expenditures in household i at time t (c_{it}) are expressed in natural logs. c_{it} is regressed on oil palm cultivation (OP_{it}) and a set of k household characteristics (x_{itk}):

$$c_{it} = \beta_0 + \beta_1\, OP_{it} + \ \beta_{2k}\, x_{itk} + \mu_i + \varepsilon_{it} \qquad (1)$$

where μ_i is the unobserved time-invariant heterogeneity of the model, and ε_{it} is the independent identically distributed error term. We estimate separate models for total consumption expenditures, food expenditures, and non-food expenditures. In all models, we are particularly interested in the estimates for β_1. As oil palm cultivation (OP_{it}) is defined as a dummy variable, and the dependent variables are expressed in log terms, the percentage effect of cultivation on consumption is calculated as $\left\{ e^{\widehat{\beta_1} - 0.5\hat{V}\left(\widehat{\beta_1}\right)} - 1 \right\}$, where $V)$ is the estimated variance of $\widehat{\beta_1}$ (van Garderen and Shah 2002). The variance of the percentage change is calculated as $e^{2\widehat{\beta_1}} \left\{ e^{-\hat{V}\left(\widehat{\beta_1}\right)} - e^{-2\hat{V}\left(\widehat{\beta_1}\right)} \right\}$.

One potential problem with the random-effects models in Eq. (1) is that oil palm cultivators might differ systematically from non-cultivators in terms of certain unobserved characteristics, for example managerial skills or risk attitudes. Such unobserved characteristics may also influence household consumption, which could lead to biased estimates of β_1 (often referred to as selection bias). Such potential bias due to unobserved heterogeneity is tested by additionally estimating fixed-effects models. Fixed-effects models use differencing techniques, thus canceling out any time-invariant unobserved heterogeneity. A Hausman specification test (Hausman 1978) is used to compare the fixed-effects and random-effects estimates. A significant Hausman test statistic would suggest that the random-effects estimates are biased, whereas an insignificant test would mean that the null hypothesis of no bias through time-invariant unobserved heterogeneity cannot be rejected.

Estimating Temporal Differences in Oil Palm Effects

To analyze whether the benefits of oil palm cultivation vary over time, we run separate regression models with cross-sectional data for 2012 and 2015. These cross-sectional models are estimated with ordinary least squares (OLS) and the same set of explanatory variables as in the panel random-effects specifications. We are particularly interested in comparing the effects of oil palm cultivation between 2012 and 2015. Given that the non-cultivating households primarily rely on rubber farming and the price of rubber declined between 2012 and 2015, we expect larger benefits of oil palm cultivation in 2015.

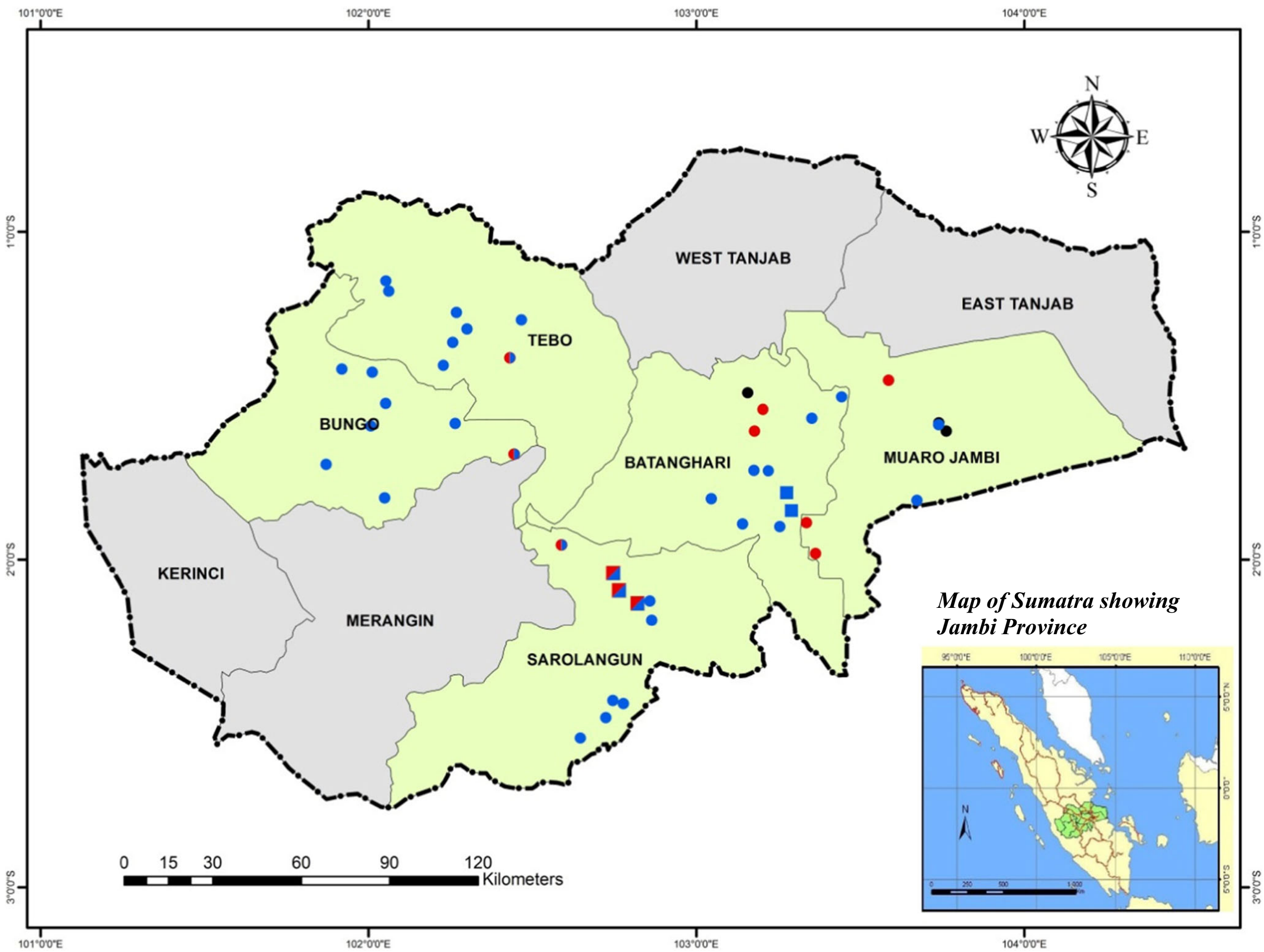

Fig. 1 Map of Jambi Province showing sample villages. Notes: Dots and squares indicate randomly and purposively selected villages, respectively. Blue dots/squares represent villages where rubber is the main crop (rubber area is larger than oil palm area). Red dots/squares represent villages where oil palm is the main crop

Estimating Spatial Patterns and Spillovers

In a separate step of the analysis, we investigate spatial patterns in the estimates. We can differentiate between spatial correlation in the error term and spatial spillover effects of the dependent variables and independent variables. There may be spatial correlation of unobserved factors (e.g., soil fertility) that also influence the economic effects of oil palm cultivation. Such spatial dependence would lead to patterns in the error terms and underestimate the standard errors. We cluster standard errors at the village level to avoid this problem. Spatial spillover effects can have more severe consequences, as they can lead to biased estimates (Elhorst 2010; Wollni and Andersson 2014). Standard models of impact assessment, such as those in Eq. (1), are based on the assumption that outcomes for oil palm cultivators and non-cultivators depend solely on own cultivation, not on the cultivation of oil palm by others. This assumption is violated when spatial spillover effects occur. As discussed above, the cultivation of oil palm by some farmers could also affect others, for instance through changes in factors markets or broader infrastructure developments. To address the potential issue of spatial dependence and empirically assess the existence and magnitude of spillover effects of oil palm cultivation, we use a spatial Durbin model with random effects as follows (Elhorst 2010; LeSage and Pace 2009):

$$c_{it} = \beta_0 + \beta_1\, OP_{it} + \rho\, w.OP_{it} + \beta_2\, x_{it} + \lambda\, w.c_{it} + \mu_i + \varepsilon_{it} \tag{2}$$

where w is an $n \times n$ spatial weights matrix, based on the inverse distance between the households' residence, and n is the total number of households in the sample. The coefficient ρ measures the lagged effect of cultivation, while λ, the spatial autoregressive coefficient, measures the lagged effect of consumption expenditures. Since the individual weight of a household decreases with an increasing number of neighbors, the weights matrix is row-standardized, such that for each i, $\sum_j w_{ij} = 1$.

Taking the partial derivative of the model in Eq. (2) with respect to oil palm cultivation, the estimate not only shows the livelihood effects oil palm cultivation on cultivating farm households but also the effect on neighboring households. The first effect is called direct effect and the latter is called indirect effect or spillover effect. We set the threshold of neighborhood distance for spatial effects estimation at 10 km, since spillovers beyond that distance are rather unlikely. The use of a spatial Durbin model and taking the partial derivative is often the preferred method to calculate spillovers (Elhorst 2010). However, critics also underline certain shortcomings with this method, such as the *a priori* specification of the spatial weights matrix, difficulties in justifying global spillovers, and possible bias due to omitted spatially dependent variables (Corrado and Fingleton 2012).

Results and Discussion

Descriptive Statistics

The main crop grown by the majority of farmers in the study area is rubber. Oil palm was cultivated by 36% of the households in 2015. Around 60% of the oil palm cultivators also produce rubber whereas sample farmers rarely cultivated food crops (Table 1). One of the notable differences between oil palm cultivators and non-cultivators is that the former have significantly larger farms on average. Farmers with large areas of rubber were found to start oil palm cultivation significantly earlier than farmers operating on a smaller scale (Euler *et al.* 2016b). Farm size in this context refers to all land that farmers reported as owning, including land under formal and informal tenure. Farmers acquired their land mostly through inheritance or inter-vivo transfers, land market purchases, and forest-land appropriation. While about half of the plots owned by sample farmers were acquired through market purchases, 18% were acquired through forest-land appropriation. Other research in Jambi has shown that the role of land acquisition through forest land appropriation has declined over the last 15 years while the role of market purchases has increased (Krishna *et al*. 2017b).

On average, oil palm cultivation is less profitable than rubber per unit of land but more profitable per unit of labor (Table 2). These differences between the two crops were less distinct in 2015 than in 2012. The profitability of rubber cultivation declined drastically between the two survey rounds due to the low market prices for natural rubber prevailing in 2015. The profitability of oil palm also declined during the same period, albeit less steeply. In 2015, rubber continued to be more profitable per unit of land. Hence rubber is more attractive for households facing land constraints and relatively low opportunity costs of labor time.

Oil palm-cultivating households are more likely to own small non-farm businesses (e.g., trading, small shops) (Table 1). Because oil palm requires less labor than rubber, oil palm farmers can save family labor. These labor savings allow oil palm cultivators to increase their farm size (if additional land can be acquired) and/or to spend more time in non-farm economic activities. The income generated from these alternative uses of the saved time can be seen as secondary effects of oil palm cultivation. There is no difference in the availability of family labor (number of adults in the household) between oil palm cultivators and non-cultivators. Human capital endowments, which we capture through age and education of the household head, are also similar between the two groups. Oil palm farmers are residing closer to markets, take more credits from formal sources, and are more likely to hold formal titles for the land cultivated.

Demographic developments may also play an important role for land use and land-use changes. Since the 1970s, Indonesia has experienced a rapid decline in annual rates of population growth. Nowadays, average fertility rates are only slightly above the replacement level, which also holds true for Jambi Province (BPS *et al*. 2013). Rural Jambi is characterized by significant migration, but migration into the region is almost at par with out-migration. In our sample, villages had a mean size of 731 households in 2015 with little variation since 2012. On average, 1.8% of the households had newly moved into the sample villages between 2012 and 2015, while 1.6% had moved out during the same period.

Hence, while global population growth contributes to rising demand for agricultural products, population growth in rural Jambi itself is small and was not found to be a major driver of land-use change in the sample villages. However, as a growing share of the local population works outside the agricultural sector, finding labor for agricultural production is increasingly difficult, especially since much of the labor required in rubber and oil palm cannot be easily mechanized. With a decreasing supply of cheap labor in rural Jambi, the cultivation of oil palm may gain further attractiveness over rubber due to its lower labor requirements.

The cultivation of oil palm and rubber also differs in terms of inputs other than labor. The literature suggests that the use of chemical inputs, such as fertilizer, is lower in rubber than in oil palm (Clough *et al*. 2016; Budidarsono *et al.* 2012). Our data show that input expenditures vary significantly, not only between crops but also over time (Table S1). The temporal variability is possibly a response to output price changes (Fig. 2). Rubber prices decreased from about 30,000 Indonesian Rupiah (IDR) in 2012 to about 15,000 IDR in 2015, resulting in severe reductions in income from rubber cultivation [1 US$ = 9370 IDR in 2012 and 13,390 IDR in 2015 (World Bank 2016)]. Palm oil prices were also lower in 2015 than in 2012, but the difference is less pronounced than in rubber. The higher involvement of all farmers in own non-agricultural business

Table 1 Differences in farm household characteristics between oil palm cultivators and non-cultivators

	Survey round 2012		Survey round 2015	
	Cultivators [$n = 238$]	Non-cultivators [$n = 441$]	Cultivators [$n = 248$]	Non-cultivators [$n = 435$]
Livelihood indicators: consumption expenditure (million IDR/year/AE)				
Total consumption expenditure	24.527** (15.210)	20.090 (31.311)	23.956*** (16.757)	17.841 (13.394)
Non-food expenditure	11.675 (12.710)	9.160 (27.643)	12.348*** (13.982)	8.439 (10.738)
Food expenditure	12.853*** (6.574)	10.931 (6.086)	11.608*** (6.229)	9.402 (4.761)
Household characteristics				
Cultivates rubber (=1)	0.613***	0.946	0.601***	0.947
Farm size owned (ha)	5.414*** (5.289)	3.337 (3.955)	5.474*** (5.224)	3.208 (4.213)
Number of adults in the household	2.849 (1.064)	2.980 (1.227)	2.964 (1.125)	2.922 (1.141)
Female-headed household (=1)	0.021***	0.068	0.028***	0.103
Age of the household head (years)	45.508 (12.183)	45.773 (12.277)	47.661 (10.978)	47.485 (11.793)
Education (years of schooling)	7.752 (3.604)	7.302 (3.680)	7.335 (3.526)	7.115 (3.780)
Own business (=1)	0.231	0.186	0.335***	0.221
Employed (=1)	0.412	0.476	0.556	0.570
Migrant (=1)	0.576***	0.374	0.548***	0.379
Transmigrant village (=1)	0.437***	0.236	0.411***	0.248
Distance to the nearest market (km)	5.720** (7.482)	7.154 (7.359)	4.594*** (5.216)	6.036 (6.027)
Formal credit (=1)	0.353***	0.184	0.480***	0.274
Share of titled land (0–1)	0.303*** (0.408)	0.172 (0.350)	0.339*** (0.419)	0.224 (0.390)

Mean values are shown with standard deviations in parentheses

***, ** Difference with non-cultivators in the same survey round are statistically significant at 0.01 and 0.05 levels, respectively

activities and off-farm employment in 2015 (Table 1) can be interpreted as an economic strategy to cope with declining prices in the markets for agricultural cash crops.

Possibly as a result of the higher involvement in off-farm economic activities, mean household consumption expenditures showed only a moderate decrease between 2012 and 2015, in spite of lower output prices (Table 1). That is, farm households were mostly able to maintain their living standard. The decrease was more pronounced for non-cultivators of oil palm (−11%) than for oil palm cultivators (−2%), as one would expect given the higher dependence of non-cultivators on rubber prices. Among the non-cultivators of oil palm, the decrease was stronger for non-food expenditures (−14%) than for food expenditures (−8%). This is not surprising because food is a basic need, so that households try to maintain consumption levels to the extent possible even when their income decreases.

Average Livelihood Effects of Oil Palm Cultivation

The Hausman test of the effects of oil palm cultivation on household livelihoods (Fig. 3) and the underlying regression models with total consumption expenditures, food expenditures, and non-food expenditures as dependent variables

Table 2 Labor and land productivity of oil palm and rubber

	Survey round 2012				Survey round 2015			
	Oil palm		Rubber		Oil palm		Rubber	
	n	Mean (Std. dev.)	n	Mean (Std. dev.)	n	Mean (Std. dev.)	n	Mean (Std. dev.)
Labor productivity [000 IDR /hour]	132	78.477*** (73.429)	313	23.756 (19.105)	168	46.588*** (114.399)	330	10.698 (12.907)
Land productivity [Mil. IDR /ha /year]	134	13.459*** (10.085)	314	19.206 (12.376)	168	8.221*** (8.271)	330	10.260 (7.471)

Statistical significance was estimated using Kruskal-Wallis equality of populations rank test comparing the variables across the two crops. Only plots surveyed in both rounds were included in the analysis. All unproductive plots were excluded and tree age restricted from 5 to 25 years. Monetary values from 2012 were inflation-adjusted

*** Difference between mean values for oil palm and rubber within the same survey round is statistically significant at 0.01 level

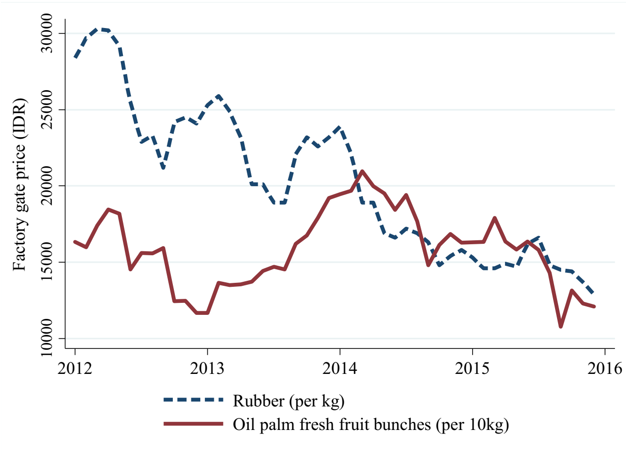

Fig. 2 Price movement of rubber and palm between 2012 and 2016. Notes: Rubber price data from Gabungan Perusahaan Karet Indonesia (GAPKINDO), Jambi. Oil palm fresh fruit bunch price data from Dinas Perkebunan, Jambi

(Tables S2-S4) rejects the null hypothesis of no bias through time-invariant unobserved heterogeneity in the random-effects specification. In two of the models (total expenditure and non-food expenditure), the effect size of oil palm cultivation is larger in the fixed-effects than in the random-effects specification. However, the random-effects models are more efficient and also more comparable with the cross-section OLS models. Hence, we proceed with interpreting the random-effects estimates, cautioning that these effects may possibly underestimate the impacts of oil palm cultivation.

The random-effects model shows a positive and significant effect of oil palm cultivation on total household consumption. The point estimate in the full model suggests a 14% improvement in household livelihoods through oil palm cultivation (Fig. 3a). The full model controls for farm size and the existence of non-farm businesses in the household, hence the 14% is the primary effect of cultivation on livelihoods without including possible secondary effects that result from the reallocation of saved labor time. In an alternative model, we exclude the existence of own non-farm businesses from the set of explanatory variables. The point estimate of oil palm cultivation does not change much, suggesting that secondary effects from reallocating household labor to non-farm businesses are small. In yet another model we exclude farm size as explanatory variable. In this model, the point estimate of oil palm cultivation increases to 22% (Fig. 3a), suggesting that there are positive secondary effects on household livelihoods resulting from farm size increases. As mentioned above, the lower labor requirement in oil palm allows households to cultivate additional land, thus further increasing the income from farming.

The breakdown of household expenditure types shows that the effect of oil palm cultivation is positive and significant on both food consumption (Fig. 3c) and non-food consumption (Fig. 3b). Yet, the effect on non-food consumption (19%) is larger than the effect on food consumption (10%). This difference is expected. Most farm households in the sample are above the poverty line (BPS 2014) and not chronically food-insecure. Hence, a larger share of the additional income is spent on non-food goods and services.

Temporal Differences

The cross-sectional OLS models for 2012 and 2015 models include farm size and own non-farm businesses as control

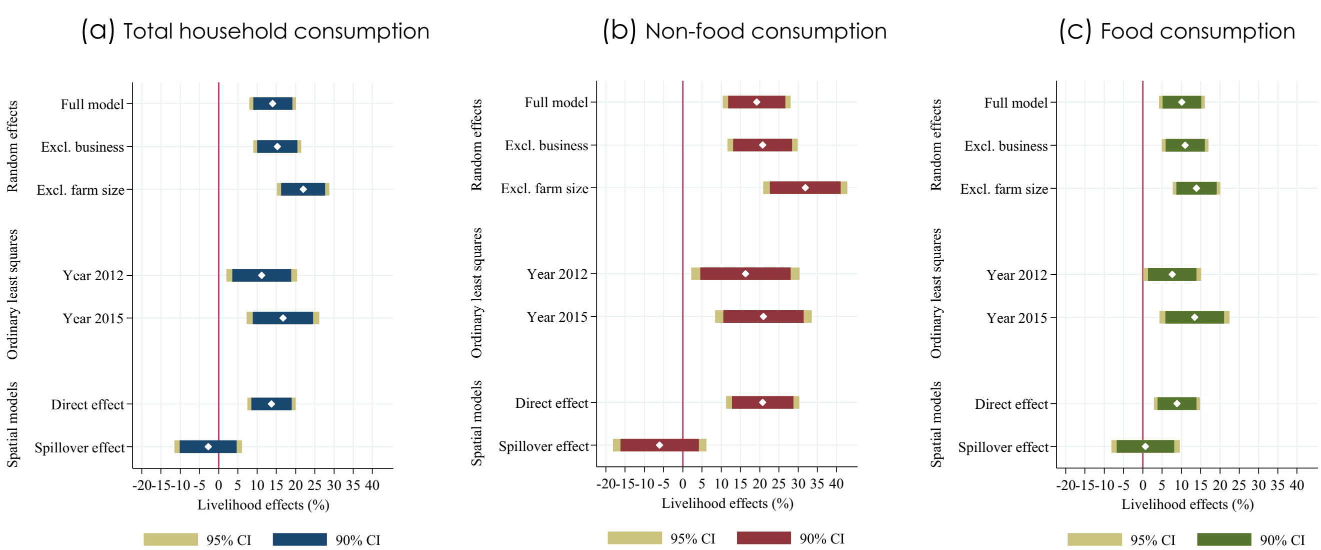

Fig. 3 Livelihood effects of oil palm cultivation. **a** Total household consumption. **b** Non-food consumption. **c** Food consumption. Notes: Consumption is measured in terms of annual household expenditures for food and non-food goods and services per adult equivalent. Average marginal effects are shown. The underlying regression models are presented in Tables S2, S3, and S4

variables, so that only the primary effects of oil palm cultivation are considered. In both years, oil palm cultivation had positive and significant effects on household livelihoods, but the effects were larger in 2015 than in 2012 (Fig. 3). In 2012, the average effect on total household consumption was 11%, whereas in 2015 it was 17% (Fig. 3a). This increase in the percentage effect is not because the income from oil palm increased over time in absolute terms. In fact, the absolute profitability of oil palm was lower in 2015 than in 2012 due to declining output prices (Table 2). However, the relative profitability of oil palm increased because the decline in rubber prices was stronger than the decline in palm oil prices.

The breakdown by food and non-food consumption expenditures in these OLS models shows another interesting result. The effect of oil palm cultivation on both types of expenditures was larger in 2015 than in 2012 (Fig. 3b and c), but the relative increase in the mean effect was stronger for food consumption (63%) than for non-food consumption (31%). These patterns suggest that oil palm cultivation has helped farm households reduce the risk of food insecurity during the rubber price crisis.

Spillover Effects

The direct effects are those that occur through own cultivation of oil palm, but now controlling for spatial dependence. The estimates are positive, statistically significant, and similar in magnitude to the ones from the random-effects specifications (full models) (Fig. 3). Hence, controlling for spatial dependence does not alter the findings. The estimated spillover effects are small and statistically insignificant, i.e., during the study period the livelihoods of neighboring households were not significantly influenced through the cultivation of oil palm by others. The insignificant estimates do not necessarily imply that the expansion of oil palm would leave, for example, non-cultivating households completely unaffected. It is possible that negative spillovers through some mechanisms were compensated by positive spillovers through other mechanisms. But our findings suggest that the total spillovers did not affect the livelihoods of other farm households in a significantly positive or negative way.

Conclusion

Our empirical study with farm household data from Jambi Province, Sumatra, shows that the expansion of oil palm has affected the livelihoods of cultivating farm households in a positive way. This result is consistent with previous research in Sumatra and other parts of Indonesia (Krishna *et al.* 2017a; Euler *et al.* 2017; Bourke and Harwood 2009), although previous studies had not used panel data for the analysis of impacts as we have done here.

Oil palm contributes to higher household consumption, including food and non-food expenditures. On average, oil palm does not generate higher profits per unit of land than rubber, the main alternative crop. However, oil palm requires less labor, so that oil palm-cultivating households are able to manage larger areas of land with the same labor input. When holding farm size constant, the average improvement in household livelihoods through oil palm cultivation was 14%. When letting farm size vary, the effect increased to 22%. These results suggest that parts of the total economic benefits are indeed the result of oil palm cultivators expanding their farm size. We also showed that the effects of oil palm cultivation vary over time. Due to the sharp price decline in international rubber markets, the relative improvements in household livelihoods through cultivating oil palm increased between 2012 and 2015. We did not find significant spillover effects on the livelihoods of neighboring farm households.

Our results refute the commonly held perception that oil palm diffusion would only benefit large plantation companies and would affect the livelihoods of the local population in a negative way. Our data are not representative for the entire population of Jambi, because we only looked at farm households. But most of the farm households benefit significantly. Unquestionably, oil palm monocultures are also associated with environmental problems. And the fact that the labor savings through oil palm cultivation allow smallholders to expand their farm size may contribute to additional forest clearing when effective rules to curb deforestation are not in place. Policies aimed at more sustainable land use are required. But such policies cannot ignore the economic benefits of oil palm cultivation for local farmers. Only when the incentive structures of local smallholders are properly understood, can socioeconomic and environmental goals be reconciled through appropriate policy interventions.

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Data Availability The data used in this study are archived with openly accessible, keyword-searchable metadata and data holder contact details for data requests (https://efforts-is.uni-goettingen.de). Datasets used in this study have the following identification numbers: 12,620, 13,500, 13,501, 13,520, 13,660, 13,642, 13,643, 13,644, 13,647, 13,648, 13,649, 13,650, 13,651 (household-level data); 13,521, 13,600, 13,601, 13,620 (plot-level data); 13,680 (village-level data).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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