Labor-saving technological change and decreasing fertility rates: The oil palm boom in Indonesia

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Abstract:

Although new production technologies are often regarded as one of the key drivers of the reduction in live birth per women, empirical evidence is scarce. This paper addresses this gap, exploring the expansion of oil palm in Indonesia. We argue that this type of technological change is rather unique, as it induces gender-specific labor savings that affect not only large-scale farms but also smallholder farmers. We use Becker's quantity-quality model to identify different causal mechanism through which the expansion of oil palm could affect fertility rates. Our identification strategy relies on an instrumental variables approach with regency-fixed effects, in which the expansion of area under oil palm at regency level is instrumented by regency-level attainable yield of oil palm interacted with the national oil palm expansion. We find consistently negative effects of the oil palm expansion on fertility. The results suggest that the negative effect is mainly explained by increasing female wages and increasing consumption expenditure. This suggests that the fertility reduction was driven by income effects of the oil palm boom at the household level, as well increased female opportunity costs of child rearing.

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1 Introduction

Reducing fertility is often seen as one key instrument in order to increase human well-being. At the individual level, the health burden for women (including the risk of dying in childbed) falls as an immediate consequence of reduced number of births. On the other side, low fertility rates are often associated with higher incomes, and more generally with higher and more sustained economic growth. The latter observation, however, derives entirely from correlations of income and fertility in cross-country analyses (Galor & Weil 2000).

Different theories exist about what triggers decreasing fertility rates. Technological change is generally seen as one (key) driver of the historical fertility transition in the US and Europe (Galor & Weil 2000; Guinnane 2011). In particular, mechanization in agriculture as well as the sectoral shift from employment in agriculture towards employment in industry seems to have played a crucial role. Based on models of fertility decisions developed in Becker (1960) and Becker and Lewis (1973), the argument is that technological progress increased returns to education. This then increased the demand for the quality of children and reduced demand for the quantity of children. This theory was mostly backed up by empirical findings (Bleakley & Lange 2009; Becker et al. 2010; Fernihough 2017), although the findings are not unambiguous (Black et al. 2005).

In low-income settings, this relationship is less clear. For one, employment is still largely dominated by agriculture, and attempts to trigger industrialization processes often failed. On the other side, mechanization in agriculture is usually concentrated on large farms, thus affecting only a relatively small elite. Consequently, only few studies have looked at the relationship between mechanization and fertility in low-income settings, and at the mechanisms underlying this relationship. Rosenzweig and Evenson (1977) and Levy (1985) are notable exceptions. However, these concentrate entirely on mechanization in agriculture and on subsequent changes in the demand for child labor and its effects on fertility.

This paper explores a different type of technological change: the expansion of oil palm in Indonesia. We argue that this type of technological change is rather unique, as it affects not only large-scale farms but also smallholder farmers. And in contrast to most technological innovations available to smallholder farmers it is not factor neutral. In contrast, similarly to mechanization, oil palm is a labor-saving agricultural technology compared to other competing crops in the region, and frees up a substantial amount of labor from agriculture (Euler et al. 2017; Rist et al. 2010). This paper focuses on understanding the effects of the oil palm boom on fertility decisions in Indonesia, and in identifying the causal mechanisms underlying such decisions.

Our results contribute to two different strands of literature. We first add to the literature on the fertility transition by showing the impact and transmission mechanisms of a labor-saving agricultural technology, which unlike mechanization is also rapidly adopted by smallholder farmers. Second, regarding the literature on land-use change, we stress that in a more holistic approach to land-use change modelling, demography should not be taken as an exogenous variable.

The remainder of this paper is structured as follows: In section 2, we present evidence on the factor productivity of oil palm using micro-level data from Jambi Province. Section 3 presents the conceptual framework. In section 4, we introduce the different data sources to test our hypotheses. Our estimation strategy is presented in section 5. Section 6 reports results and the transmission mechanism, and section 7 concludes.

2 Background: Oil palm – a labor-saving technology?

Global palm oil production rose steeply by 300% between 1990 and 2010 with Indonesia emerging as the world's largest producer by 2009 (Byerlee et al. 2017; Cramb & McCarthy 2016). This expansion has caused a drastic loss of biodiversity (Clough et al. 2016; Wilcove & Koh 2010), reduction of water resources (Merten et al. 2016) and increased carbon emissions (Burney et al. 2010). However, the oil palm expansion also led to significant economic gains such as poverty reduction and increased welfare of smallholder farmers (Edwards 2016; Krishna et al. 2017a). The increase in welfare seems to be driven mainly by the lower labor intensity of oil palm compared to competing crops, however, also infrastructure development triggered by oil palm expansion seems to have been important for economic growth.

The main competing crops for oil palm seem to be rubber and rice. While no national data on land-use history is available, data from the PODES suggests that villages cultivating oil palm are often simultaneously involved in rubber or rice cultivation.[1]

In order to provide more detailed evidence on factor productivity of oil palm compared to other crops, we use farm household data collected in Jambi province (Sumatra) in 2012 and 2015. A multi-stage sampling framework was used to obtain a representative sample of 700 local farm households in 45 villages in the tropical lowlands of Jambi.[2] The data contains detailed plot input and output information for farmers involved in the cultivation of oil palm and rubber.[3] In addition, we cite evidence from the literature for rice cultivation.

Plot level estimates in Table 1 show that labor productivity per hour is significantly higher in oil palm compared to rubber[4] and according to literature also for rice (Rist et al. 2010). In contrast, land productivity of oil palm is lower than in rubber cultivation.

Our data also suggests that the gains in labor productivity are gender specific and largely driven by male labor (table 1). A similar picture emerges looking at wages paid in both activities: wages are higher for men in oil palm than in rubber cultivation, which reflects the higher labor productivity in oil palm. Typically, food crops such as rice also involve comparably more female labor than cash crop cultivation, and rice cultivation in Indonesia is no exception. Rice has a low labor productivity in general, and there is no evidence that female labor is more or less productive than male labor in rice cultivation (Li 2015; Feintrenie et al. 2010).

Given land constraints, oil palm can be hence characterized as a new labor saving technology in most regions of Indonesia.

3 Conceptual framework: A simple model on oil palm expansion and fertility

The previous section highlighted a range of mechanisms through which oil palm could affect household decision making. This section builds on the Q-Q model developed in Becker and Lewis (1973) to derive testable predictions of the effect of the oil palm expansion on fertility. In particular we seek to highlight the mechanisms through which this effect might be operating.

We follow Becker and Lewis (1973) in assuming a household utility function of the form $U(n, q, Z)$ with q being the quality of each child, n the number of children and Z other commodities. This utility function is maximized subject to the typical budget constraint.

We consider now how the adoption of a new agricultural technology, such as oil palm, affects the demand for children. We assume that the technology is adopted because it increases farm-income and do not model the agricultural production function explicitly. Furthermore, we assume that the positive

[1] PODES data covers all villages and city regencies in whole Indonesia. In 53% of the village where oil palm was the first or second important planation crop in 1993, rubber was either the first or second important crop. In some villages coco and coconut coexisted also with oil palm. In 63% of the oil palm village rice was also mentioned as important food crop.

[2] For more details on the sampling framework, see Krishna et al. 2017b.

[3] We use this data, because no nationally representative micro data with detailed input and output information is available in Indonesia.

[4] Note that the data stems from smallholder plantations. Since large-scale oil palm plantations use the same technology as smallholder farmer, we expect similar land and labor productivities on plantations.

income effect dominates in all population segments, which is supported by empirical literature (Edwards 2016). Given the effects on wages and infrastructure development cited above, we expect oil palm to affect fertility mainly through an income effect, a price effect on child quantity, and a price effect on child quality. These effects will be discussed in the following.

Income. If oil palm raises farm income and income from agricultural employment, households can invest the additional income in increasing the number of children, in increasing child quality or both. The number of children could hence decrease or increase. Now, assuming the household increases the quality of each child, this affects the shadow price of child quantity through the interaction term between quality and quantity.[5] Therewith, even a small increase in q could have a large and negative effect on *n*. This is why we generally expect the income effect of child quantity to be negative.

Infrastructure. The infrastructure created due to oil palm reduces the price of child quality. Higher incomes can provide higher tax revenues for local governments, which can in turn lead to higher investments in health, education and transportation infrastructure. An increase in public funding can also stem from the desire of governments to attract private investors into certain regions. Since fresh fruit bunches have to be brought to palm oil mills within two days to guarantee high quality oil, transportation infrastructure such as asphalt roads are in particular likely to be associated with the oil palm expansion. These investments would reduce the cost of accessing education, thereby decreasing the cost of investing in any child's quality. In the Q-Q model, a reduction in the price of child quality would increase investments in child quality, and through the interaction between quality and quantity, this would again decrease the demand for children.

Maternal opportunity costs of time. Not only the price of child quality, also the price of quantity is expected to change with the oil palm expansion. This variable captures among others the opportunity costs of child rearing. As noted in the preceding chapter, oil palm cultivation is less labor intensive compared to competing crops, and employs considerably less women than other crops. If female shadow wages in agriculture fall, they could either stop working, or shift to other sectors. However, as the oil palm expansion goes hand-in-hand with infrastructure development, wages for women in other sectors than agriculture could even increase, thus drawing more women into the labor force, and out of agriculture. This provides two possible scenarios: If female labor is not sufficiently demanded, we would expect that female labor force participation or female wages decrease. This implies a reduction of p_n and *ceteris paribus* an increase in the demand for children. In the second scenario, women leave the agricultural sector and enter the more profitable non-agricultural sector. Then, we would expect p_n to increase due to higher wages, leading to decreasing fertility.

Child labor. A second effect on the price of child quality might stem from differences in the returns to child labor between oil palm and competing crops. In many countries children generate income through family work or wage work, thereby offsetting some of their direct costs such as costs of clothing and food. We are not aware of any detailed empiric examination of child labor in oil palm cultivation. Anecdotal evidence suggests that children can be involved in picking up loose fruits, which fell of the main bunch during harvesting (Koczberski 2007). However, harvesting and cutting of oil palm necessitates too much physical strength to involve child labor. Rubber and rice cultivation, in contrast, involve more family labor and theoretically more child labor. We therefore expect that oil palm would rather decrease the returns to child labor. If returns to child labor fall, this increases the cost of child quantity p_n, and parents are more likely to reduce the number of children.

We admit that the framework of a Q-Q model is quite narrow and that other mechanisms could be at work. We test two potential alternative arguments in more detail, which seem particularly relevant in this context: Migration and child mortality.

[5] See Becker (1981) or Becker & Lewis (1973) for more details.

4 Data

We combine different datasets to assess the effect of the oil palm expansion on fertility, and to analyze the underlying mechanisms.[6]

The PODES data provides the earliest data on oil palm that is nationally representative and can be disaggregated by regency, but data is only available for 1993 and 2003. Administrative data on the oil palm expansion at regency level is available since 1996. The Tree Crop Statistics are published annually by the Indonesian government (Ministry of Agriculture 2017) and can accessed through the Indonesia Database for Policy and Economic Research (INDO-DAPOER) which is maintained by the World Bank (World Bank 2017).[7] Figure 1 illustrates the regional oil palm expansion of smallholders in Indonesia

Fertility outcomes are taken from the SUSENAS data. The SUSENAS collects demographic and socioeconomic characteristic of individuals on an annual basis, and is designed to be representative at the regency level. The SUSENAS provides information on the number of all ever occurring live births per woman, for all women older than 10 years. We use this variable as our measure of fertility, and restrict the sample to women between the age 15 and 49 years. Figure 2 presents the fertility trends for different islands in Indonesia. The figure shows that the fertility rate decreased until 2005, stagnating on some islands in subsequent years.

The Global Agro-Ecological Zones (GAEZ) database provides simulations on agro-climatic attainable yield and suitability indices for crops under different conditions. GAEZ provides data to calculate suitability of oil palm at regency level. Figure 3 illustrates the results.

Finally, we use the Demographic and Health Surveys (DHS) and SAKERNAS labor survey to obtain additional control variables.

5 Estimation strategy

Eliciting a causal effect from oil palm expansion on fertility involves major challenges such as unobserved heterogeneity and reverse causality. We therefore use an instrumental variables approach combined with regency-fixed effects to identify causal effects.

Our instrument combines time-invariant agro-climatic suitability for oil palm with the national change in oil palm cultivation, and is inspired by Duflo & Pande (2007). We interact the suitability of oil palm at regency level from GAEZ with the annual expansion of oil palm at national level. We assume that national expansion is driven by world market prices and policies of the central government and is not affected by idiosyncratic regional developments which could be correlated with both fertility and oil palm expansion.

This provides a prediction of how much area in a regency should be cultivated by oil palm in a given year based on its suitability for oil palm cultivation, taken the national expansion as given. This delivers an instrument which highly correlates with the actual expansion, since next to access to land and transport costs, agro-ecological suitability is a major determinant of growing locations for crops. Importantly, we expect this instrument to be exogenous, i.e. to affect fertility only through its effect on oil palm expansion, and not through any other mechanisms.

A couple of possible threats to identification exist such as different trends in fertility for oil palm growing region or that oil palm expansion follows the expansion of other crops. We, however, allow

[6] The regencies of Papua, Aceh and the Maluku islands were dropped since data in these regions are not available for all years due to social unrest. Since oil palms are not cultivated within cities, we exclude also all "city" regencies (kotas) from the analysis.

[7] We update the database with more recent data from the Tree Crop Statistics to complete the time series until 2016.

for different trends based on initial fertility and checked agricultural data for any parallel trends in crop expansion patterns.

Our first stage is hence as follows:

$$OP_{it} = \beta_o + \beta_1 AY_i * OPA_t + \beta_2 OPA_t + \beta_3 X_{it} + \beta_4 y_t * p_p + \beta_5 y_t + \mu_i + \varepsilon_{it} \qquad (1)$$

Where OP_{it} is the share of oil palm villages within a regency for the 1993-2003 dataset or the share of smallholder oil palm area of the total regency area for 1996-2016 dataset. AY_i is the attainable yield for oil palm in each regency i and OPA_t is the oil palm area in hectare on the national level in year t. X_{it} includes further controls such as initial levels of fertility, sectoral shares, wages and electrification multiplied by a time trend. y_t is a time trend and p_p are island dummies. μ_i are regency fixed effects.

The second stage of our fixed effects 2SLS models is as follows:

$$FR_{hit} = \beta_o + \beta_1 \widehat{OP}_{it} + \beta_2 OPA_t + \beta_3 X_{hit} + \beta_4 y_t * p_p + \beta_5 y_t + \mu_i + \varepsilon_{it} \qquad (2)$$

FR_{hit} is the fertility rate of women between 15-49 years per regency in a given year. The other variables are the same as in equation (1).

6 Results

6.1 Effect of oil palm expansion on fertility

In table 2 we present our main results for equation (2). Panel A reports the results for the 1993-2003 dataset using PODES data for oil palm expansion, while Panel B reports the results for the 1996-2006-2016 dataset that uses data from Tree Crop Statistics for oil palm expansion. In columns (1) to (3) we use ordinary least squares with regency fixed effects, adding island time trends in column (2) and province time trends to column (3). In columns (4) to (8) we use the instrumental variables approach described in the section 5. To assess the robustness of our findings, we subsequently add further controls such as island or province trends in columns (5) and (6), respectively. We additionally control for initial levels of fertility, wages, electrification and sectoral shares interacted with a time trend in columns (6) and (7) and for women's age in column (8). The results show a consistently negative effect of the oil palm expansion on fertility. The effect is always statistically significant in the preferred fixed effect instrumental variable estimations. Column (8) is the preferred specification.

The estimated effect sizes are increasing significantly when moving from fixed effect estimates (FE) to our instrumental variables approach. This could indicate a weak instrument problem; however, our first stage Kleibergen Wald F-statistic suggests that our instrument is reasonably strong in most regressions ranging from 8.905 to 25.996. There could be three other reasons for having lower fixed effect estimates. First, our IV estimates capture the local average treatment effect of oil palm expansion. We thus show an effect for regencies where oil palm was planted because the regencies had favorable agro-ecological conditions and not for example because of policy regulations. Plantations in favorable agro-ecological conditions are likely to have higher returns and we assume hence that the effects on fertility could also be larger. We caution hence that our estimates present an upper bound to the average treatment effect. Second, the IV approach might have corrected endogeneity biases. Lastly, the data on the extension of oil palm in the regencies may involve significant measurement errors, while the suitability index is based on agro-climatic, soil and terrain conditions which may be more precisely measured. Our IV may have hence corrected measurement errors, which would have induced an attenuation bias in our fixed effect estimates.

We conducted several sensitivity checks and tested the effects of including control for migration and child mortality. The results remained however stable. Results can be obtained from authors.

6.2 Effect of oil palm expansion on income and sectoral shares

To support our theoretical considerations in the preceding sections on the effect of oil palm expansion on income and sectoral shares, we regress a set of labor market variables on oil palm expansion. In Table 3 and 4 we report results on wages in different sectors for men and women, respectively, using the same instrumental variables approach as for fertility. The results show that oil palm expansion increased wages for both men and women in columns (1). These wage increases are driven in particular by the non-agricultural sector (see columns (2) and (3)). Since we argue that oil palm leads to income gains and triggered infrastructure development, this result seems plausible. In table 3 column (6) we show that male wages in agricultural employment also rose, most likely due to higher labor productivity. Our assumption that the oil palm expansion increased incomes is hence supported by our data.

Next, we report the effect of oil palm expansion on sectoral shares and labor force participation. The results in table 5 column (1) document that female labor force participation did not decrease significantly due to oil palm expansion which confirms our assumptions. As expected from our micro-data, we observe in column (2) that women shift from the agricultural to non-agricultural sector. Although we did not find significant results, column (3) indicates that women shifted mainly out of family agriculture. For men, we find that participation in wage employment in agriculture increased significantly in column (8), which is likely due to the increasing demand for plantation workers. Based on these results, we expect that the share of women in the non-agricultural sector and increased female wages act as mediating variables in our models.

6.3 Transmission mechanisms

6.3.1 Income effect

The previous chapter reported higher income due to oil palm expansion. Increasing income would lead, assuming a positive income elasticity of child quality, to decreasing fertility rates. We test this proposition using consumption expenditure per capita as proxy for income, for which we have data on the micro-level matching with our fertility data. Table 7 presents the results in column (1). The effect of oil palm on fertility is decreasing with the inclusion of consumption expenditure for both time periods from 1.9 to 1.71 and from 7.09 to 6.58. Higher consumption expenditure has significant negative effect on fertility. This indicates that part of the observed effect is running via an income effect with higher elasticity of child quality, although only a small share of the overall fertility effect can be explained by higher incomes.

6.3.2 Infrastructure

The infrastructure effect suggests that the oil palm expansion might reduce the costs of children quality through better infrastructure. We use electrification through the public grid for both time periods and prevalence of asphalt roads and secondary schools for 1993-2003 as controls for infrastructure. If infrastructure development decreases the costs of children quality, we expect that enrollment rates increase; we use hence the enrollment of children (age 10-15 years) as additional control variable. Table 7 reports the results in columns (2)-(4). Only the share of villages with asphalt roads has a significant effect. The effect of oil palm expansion on fertility does not change in a drastic way compared to the income effect. In Panel B shows even a very slight increase in the effect of oil palm expansion. This indicates that reductions in the price of child quality – via infrastructure development - do not explain the observed negative effect on fertility in fundamental way.

6.3.3 Maternal opportunity costs of time

Table 8 presents the results of regressing fertility on the oil palm expansion if labor market controls are included. We observe a strong negative effect of the share of women involved in agricultural labor or agricultural family labor on fertility, holding female workforce participation constant. However, we do not observe that the sectoral variables have a strong impact on the magnitude of the oil palm coefficient. This also holds true if we only look at the subsample of working women[8]. Only in Panel A, we observe a slight reduction. We observe in column (4) and (5), however, that changes in female wages in agriculture and in non-agriculture are reducing the effect of the oil palm expansion on fertility quite strongly. We use wage data from SAKERNAS, since SUSENAS does not provide consistent data on wages. In column (6) and (7) we test if we can observe the same effect with male wages. The results show that only the inclusion of female wages explains part of the negative effect of oil palm expansion on fertility.

The observed effect of female wages could theoretically be explained by an income effect, an opportunity cost effect or an empowerment effect, the latter is tested in the next section. Based on regression outcomes we tend to reject the income effect, since neither male wages nor consumption expenditure explains the observed effect. The results rather indicate that higher opportunity costs of child rearing due to higher wages could be one important explanation. In table 6 we report the effect of oil palm expansion on working hours. Column (9) shows that women below 25 years increased their working hours significantly in both panels. This further supports the hypothesis that oil palm expansion increased women's wages, which lead to higher opportunity costs of child rearing and that young women, which are more likely without children, increase their working hours and postpone having children. If we include female wages into the regression we observe that the effect of oil palm expansion on working hours decreases slightly, which could be an indication that the increase of working hours could be driven by higher wages[9].

6.3.4 Child labor

Table 9 reports the results for the effect of oil palm expansion on child labor, testing the price effect of child labor. Child labor is reported for the age group between 10 and 15 years. We define child labor as doing some work, which does not need to be the primary activity. Household work is not included. In column (1) we pool boys and girls; in column (3) and (4) we split the sample for gender. In column (2) we report the effect of oil palm expansion on if a child is working in family agriculture. We did not find significant results in any specification. We conclude that changes in child labor are not an important mechanism in explaining the negative effect of oil palm expansion on fertility.

7 Conclusion

We contributed to the literature by disentangling the effect of a labor saving agricultural technology on fertility and by demonstrating that demography is not exogenous to land-use change. In the first step we present evidence that oil palm is indeed labor saving. Based on this observation, we developed testable hypotheses using the Becker's Q-Q framework. Using an instrumental variables

[8] Results can be obtained from authors.
[9] Results can be obtained from authors.

approach with regency-fixed effects, we find that the oil palm expansion significantly reduced fertility. This effect is persistent even after controlling for differential island trends and differential trends depending on initial values of fertility, electrification, wages and sectoral shares. While our estimates likely represent an upper bound to the average treatment effect, they suggest that the oil palm expansion explains up to 20% of the fertility reduction observed in Indonesia in the time period between 1993 and 2016. We then tested different transmission mechanisms, and found that child mortality, migration patterns and infrastructure development do not explain our results. We do find evidence for a small income effect: oil palm increased income and with rising incomes fertility declined. Women shifting out of the agriculture to the non-agricultural sector, appears to have played role in the 1993-2003 time period, but to lesser extent than expected. The most important mechanism, however, seem to have been increasing wages of women. We are inclined to reject that increasing wages reduced fertility via income or empowerment effects, since we do not observe that controlling for male wages or consumption expenditure affect the estimated effect of oil palm on fertility, and because investment in children's education did not change. We interpret the result hence as an indication that the opportunity costs of child rearing increased for women.

We have to note some caveats. For the time period 1996-2016 we seem to be missing one important transmission mechanism, since the effect of oil palm on expansion remained significant even after including all possible control variables. Second, our data on wages is only representative on the province level, allowing only limited spatial variation. Third, we can only control for oil palm expansion driven by smallholder farmers.

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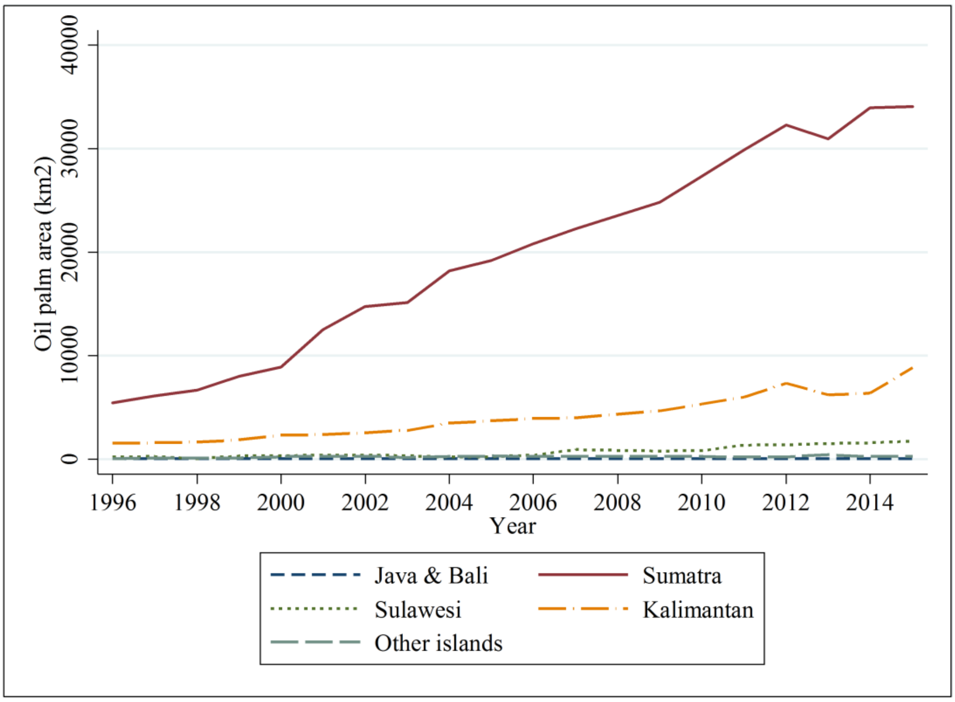
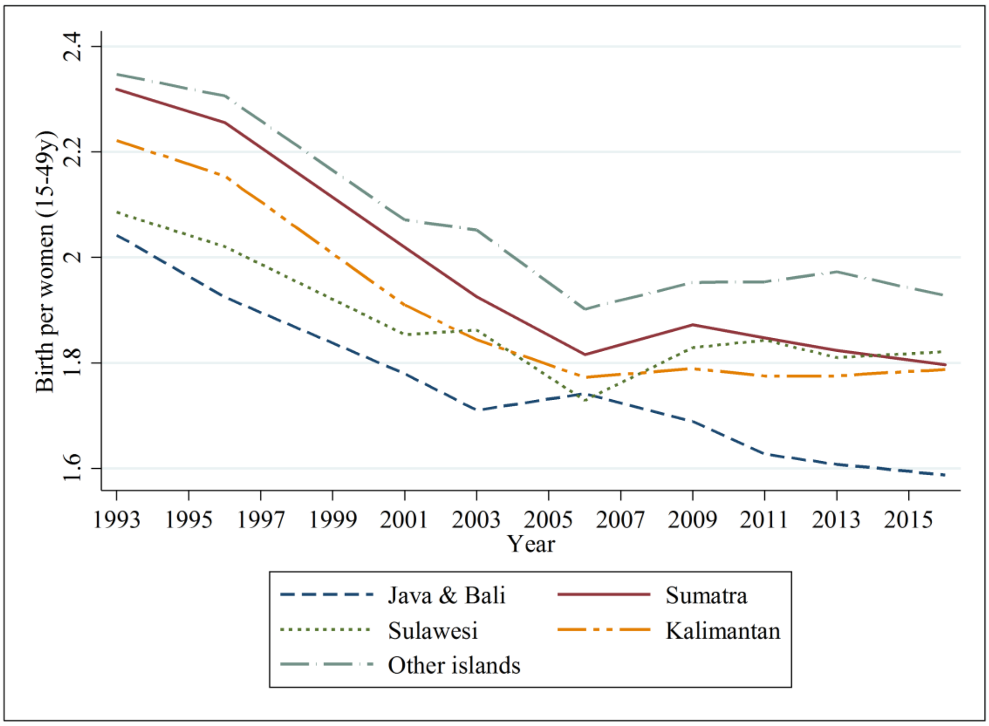
Figures

Figure 1: Regional oil palm expansion of smallholders in Indonesia



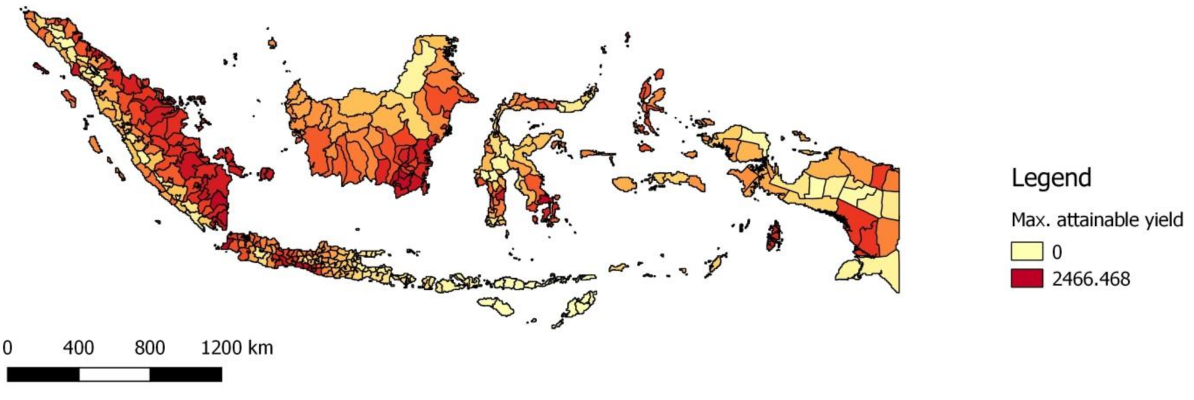
Source: Tree crop statistics, INDO-DAPOER.

Figure 2: Regional fertility trends in Indonesia



Source: Based on SUSENAS from 1993, 1996, 2001, 2003, 2006, 2009, 2011, 2013 and 2016

Figure 3: Regency-wise attainable yield for oil palm in Indonesia



Source: GAEZ. Max attainable yield is in palm oil (kg/ha). Conversion factor to oil palm fresh fruit bunches is 0.225.

Tables

Table 1. Labor and land productivity of oil palm and rubber

	Oil palm		Rubber	
	Obs.	Mean (Std. dev.)	Obs.	Mean (Std. dev.)
Labor productivity [000 IDR/h/ha /year]	437	65.4*** (93.94)	967	18.428 (18.171)
Land productivity [000 IDR/ha /year]	437	11714.02*** (10396)	967	15419.47 (11549.01)
Capital input [000 IDR/ha /year]	439	2653.118*** (2662.383)	973	651.995 (1021.978)
Female labor input [Hours/ha/year]	439	25.764*** (65.35)	973	313.761 (471.624)
Male labor input [Hours/ha/year]	439	237.696*** (211.089)	973	854.687 (997.983)
Female wages [000 IDR/hour]	17	12.442 (11.353)	27	10.437 (1.751)
Male wages [000 IDR/hour]	167	18.227*** (17.222)	319	14.411 (15.580)

Notes: Statistical significant difference between crops was estimated using a t-test. Unproductive plots were excluded and tree age restricted to productive age from 5 to 25 years (except for wage data). For the male wage data two outliers with more than 10 times the average wage were excluded. Hours worked includes family as well wage labor. Monetary values from 2012 were inflation-adjusted.

Table 2: Effect of oil palm expansion on fertility

PANEL A	1993-2003							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	OLS	IV	IV	IV	IV	IV
Share of villages with OP (%)	-0.467***	-0.315**	-0.548***	-3.056***	-1.172*	-5.143**	-2.804***	-1.902**
	(0.117)	(0.159)	(0.170)	(0.736)	(0.656)	(2.046)	(1.052)	(0.897)
Regency & Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Island trends	No	Yes	No	No	No	Yes	Yes	Yes
Province trends	No	No	Yes	No	Yes	No	No	No
Initial levels x trend	No	No	No	No	Yes	No	Yes	Yes
Women's age	No	No	No	No	No	No	No	Yes
F-stat	371.677	154.411	121.714	148.439	84.298	69.810	97.262	787.982
Kleibergen F-stat				25.996	13.272	8.905	10.664	10.663
Observations	366496	366496	366496	366496	366496	366496	366496	366496

PANEL B	1996-2006-2016							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	OLS	IV	IV	IV	IV	IV
Share of smallholder OP in regency (%)	-0.904	0.028	-0.862	-8.419***	-4.862**	-10.57**	-6.723**	-7.090**
	(0.581)	(0.585)	(0.564)	(2.754)	(2.006)	(5.018)	(2.920)	(2.969)
Regency FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Island trends	No	Yes	No	No	No	Yes	Yes	Yes
Province trends	No	No	Yes	No	Yes	No	No	No
Initial levels x trend	No	No	No	No	Yes	No	Yes	Yes
Time FE & Women's Age	No	No	No	No	No	No	No	Yes
F-stat	312.924	147.331	108.887	152.315	183.548	83.349	240.026	807.516
Kleibergen F-stat				20.557	15.312	10.315	11.971	11.970
Observations	627282	627282	627282	627282	627282	627282	627282	627282

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions include national oil palm area. Initial levels of fertility, electrification, share of labor in agricultural and agricultural wages are included in column (7) and (8).

Table 3: Effect of oil palm on male wages in regencies (2001-2015)

	IV						
	(1) Wage of men	(2) Wage of men in non-agricultural	(3) Wage of men in agricultural	(4) Wage of low educated men	(5) Wage of high educated men	(6) Wage of men in agricultural wage labor	(7) Wage of men in agricultural self-employment
Share of smallholder OP in regency (%)	6.602*	8.810**	4.522	3.143	8.665**	12.748*	4.415
	(3.822)	(4.091)	(5.106)	(4.380)	(4.298)	(6.683)	(6.230)
Regency fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-stat	496.568	37.588	26.423	48.478	32.504	15.520	17.757
Kleibergen F-stat	12.984	12.984	12.955	12.908	12.983	13.181	12.388
Observations	2994	2994	2947	2990	2993	2843	2824

Standard errors (clustered on regency level) in parentheses. No data for 2008. We control for mean age of male or female working age population respectively. Low education means none or only primary education.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Effect of oil palm on female wages in regencies (2001-2015)

	IV					
	(1) Wage of women	(2) Wage of women in non-agricultural	(3) Wage of women in agricultural	(4) Wage of low educated women	(5) Wage of high educated women	(6) Wage of women in agricultural wage labor
Share of smallholder OP in regency (%)	10.532**	10.961**	5.097	8.395	10.429**	9.839
	(4.805)	(5.006)	(5.740)	(5.725)	(5.184)	(7.821)
Regency fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
F-stat	373.087	15.649	22.503	23.138	24.987	16.259
Kleibergen F-stat	13.034	12.822	12.794	12.606	12.787	11.547
Observations	2993	2987	2843	2970	2970	2652

Standard errors (clustered on regency level) in parentheses. No data for 2008. We control for mean age of male or female working age population respectively. Low education means none or only primary education.* * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Effect of oil palm on sectoral shares in regencies (2001-2015)

	IV							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Female labor force participation	Share of women in non-agricultural work	Share of women in agricultural family work	Share of women in agricultural wage work	Male labor force participation	Share of men in non-agricultural work	Share of men in agricultural family work	Share of men in agricultural wage work
Share of smallholder OP in regency (%)	-2.435	3.875**	-2.820	-0.297	-0.474	-1.604	-0.334	2.131***
	(1.698)	(1.867)	(1.885)	(0.767)	(0.718)	(1.073)	(0.641)	(0.776)
Regency fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F-stat	12.937	33.686	26.107	8.397	25.292	44.521	24.689	8.065
Kleibergen F-stat	12.910	12.910	12.910	12.910	13.050	13.050	13.050	13.050
Observations	2995	2995	2995	2995	2995	2995	2995	2995

Standard errors (clustered on regency level) in parentheses. No data for 2008. We control for mean age of male or female working age population respectively * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Effect of oil palm on labor outcome and age at marriage

PANEL A					1993 - 2003				
	(1) Work force participation	(2) Working in agricultural family work	(3) Working in agricultural wage work	(4) Working in Non-agriculture	(5) Household head working in self-employed agricultural	(6) Ever married (=1)	(7) Age at first marriage for women below 25	(8) Working hours of women below 25	(9) Working hours of women above 25
Share of villages with OP (%)	-0.242	-0.927**	0.499	0.428	-0.777**	-0.310**	5.091*	1.773**	0.363
	(0.356)	(0.420)	(0.331)	(0.407)	(0.335)	(0.150)	(2.697)	(0.799)	(0.414)
F-stat	87.301	5.368	54.568	11.342	10.216	811.44	219.344	16.276	25.859
Kleibergen F-stat	10.668	12.519	12.519	12.519	12.519	10.668	9.893	11.234	13.061
Observations	366571	171012	171012	171012	171012	366571	42694	42432	118683

PANEL B					1996-2006-2016				
	(1) Work force participation	(2) Working in agricultural family work	(3) Working in agricultural wage work	(4) Working in Non-agriculture	(5) Household head working in self-employed agricultural	(6) Ever married (=1)	(7) Age at first marriage for women below 25	(8) Working hours of women below 25	(9) Working hours of women above 25
Share of smallholder OP in regency (%)	-0.243	0.729	-0.887	0.158	0.353	0.381	22.280	4.062*	-1.504
	(0.939)	(1.309)	(0.841)	(1.249)	(1.082)	(0.448)	(14.869)	(2.358)	(1.398)
F-stat	235.076	44.720	76.594	86.370	72.829	1449.73	379.073	28.764	36.920
Kleibergen F-stat	11.976	13.567	13.567	13.567	13.567	11.976	10.681	13.210	13.655
Observations	627352	289887	289887	289887	289887	627353	60466	57364	215344

Standard errors (clustered on regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV regressions are reported. All regressions include national oil palm area, regency fixed effect, island time trends, initial values times a year trend and year dummies. Initial levels of fertility, electrification, share of labor in agricultural and agricultural wages are included. For columns (2)-(5) and (8) to (9) only the subset of working women was used.

Table 7: Effect of oil palm on fertility- Income and infrastructure

PANEL A	1993-2003				
	(1) IV	(2) IV	(3) IV	(4) IV	(5) IV
Share of villages with OP (%)	-1.709*	-1.865**	-1.888**	-1.890**	-1.571**
	(0.992)	(0.908)	(0.921)	(0.884)	(0.796)
Consumption expenditure p. c. (log)	-0.732***				
	(0.018)				
Enrollment of children in regency (10-15y)		-0.936	-0.933		
		(0.993)	(0.999)		
Avg. access to public electricity in regency			-0.075	-0.025	
			(0.148)	(0.153)	
Share of villages with secondary school in regency				-0.109	
				(0.132)	
Share of villages with asphalt road in regency				-0.212**	
				(0.092)	
Age at first marriage					-0.147***
					(0.005)
Ever married (=1)					3.911***
					(0.097)
F-stat	730.628	734.644	681.427	632.613	768.61
Kleibergen F-stat	10.662	10.315	10.252	10.631	10.661
Observations	366488	366496	366496	366496	366496

PANEL B	1996-2006-2016				
	(1) IV	(2) IV	(3) IV		(5) IV
Share of smallholder OP in regency (%)	-6.587**	-7.173**	-7.088**		-7.191**
	(2.948)	(2.898)	(2.900)		(2.813)
Consumption expenditure p. c. (log)	-0.562***				
	(0.013)				
Enrollment of children in regency (10-15y)		-0.287	-0.288		
		(0.765)	(0.759)		
Avg. access to public electricity in regency			-0.053		
			(0.139)		
Age at first marriage					-0.138***
					(0.002)
Ever married (=1)					3.803***
					(0.058)
F-stat	793.630	755.940	710.903		728.93
Kleibergen F-stat	11.968	13.445	13.389		11.970
Observations	627282	627282	627282		627282

Standard errors (clustered on regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions include national oil palm area, regency fixed effect, island time trends, initial values times a year trend and year dummies. Initial levels of fertility, electrification, share of labor in agricultural and agricultural wages are included.

Table 8: Effect of oil palm on fertility – Labor market

PANEL A	1993-2003						
	(1) IV	(2) IV	(3) IV	(4) IV	(5) IV	(6) IV	(7) IV
Share of villages with OP (%)	-1.949**	-1.845**	-1.841**	-1.493**	-1.459*	-2.141**	-1.946**
	(0.912)	(0.889)	(0.886)	(0.748)	(0.750)	(1.035)	(0.882)
Work (=1)	-0.194***	-0.325***	-0.282***		-0.324***	-0.325***	-0.325***
	(0.014)	(0.013)	(0.013)		(0.013)	(0.013)	(0.013)
Work in agriculture (=1)		0.270***			0.269***	0.270***	0.269***
		(0.019)			(0.019)	(0.019)	(0.019)
Family labor (=1)			0.253***				
			(0.018)				
Women's wage in non-agriculture				-0.245**	-0.239**		-0.075
				(0.117)	(0.118)		(0.244)
Women's wage in agriculture				-0.066	-0.067		-0.144
				(0.069)	(0.069)		(0.126)
Men's wage in non-agriculture						-0.456**	-0.491
						(0.220)	(0.423)
Men's wage in agriculture						-0.052	0.111
						(0.096)	(0.174)
F-stat	832.640	776.356	774.015	690.431	686.911	666.655	589.484
Kleibergen F-stat	10.664	10.659	10.663	13.508	13.499	8.725	10.368
Observations	366496	366496	366496	363396	363396	366496	363396

PANEL B	1996-2006-2016						
	(1) IV	(2) IV	(3) IV	(4) IV	(5) IV	(6) IV	(7) IV
Share of smallholder OP in regency (%)	-7.186**	-7.201**	-7.255**	-6.189**	-6.333**	-7.288**	-6.284**
	(2.984)	(2.958)	(2.956)	(2.733)	(2.763)	(2.977)	(2.748)
Work (=1)	-0.189***	-0.321***	-0.261***		-0.321***	-0.321***	-0.321***
	(0.011)	(0.011)	(0.011)		(0.011)	(0.011)	(0.011)
Work in agriculture (=1)		0.317***			0.317***	0.318***	0.318***
		(0.018)			(0.018)	(0.018)	(0.019)
Family labor (=1)			0.272***				
			(0.016)				
Women's wage in non-agriculture				-0.188**	-0.182**		-0.212**
				(0.086)	(0.088)		(0.087)
Women's wage in agriculture				0.027	0.030		0.034
				(0.046)	(0.046)		(0.050)
Men's wage in non-agriculture						0.169	0.180
						(0.145)	(0.136)
Men's wage in agriculture						-0.050	-0.062*
						(0.033)	(0.034)
F-stat	836.279	841.093	769.221	729.541	767.538	752.497	710.952
Kleibergen F-stat	12.062	12.062	12.062	12.088	12.089	11.978	11.700
Observations	627281	627281	627281	627282	627281	627281	627281

Standard errors (clustered on regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All regressions include national oil palm area, regency fixed effect, island time trends, initial values times a year trend and year dummies. Initial levels of fertility, electrification, share of labor in agricultural and agricultural wages are included

Table 9: Effect of oil palm on child labor

PANEL A	1993-2003			
	(1) Child labor	(2) On-farm child labor	(3) Male child labor	(4) Female child labor
Share of villages with OP (%)	0.063 (0.268)	0.037 (0.287)	0.046 (0.318)	0.066 (0.250)
F-stat	109.166	57.045	99.821	74.285
Kleibergen F-stat	10.890	10.890	10.495	11.259
Observations	163212	163212	84349	78863

PANEL B	1996-2006-2016			
	(1) Child labor	(2) On-farm child labor	(3) Male child labor	(4) Female child labor
Share of smallholder OP in regency (%)	-0.630 (0.991)	-0.336 (0.886)	-0.469 (1.047)	-0.832 (0.972)
F-stat	69.616	40.088	74.134	42.160
Kleibergen F-stat	13.206	13.206	13.001	13.406
Observations	262806	262806	135637	127169

Standard errors (clustered on regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV regressions are reported. All regressions include national oil palm area, regency fixed effect, island time trends, initial values times a year trend and year dummies. Initial levels of fertility, electrification, share of labor in agricultural and agricultural wages are included.