Agricultural productivity and fertility: Evidence from the oil palm boom in Indonesia^{*}

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Abstract: We analyze the link between agricultural productivity growth and fertility, using the oil palm boom in Indonesia as empirical setting. During the time period 1996 to 2016, we find consistently negative effects of the oil palm expansion on fertility. We explain this finding with rising farm profits, that led to consumption growth, the expansion of the non-agricultural sector, increasing returns to education and to higher school enrollment. Together these findings suggest that agricultural productivity growth can play an important role in accelerating the fertility transition, as long as the economic benefits are large enough to translate into local economic development.

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1 Introduction

The post-world war period has been marked by impressive declines in fertility in almost all developing countries.¹ Cross-country comparisons suggest that the fertility reduction in this setting can be explained by the sustained (*i.e.* long-run) economic growth experienced by many of these countries (Chatterjee & Vogl 2018). Yet, evidence about the mechanisms through which fertility change and economic growth are related in this time-period remains scarce.

The empirical phenomenon at first glance resembles the fertility decline experienced by the US and Western Europe during the process of industrialization. This suggests that similar forces might explain the recent decline in fertility in developing countries, that is: technical change, structural transformation, and a rising demand for high-skilled labor (Galor & Weil 2000; Galor 2012).² But at closer examination, it seems that not all development trajectories observed in developing countries since the 1960s mirror the experience of current high-income countries during the 19th and early 20th century. In many developing nations, agriculture remains an important economic sector, and employs a large share of the labor force. Some countries, such as Indonesia, India, Pakistan, Bangladesh or Myanmar, saw impressive declines in fertility during time periods in which the share of agricultural workers in the workforce was largely

¹ We define developing countries as those eligible for IDA (International Development Association) or IBRD (International Bank for Reconstruction and Development) funding according to World Bank guidelines. The fertility figures are from the World Development Indicators database (data retrieved on April 8, 2019).

² The literature points to different mechanisms through which the industrialization process reduced fertility. Galor & Weil (2000) stress the importance of increases in the returns to education. Others emphasize increasing maternal opportunity costs of time as wages rose and new employment opportunities became available (Brown & Guinnane 2002), in particular where technical change was gender-biased and increased women's relative wages (Galor & Weil 1996). Additional mechanisms include the decreasing compatibility of work and child rearing during the structural transformation (Rindfuss & Brewster 1996), and the diminishing value of child labor (Hazan & Berdugo 2002; Doepke 2004).

stagnating.³ Meanwhile, many developing countries have experienced growth in agricultural productivity which was largely driven by the introduction of new high-yielding varieties as well as higher intensities in irrigation and fertilizer application (Evenson & Gollin 2003), but also by mechanization (Pingali 2007), the adoption of herbicides (Haggblade et al. 2017), and the introduction of new insect-resistant and herbicide-tolerant crop varieties (Qaim 2016).

In this paper, we provide empirical evidence on the relationship between agricultural productivity growth and fertility in a developing country context, and seek to shed light on the mechanisms that drive this relationship. Specifically, we explore the expansion of oil palm cultivation in Indonesia between the 1990s and 2016, which was largely the result of an increase in global demand for renewable fuels, the increase in consumption of vegetable oils in emerging economies, and the strong support by the Indonesian government.

The oil palm boom led to massive changes in the agricultural sector and the Indonesian economy as a whole. Oil palm is characterized by a substantially higher land- and labor-productivity than other crops in the region, and has been shown to change the gender composition of labor in agriculture (Rist et al. 2010; Kubitza et al. 2018), and to lead to substantial income and consumption gains (Krishna et al. 2017, Edwards 2019). Importantly, because the cultivation of oil palm is not more skill-intensive than other crops, oil palm was not only adopted by large-scale farms but also by many smallholder farmers.

To guide our empirical analysis, we model the oil palm expansion as an increase in the productivity of land and of male (but not female) labor within agriculture in a two-sector economy. As oil palm leads to income gains among landowners, it is expected to generate local economic development (accompanied by rising returns to education) if the demand for (non-traded) non-agricultural goods increases sufficiently. The increase in male labor productivity

³ The fertility figures and workforce composition are from the World Development Indicators database (data retrieved on April 22, 2020).

will shift the labor composition in agriculture towards men, and raise male wages. Female wages are expected to increase in the non-agricultural sector as long as the positive local economy effects (*i.e.* demand for the non-agricultural good) outweigh the negative labor demand effects for women in agriculture.

We build on Becker's canonical model to interpret the effects of oil palm on fertility (Becker & Lewis 1973; Becker 1981), and highlight three main mechanisms. The first mechanism is related to the opportunity costs of maternal time: To the extent that the expansion of oil palm raises women's wages, women are expected to spend less time on childrearing activities. The second mechanism is an income effect: income gains are typically associated with higher fertility, but may decrease fertility under very specific circumstances. The third mechanism is related to changes in the returns to education: As returns to education rise, parents are expected to invest more in their children's education, with negative effects on fertility. We also discuss five alternative mechanisms that are not motivated by our model but could equally explain the link between oil palm and fertility: child labor, reductions in child mortality, infrastructure development, female empowerment, and migration.

In our empirical analysis, we combine a large set of different data sources. We use Indonesia's socio-economic survey (SUSENAS) to assess changes in fertility, measured as the total number of children ever born.⁴ Data on wages, labor supply and sector of work are obtained from the national labor force survey (SAKERNAS). For the oil palm expansion, we rely on administrative data published by the Indonesian government, the Tree Crop Statistics, a data source which is also used to analyze the effects of oil palm on poverty rates (Edwards 2019a). Due to data availability, we focus on the oil palm expansion of smallholder farmers in the main analysis, and investigate effect heterogeneity across producer types as robustness

⁴ The same outcome variable was used *inter alia* by Grimm et al. (2015) to examine the effect of electrification on fertility in Indonesia.

check. To complement these data, we use land-use data from Indonesia's village census (PODES), which is available for 1993 and 2003, and remote sensing data on large-scale oil palm estates, which is available from 1995 to 2015. For our robustness checks, we use data from PODES, from Indonesia's Population Census and Intercensal Survey (SUPAS), from the Demographic and Health Surveys (DHS), as well as from different administrative sources.

Our identification strategy builds on the fact that agro-climatic characteristics affect a regency's suitability for oil palm cultivation.⁵ Similarly to Duflo & Pande (2007), we exploit two sources of variation in a fixed-effects instrumental-variables (IV) approach: First, we exploit differences across space in terms of the agro-climatically attainable yield for oil palm from the Global Agro-Ecological Zones (GAEZ) data. Second, we exploit differences in the national expansion of oil palm area across time. The national expansion is used as a proxy for the development in global demand for palm oil. Combining these two sources of variation, we instrument regency-level oil palm area by its predicted level if the expansion were entirely driven by productivity concerns, that is, if oil palm was more quickly introduced in areas that are better suited to oil palm cultivation and only subsequently to less well-suited areas. This identification strategy strongly relies on the assumption that – conditional on all covariates – oil palm suitability has no (direct or indirect) effect on fertility, other than via the expansion of oil palm.

Using this instrumental-variables approach, we find consistently negative effects of smallholder oil palm expansion on fertility. These results are robust to controlling for region-by-year fixed effects and for differential time trends between regencies with different initial characteristics, such as fertility, electrification, female labor force participation and male

⁵ Regencies (kabupaten) and city districts (kota) form the second tier of local government in Indonesia. Provinces are the highest tier of the local government. Since the decentralization in 2001, regencies (and city districts) have the main responsibility for providing public services.

agricultural wages. The results are also robust to a broad set of alternative specifications, including the use of different measures of oil palm expansion and of fertility, of different time periods, as well as to controlling for province-specific time trends, for time trends that vary with the altitude of a regency, or with the suitability for other crops.

We proceed by exploring the importance of different mechanisms through which the fertility effect might be operating. We show that smallholder oil palm expansion triggered income gains and broader local economic development, which increased the returns to education. Our results suggest that the fertility reduction is strongest in areas that experience higher income effects and where the returns to education rose more pronouncedly. Interestingly, changes in returns to education are not originated in the new technology: oil palm is not more skill intensive than other crops in the region. Instead, the oil palm expansion induced local economic development and led to a growing non-agricultural sector. This raised returns to education. Taken together, our findings suggest that agricultural productivity growth can accelerate a country's fertility transition even if it does not directly affect returns to education or the opportunity costs of time, as long as income gains are large enough, and accrue to a substantial share of the population, such as to trigger local economic development and increases in the returns to education.

Our contributions are as follows. First, we add to the empirical literature on the role of productivity growth, and the importance of different mechanisms, in reducing fertility (Rosenzweig & Evenson 1977; Levy 1985; Wanamaker 2012; Ager et al. 2019). For the industrialization process in the US, Wanamaker (2012) argues that structural change led to fertility reductions because it increased maternal opportunity costs of time and induced a separation of migrant households from their extended family network. In the same context, (Ager et al. 2019) attribute the decline in fertility to higher opportunity costs of raising children as households switched into manufacturing, as well as to income declines within agriculture. Rosenzweig & Evenson (1977) and Levy (1985) analyze the link between technological innovations, agricultural productivity and fertility in the context of India and Egypt,

respectively. Both papers concentrate entirely on changes in the demand for child labor as main mechanism. In contrast to previous work, we find no link between fertility and opportunity costs of time (either the mother's or the child's).

Second, we contribute to the literature that seeks to understand the relationship between economic growth and fertility in developed and in developing countries (Sobotka et al. 2011; Brueckner & Schwandt 2015; Vogl 2016; Chatterjee & Vogl 2018). In line with previous work from developing country contexts, we find negative long-run effects of economic growth on fertility. We add to this literature by trying to disentangle the mechanisms through which this negative relationship comes about.

Finally, we contribute to the growing literature on the effects of oil palm cultivation in Indonesia. Previous research has documented negative environmental effects such as a drastic loss of biodiversity (Wilcove & Koh 2010; Grass et al. 2020) and increased carbon emissions (Burney et al. 2010), but also negative social impacts such as land conflicts (Obidzinski et al. 2012). However, the oil palm expansion also seems to have led to significant economic gains such as poverty reduction and increased welfare of smallholder farmers (Krishna et al. 2017; Edwards 2019a). To the best of our knowledge, our study is the first to address the demographic effects of the oil palm boom in Indonesia.

The remainder of this paper is structured as follows: In Section 2, we provide background information on the oil palm expansion in Indonesia and present evidence on the factor productivity of oil palm relative to alternative crops. Section 3 presents the conceptual framework. In Section 4, we introduce the different data sources used in the analysis. Our estimation strategy is presented in Section 5. Section 6 reports our main results, as well as several robustness checks, and an analysis of the transmission mechanisms. Conclusions are presented in Section 7.

2 Background: Oil palm cultivation in Indonesia

In response to global demand, oil palm cultivation in Indonesia increased sharply between 1990 and 2015 (*c.f.* Panel A of Figure 1), with Indonesia emerging as the world's largest palm oil producer around 2009 (Byerlee et al. 2017). The Indonesian government has been actively promoting the expansion of oil palm since the 1970s by supporting the establishment of large-scale plantations on the outer islands (Verheyne 2010).⁶ In these sparsely populated regions, laborers were often recruited from the central islands, especially Java, to work on the plantations. But while large privately-owned plantations still dominate oil palm cultivation in Indonesia, adoption is also widespread among smallholder farmers, with smallholders cultivating roughly 40% of the country's total oil palm area in 2016, as reported in Figure B1 (Figures B1 to B3 are available in online appendix B).

The oil palm boom brought substantial changes to Indonesia's agricultural sector. Panel B of Figure 1 documents that the expansion of oil palm coincided with a marked increase in the area used for agriculture. Between 1991 and 2015 agricultural area increased by 37%. This expansion in agricultural land has come mostly at the expense of forests, and the rapid deforestation has been one of the main ecological concerns associated with the oil palm boom in Indonesia (Koh et al. 2011; Carlson et al. 2018). The expansion of oil palm also coincided with a decline in the relative importance of other crops. Panels C and D of Figure 1 plot the change over time in agricultural area devoted to the country's three main food and three main plantation crops (as observed in 1981), respectively. Between 1990 and 2016 the share of the area harvested with rice in total area harvested decreased from 39% to 32%, with similar

⁶ In so-called Nucleus Estate and Smallholder (NES) schemes, the government supported the establishment of large plantations surrounded by smallholder farms. In such schemes, smallholder farmers were tied to large oil palm companies via contract farming. With the decentralization process starting in 1998, market liberalization, and the subsequent decrease in governmental support for NES schemes, more independent adopters emerged and contractual ties between contract farmers and companies loosened (Euler et al. 2016).

reductions (albeit to a smaller extent) in maize and cassava. Oil palm cultivation also seems to have replaced the cultivation of other plantation crops, such as rubber, coconut and coffee.

Figure 1: Cultivation area of oil palm and other main crops in Indonesia

Source: Panels A, B and C: FAO Production data, Panel D: Tree Crop Statistics and FAO production data.

Notes: The FAO defines agricultural area as the sum of land under temporary and permanent crops, land under temporary and permanent meadows and pastures, and land that is temporary fallow or under protective cover. The share of food crops (Panel C) is calculated as the area harvested with each crop divided by the total area harvested. The share of main plantation crops is calculated as the area planted with each crop (Tree Crop Statistics) divided by the total agricultural area (FAO production data), in the absence of information about the total area planted in the FAO data.

The increasing dominance of oil palm cultivation also had repercussions on the local economy: Previous work finds that the expansion of oil palm has been associated with substantial welfare gains, especially among smallholder farmers (Rist et al. 2010; Euler et al. 2017; Edwards

2019a). These changes can be explained by substantial differences in the cultivation of oil palm vis-a-vis other crops, particularly rice and rubber. First, fresh oil palm fruit bunches have to be processed in palm oil mills shortly after harvest. This necessitates improved road infrastructure to quickly transport the fresh fruit bunches from the producer to the mill, and reliable access to electricity to run palm oil mills.⁷

Second, the output per worker is substantially higher in oil palm cultivation as compared to other crops. Plot-level estimates from farm-household data, collected in Jambi province (Sumatra) in 2012 and 2015, illustrate the differences in factor productivity between oil palm and rubber, with the farm profit per hour being significantly higher in oil palm than in rubber cultivation (as reported in Table 1). Household characteristics and the sampling strategy are outlined in Table B1 (Tables B1 to B20 are available in online appendix B). These findings are in line with (Rist et al. 2010), who also find a considerable difference in the daily output per worker between oil palm cultivation (\$ 47.33) and rice cultivation (\$ 2.27). The differences in labor productivity might also explain why the cultivation of oil palm is associated with a reduction in the amount of agricultural labor per hectare (both women and men).

Third, oil palm seems to have induced gender-specific changes in the demand for labor in agriculture. As can be seen in Table 1, the ratio of female to male labor is substantially smaller in oil palm (11%) than in rubber cultivation (37%). This is also true for large-scale plantations, and is mainly due to the tasks associated with oil palm cultivation. While rubber tapping is often done every day or every two days and does not necessitate a lot of physical strength, oil palm harvesting is done a lot less frequently (on average every two weeks), and mostly by men because it is physically demanding. Women are mainly involved in the collection of loose oil palm fruits and in maintenance work (Koczberski 2007; Li 2015). Again, similar differences

⁷ Some high-skilled labor is also needed to operate these mills, Yet, the number of mills is rather small, with 1511 in 2015 (Edwards 2019b).

are expected between oil palm and rice cultivation. Typically, the cultivation of food crops involves considerably more female labor than of cash crops, and previous studies find no evidence that female labor is less productive than male labor in rice cultivation (Feintrenie et al. 2010; Li 2015).

Fourth, land productivity (measured as farm profits per hectare) is somewhat higher in oil palm cultivation than in rubber cultivation, indicating that welfare gains might increase in initial land ownership (see Table 1).

Table 1. Factor productivity and intensity of oil palm and rubber

	Oil palm		Rubber		OLS estimates (Oil palm =1)
	Obs.	Mean (Std. dev.)	Obs.	Mean (Std. dev.)	Beta coeff. (Std. err.)
Profit per hour [000 IDR/hour]	435	61.956 (94.516)	969	13.146 (17.872)	39.725*** (6.582)
Profit per ha [000 IDR/ha/year]	439	10718.073 (10729.864)	972	8857.845 (812468.901)	296.358 (1133.671)
Variable inputs [000 IDR/ha/year]	439	2653.118 (2662.383)	973	651.996 (1021.978)	1358.937*** (191.010)
Male labor input [Hours/ha/year]	439	237.696 (211.090)	973	854.687 (997.983)	-574.337*** (48.534)
Female labor input [Hours/ha/year]	439	25.764 (65.350)	973	313.761 (471.624)	-268.782*** (37.107)

Source: Smallholder household data, Jambi province 2012 and 2015.

Notes: Regressions control for year and household fixed effects. Labor input includes family as well wage labor. All monetary variables are in constant 2012 values. Profits are calculated as plot revenues minus expenditures for variable inputs and labor (family labor priced at province level agricultural wages). Sample: Plots of local smallholder farmers. Unproductive plots were excluded and tree age restricted to main productive age from 5 to 25 years. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Finally, it seems important pointing out that the cultivation of oil palm is no more skill intensive than the cultivation of other crops, and of rubber in particular. We show in Table B1 that oil palm farmers in Jambi province are not significantly more educated than rubber farmers,

and in Table B2 that the difference in land and labor productivity between oil palm and rubber is not driven by differences in the years of education of the household head. In Section 5, we also examine if men and women living in oil palm cultivating areas have higher levels of education at the onset of the oil palm boom, and find no evidence that this is the case.

3 Conceptual framework

In this section, we formalize how we expect oil palm cultivation to affect agricultural production, income, female employment, and fertility choices.

3.1 Agricultural productivity and structural change

Consistent with the stylized facts described above, we characterize the expansion of oil palm as an increase in the productivity of land and of male (but not female) labor within agriculture. The formal model is available in online appendix A.1.

The increase in land productivity will lead to positive income effects among landowners. In a small open economy with two sectors, these income gains are expected to generate local economy effects and an expansion of the non-agricultural sector through increased consumption of (non-traded) non-agricultural goods. The local economy effects will likely be most pronounced in areas in which the oil palm cultivation is dominated by smallholder farmers, since smallholder farmers are more likely to spend their additional income locally than owners (or shareholders) of large-scale plantations. In areas with a higher share of large-scale plantations in oil palm cultivation, the economic gains might also be more concentrated among a small group of landowners, thus muting the expansion of the non-agricultural sector. To the extent that the non-agricultural sector exhibits a higher demand for skilled labor, a growing non-agricultural sector also implies an increasing demand for skilled workers, and rising returns to education.

The increase in male labor productivity will affect the gender-composition within agriculture as well as total labor demand in the agricultural sector. Under fairly standard assumptions, the

share of women working within the agricultural sector is expected to decline (see online appendix A.1). Total labor demand in agriculture will remain constant or even increase as long as the agricultural area can be expanded at reasonable cost (*i.e.* through deforestation).

Changes in wages and employment, finally, will be a function of local economy and labor demand effects. For men, we expect them to go in the same direction, such that employment and wages are expected to increase in both sectors. For women, these effects go in opposite directions. In areas in which the expansion of the non-agricultural sector is strong enough to absorb female labor that is freeing-up in the agricultural sector, non-agricultural wages are expected to increase and female employment to remain constant.

3.2 The demand for children

Economic theory of fertility goes back to works of Becker (1981) and Becker & Lewis (1973). In the basic static model, a household maximizes utility, subject to a budget constraint, by choosing the optimal number of children and level of human capital investment in each child. In such a model, we expect the expansion of oil palm to affect fertility through a combination of opportunity costs of time, income and returns to education effects. Several alternative explanations for a relationship between oil palm and fertility are discussed in the online appendix A.2 and in Section 6.4.

Maternal opportunity costs of time. Raising children in the context of rural Indonesia requires the allocation of maternal time (pregnancy, childcare) in addition to monetary inputs. A rise in (female) wages implies that the price of raising children increases and the demand for children declines and *vice versa*. In areas in which wages increased with the oil palm boom, we expect women to reallocate their time away from child rearing in favor of income earning activities (thereby reducing fertility). Likewise, a shift in female employment towards the non-agricultural sector, which is less well suited for combining child rearing and income generation

due to the distance between dwelling and workplace or due to a less amenable working environment, could reduce fertility.

Income. As oil palm raises the productivity of land and labor, smallholder farmers as well as agricultural workers experience a direct income gain. The relationship between income and fertility has been positive over much of human history (Galor 2005, 2012), and is typically found to be positive in developed countries (Black et al. 2013; Bleakley & Ferrie 2016), suggesting that children are a ‘normal good’. Developing country evidence (Vogl 2016) also points to the possibility of a negative income-fertility relationship which could be explained by the income elasticity of child quality being greater than the income elasticity of child quantity as proposed by Becker and Lewis (1973) or by behavioral explanations, such as a desire to mimic the lifestyles of well-educated and wealthy elites (La Ferrara et al. 2012).⁸

Returns to education. While cultivation of oil palm does not require higher skills than the cultivation of other crops, we expect returns to skills to increase due to the expansion of the non-agricultural sector. This will increase parents’ demand for child human capital, because investing in children’s education is likely to seem more desirable if wages of educated workers rise. Because investing in (higher) education is costly, parents of any education level could be willing to reduce fertility in response to increasing returns to education (Galor & Weil 2000). The link between increasing returns to education and decreasing fertility is empirically well established (Bleakley & Lange 2009; Becker et al. 2010; Fernihough 2017).

4 Data

We draw on different data sources to estimate the effect of the oil palm expansion on fertility and to analyze the underlying mechanisms. We combine all datasets at the regency (*i.e.* district)

⁸ Note that more recent research refutes this argument: Jones et al. (2010) show that adding a quantity-quality choice by itself does not generate a negative income-fertility relationship, unless one also assumes an unreasonably high elasticity of substitution between child quantity and consumption.

level in the boundaries of 1993. We exclude Indonesia's most populated Island, Java, from the entire analysis, because the high population density on Java makes it nearly impossible to cultivate oil palm. We also drop urban districts (kotas), as well as the conflict region Papua from our sample, leaving us with a final sample of 139 regencies. Table 2 contains summary statistics for the main variables of interest. A detailed description of all data sources and additional summary statistics can be found in Tables B3 and B4, respectively.

Oil palm expansion. Administrative data on the oil palm expansion at regency level date back to 1996, and are published annually in the Tree Crop Statistics (Ministry of Agriculture 2017). The data provide information on the area under oil palm cultivation, and distinguishes between four producer categories: smallholders, government estates, national private estates, and foreign private estates. Total oil palm area is the sum of these four producer categories. Unfortunately, only the area under smallholder cultivation is consistently reported prior to 2005, with information about the area under private or government estates, as well as total oil palm area, only being available from 2005 onwards. To exploit as much temporal variation as possible, we rely on smallholder oil palm expansion for the main analysis, and explore heterogeneity in the effect between different producer categories in Section 6.3. For now, it seems worthwhile pointing out that the expansion of oil palm in the smallholder sector moves fairly parallel in time with the expansion of the private estates (see Figure B1). It is also geographically correlated with private estates' oil palm cultivation (albeit to varying extent) for the following reasons: First, contract farming schemes between private estates and smallholder farmers were common, particularly in the early years of the oil palm expansion, and second, even independent smallholder farmers rely on access to palm oil mills, which are often established within the large-scale plantations (Euler et al. 2016). Our variable therefore picks up both forms of oil palm cultivation (smallholder and estate) to some degree. Figure 2 illustrates the expansion of smallholder oil palm area in different regions of Indonesia. It shows

a strong concentration of oil palm cultivation on Sumatra, and increasingly on Kalimantan and Sulawesi.

Table 2: Summary statistics

	Obs.	Mean	Std. dev.
Tree Crop Statistics (1996, 2001, 2006, 2011, 2016)			
<i>Regencies:</i>			
Smallholder OP area (fraction of regency area)	687	0.015	0.030
Agro-climatically attainable yield (kg/ha)	687	1502.286	667.742
SUSENAS (1996, 2001, 2006, 2011, 2016)			
<i>Women aged 15-49:</i>			
Number of children ever born alive	730842	1.932	1.950
Age (years)	730895	30.418	9.819
Work (=1)	730894	0.474	0.499
Work in agricultural sector (=1)	730895	0.255	0.436
Work in service sector (=1)	730895	0.179	0.384
Working hours	346101	33.095	17.584
Working hours in agricultural sector	186037	27.922	14.063
Working hours in service sector	131136	40.217	19.572
<i>Women aged 40-49:</i>			
Number of children ever born alive	164149	3.657	2.037
<i>All households:</i>			
Consumption Exp. p. c. (IDR/Month)	672780	76075.325	74083.048
Consumption Exp. p. c. (IDR/Month) (Hh head in agr. self-empl.)	305141	59137.907	46203.378
Consumption Exp. p. c. (IDR/Month) (Hh head in agr. empl.)	51180	66285.461	48635.584
Consumption Exp. p. c. (IDR/Month) (Hh head in non-agr.)	248741	97337.495	96651.685
<i>Children:</i>			
Enrollment (5-9 years) (=1)	193277	0.702	0.458
Enrollment (10-14 years) (=1)	322197	0.934	0.248
Enrollment (15-19 years) (=1)	269692	0.570	0.495
Enrollment (5-19 years) (=1)	785166	0.752	0.432
Enrollment (5-19 years) (Hh head in agr. self-empl.) (=1)	378841	0.715	0.451
Enrollment (5-19 years) (Hh head in agr. empl.) (=1)	56464	0.739	0.439
Enrollment (5-19 years) (Hh head in non-agr.) (=1)	298749	0.804	0.397
SAKERNAS (2001-2015)			
<i>Women aged 15-49:</i>			
Wages in agricultural sector (IDR/Hour)	65785	937.519	1562.112
Wages in non-agricultural sector (IDR/Hour)	222866	1372.321	2122.980
Wages with no or primary education (IDR/Hour)	104393	841.810	1370.808
Wages with secondary education (IDR/Hour)	121009	1128.035	1882.773
Wages with tertiary education (IDR/Hour)	63249	2263.071	2712.979

Source: Tree Crop Statistics 1996, 2001, 2006, 2011, 2016; SUSENAS 1996, 2001, 2006, 2011 2016; SAKERNAS 2001-2015.

Notes: Data are available for 139 distinct regencies (borders of 1993) with missing data for eight regencies over time. All monetary values are in constant 1996 IDR (inflation adjustments are done with the province-level poverty lines for rural and urban areas). The exchange rate was at 2342 IDR/US\$ in 1996 (World Bank 2018a).

Figure 2: Smallholder oil palm area (fraction of regency area) across Indonesia in 1996 and 2016

We tap two additional sources of information to measure the expansion of oil palm: the PODES, Indonesia's village census, and (Austin et al. 2017). The PODES data provide the earliest account of oil palm cultivation at the regency level throughout Indonesia, by recording which villages were engaged in oil palm cultivation in 1993 and again in 2003. Austin et al. (2017) compile data on the expansion of industrial-scale oil palm plantations by visually interpreting LandSat satellite imagery from the years 1995, 2000, 2005, 2010 and 2015. Due to the low resolution of the imagery, only large oil palm estates were identified.

Fertility. We use Indonesia's socio-economic survey (SUSENAS) to construct individual fertility and other socio-economic variables. The SUSENAS collects demographic and socioeconomic characteristics of individuals. Core data are collected annually, while other data such as socio-cultural and educational, housing and health, household consumption and

household expenditure modules are roughly collected every three years. The sample is representative at the regency level, and its size increased from roughly 65,000 households in 1993 to more than 200,000 households in 2016. Our measure of fertility is the number of children ever born alive to a particular woman by the time the data are collected, and is available for all women aged 15 to 49. This measure of fertility is not directly comparable to the total fertility rate (TFR). The TFR is the average number of children that would be born to every woman over her lifetime, calculated as the sum of age-specific fertility rates (number of live births in the past 12 months), assuming constant age-specific fertility rates over time and no premature deaths of women. Our measure of fertility, in contrast, captures the lifetime fertility experience of a woman up to the day of interview, and is thus sensitive to the age-distribution of women in the sample (as older women do have more children on average) and to fertility changes that already happened in the past. A comparison of fertility trends under these alternative definitions illustrates the difference: Between 1996 and 2016, the average number of children born per woman decreased from 2.11 to 1.70 in Indonesia, while the TFR fell from 2.6 to 2.4 in the same time period (World Bank 2018b). The difference between these figures highlights the importance of thinking carefully about delays in childbearing versus reductions in overall fertility in this context (a point we return to in Section 6). Additional variables derived from SUSENAS are age, education, child mortality rates, consumption expenditures per capita, labor supply, and the sector of work.

We assemble additional labor market characteristics of working-age individuals from the national labor force survey (SAKERNAS). The SAKERNAS provides information on labor supply, the sector of work, as well as on wages in different sectors. The SAKERNAS contains regency identifiers from 2000 onwards. The survey is, however, representative at the regency level only since 2007. We use the SAKERNAS to calculate province-level labor market characteristics in 1993, and to test for the effects of oil palm on labor market outcomes at regency level in the time period 2001 to 2015.

We also use the Demographic and Health Survey (DHS) data, as well as IPUMS subsamples of Indonesia's Intercensal Survey and Population Census, administrative data retrieved from Badan Pusat Statistik (BPS), and digital elevation data from the NASA Shuttle Radar Topographic Mission (SRTM) for several robustness checks. A detailed description of these data is available in Table B3.

Finally, we use data from the Global Agro-Ecological Zones (GAEZ) database for our instrumental-variables approach. The GAEZ provides agro-climatically attainable yield data (in kg/ha) for different crops in grid cells of 5 arc-minute and 30 arc-second (approximately 10x10km) resolution. These data are calculated by incorporating local agro-climatic conditions into agronomic models with pre-specified levels of inputs and management conditions (Fischer et al. 2012). We use the agro-climatically attainable yield for low input level rain-fed oil palm for the time period 1961-1990.¹ Regency-average attainable yield for oil palm is then calculated by averaging pixel values within 1993 regency boundaries. Figure 3 illustrates our calculations.

¹ While oil palms can grow on most types of tropical soil, high temperatures over the whole year, sufficient sunlight and steady rainfall are essential for growing oil palms. Steep soils increase harvesting costs and run-off. In addition, temperature decreases rapidly in the tropics with increasing elevation which renders high altitudes and mountain regions unsuitable for oil palm cultivation (Pirker et al. 2016). Attainable yield under low-input application was chosen because it is most predictive of the actual expansion of oil palm in a test area (Jambi province, Sumatra), where land-use classification based on Landsat satellite imagery is available (Melati et al. 2014).

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

Source: GAEZ.

Notes: Agro-climatically attainable yield for low input level rain-fed oil palm (kg/ha). Conversion factor to oil palm fresh fruit bunches is 0.225.

5 Estimation strategy

Eliciting a causal effect of oil palm expansion on fertility involves major challenges: First, we cannot observe a lot of regency characteristics such as cultural and political traits, as well as time variant shocks, which may correlate with the timing of the oil palm expansion as well as with the onset and speed of the fertility transition. Second, reverse causality could be driving our results if low population growth accelerates the oil palm expansion. Third, measurement error in the independent variable could bias our estimates towards zero.

We therefore employ an instrumental-variables strategy to identify causal effects. Our instrument combines spatial variation in agro-climatic suitability for oil palm cultivation with temporal variation in the country-wide cultivation of oil palm in Indonesia, and is inspired by Duflo & Pande (2007). Specifically, we interact the (time-invariant) regency-average attainable yield for oil palm with the annual expansion of oil palm area at national level. This approach provides a prediction of how much area in each regency should be cultivated with oil palm in a given year, based on the regency's suitability for oil palm cultivation and the national expansion of oil palm area. This instrument highly correlates with the actual expansion because agro-climatic suitability is a major determinant of land-use patterns. 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. This is obviously a strong assumption and warrants some discussion.

The use of the national expansion as time-varying component is similar to shift-share instruments, where initial characteristics are interacted with time-varying exogenous characteristics. In contrast to shift-share instruments, however, our approach does not rely on initial conditions, which are likely endogenous. Instead, we interact a plausibly exogenous variable with a time varying component. We also explicitly choose to use the national expansion as time varying component to minimize the risk that our instrument is affected by idiosyncratic regional developments, which could be correlated with both fertility and oil palm expansion. In contrast, we expect the national expansion to be driven by world market prices and by policies of the central government.

The main threats to identification are related to the correlates of oil palm suitability. The first concern is that other crops might have similar agro-climatic requirements. This could imply that regions with high oil palm suitability have higher levels of initial agricultural productivity and probably also economic activity absent any oil palm cultivation which also suggests different trends in fertility. A second – related – threat to identification could be that our instrument captures general geographic characteristics (such as altitude) which strongly correlate with initial levels of development, and fertility trends. In order to address these concerns, we inspect if oil palm suitability (as measured by the regency-average attainable yield) correlates systematically with socio-economic outcomes observed in 1993, *i.e.* around the onset of the oil palm boom. As depicted in Table 3, attainable yield is largely unrelated to socio-economic outcomes except for fertility (as measured by the total number of children born to a woman by the time of the survey), the share of households with access to electricity, the share of women who are working, and male agricultural wages. To account for any potentially systematic correlation between our instrument and these initial characteristics, we control for

these characteristics multiplied by a time trend in all our specifications. In various robustness checks, we also control for province-specific time trends, for time-trends that vary with average altitude or with the attainable yield for other major crops

Table 3: Initial characteristics

	Summary statistics			Regression coeff.
	Obs.	Mean	Std. dev.	Independent var.: Attainable yield (t/ha)
Number of children ever born alive, women aged 15-49 (SUSENAS 1993)	139	2.29	(0.30)	0.070* (0.041)
Share of households with access to electricity (SUSENAS 1993)	139	0.31	(0.19)	-0.073** (0.029)
Consumption expenditures per capita (SUSENAS 1993)	139	37783.2	(9023.9)	1056.930 (1355.785)
Log Consumption expenditure per capita (SUSENAS 1993)	139	10.4	(0.20)	0.037 (0.033)
Share of women aged 15-49 with less than primary education (SUSENAS 1993)	139	0.40	(0.12)	0.011 (0.017)
Labor force participation rate, women aged 15-49 (SUSENAS 1993)	139	0.55	(0.17)	-0.061*** (0.019)
Share of labor force working in agriculture, women aged 15-49 (SUSENAS 1993)	139	0.63	(0.18)	0.005 (0.024)
Share of men aged 15-49 with less than primary education (SUSENAS 1993)	139	0.30	(0.10)	-0.013 (0.014)
Labor force participation rate, men aged 15-49 (SUSENAS 1993)	139	0.86	(0.05)	-0.001 (0.006)
Share of labor force working in agriculture, men aged 15-49 (SUSENAS 1993)	139	0.65	(0.13)	-0.012 (0.019)
Log hourly female agricultural wage, current values (SAKERNAS 1993)	135	5.87	(0.33)	0.152 (0.143)
Log hourly male agricultural wage, current values (SAKERNAS 1993)	139	6.19	(0.25)	0.177** (0.083)
Median landholding (ha) (Census 1980)	139	0.54	(0.32)	0.025 (0.047)

Notes: The last column reports the coefficients from regressing the respective variable in the first column on attainable yield for palm oil (in t/ha). The dependent variables are obtained from SUSENAS 1993, SAKERNAS 1993, and the 1980 population census. All variables are measured at the regency level based on 1993 boundaries, and computed using the sampling weights needed to recover regency-level population summary statistics (except the SAKERNAS data, which are computed at province level). Robust standard errors (clustered at the province level with SAKERNAS data) in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A third caveat in our identification strategy could be the high regional concentration in the oil palm expansion. As depicted in Figure 2, the oil palm expansion started in Sumatra, and

spread only later to Sulawesi and Kalimantan.¹ It is not unlikely that regional shocks affected the oil palm expansion as well as fertility. We address this concern by controlling for region-by-year fixed effects in all our estimations.

We estimate the effect of the oil palm expansion using the following linear specification:

$$FR_{ijst} = \beta_0 + \beta_1 OP_{jst} + \beta_2' X_{ijst} + \beta_3' (M_{js} * t) + \gamma_{st} + \mu_j + \varepsilon_{ijst}, \quad (1)$$

where FR_{ijst} is the total number of children that were born to a woman i in regency j , and region s by year t . OP_{jst} is the smallholder oil palm area in regency j , region s and time t , expressed as the fraction of oil palm area in the total area of the regency to account for large differences in total area between regencies. We initially restrict our analysis to smallholder oil palm area because this is the only producer type with data available before 2005, such that $OP_{jst} = \text{smallholder OP area}_{jst} / \text{regency area}_{js}$. X_{ijst} is a vector of age-group fixed effects as the age-structure in a regency strongly determines fertility and regencies with different age-structure could be on different fertility trends. M_{js} is a vector of initial regency-level characteristics that correlate significantly with our instrument. As discussed above these characteristics are regency-average fertility, female labor force participation, share of households with access to electricity, and province-average male agricultural wages. These initial characteristics are multiplied with a linear time trend t . The region-by-year fixed effects γ_{st} control for region-specific aggregate shocks, and the regency fixed effects μ_j control for time-invariant differences across regencies. ε_{ijst} is the error term.

¹ We use the ISO 3166-2 classification of regions in Indonesia, which identifies seven distinct regions: Java, Kalimantan, Maluku, Nusa Tenggara, Papua, Sulawesi and Sumatra.

As discussed above, we estimate Equation 1 in an instrumental variables approach. The first-stage equation is specified as:

$$OP_{jst} = \alpha_o + \alpha_1 (AY_{js} * OPA_t) + \alpha_2' X_{ijst} + \alpha_3' (M_{js} * t) + \theta_{st} + \tau_j + \omega_{ijst}, \quad (2)$$

where AY_{js} is the regency-average attainable yield for oil palm in regency j and OPA_t is the oil palm area in 1 million hectares at national level in year t . θ_{st} are region-by-year fixed effects, τ_j are regency fixed effects and ω_{ijst} is an individually and identically distributed error term. All remaining variables are defined as in Equation 1.

We use survey weights in all our estimations and cluster standard errors at the regency level. We also report Anderson-Rubin (AR) confidence intervals (CI) that allow valid inference on the coefficient of the endogenous variable even when the instrument is weak. Because we do not have access to all rounds of SUSENAS data and not all key variables are accessible throughout all rounds of SUSENAS, we restrict our analysis to equal-length intervals of five years when using the SUSENAS data. Therefore, we estimate the effect of long-run changes in oil palm cultivation on long-run changes in fertility.

6 Results

6.1 The effect of oil palm cultivation on fertility

In Table 4, we present our main results, *i.e.* estimates of Equation 1, with first-stage results being available in Table B5. To assess the robustness of our findings, we present ordinary least squares (OLS) and IV estimates, and stepwise add the main controls. Column 1 shows OLS estimates with age-group, regency and time fixed effects. In Column 2, we add initial levels of fertility, female labor force participation, households with access to electricity and male wages in agriculture multiplied with a linear time trend, and region-by-year fixed effects. In Columns 3 to 6, we report the instrumental-variables estimates described in Section 5. We add initial characteristics times a linear time trend in Column 4, and region-by-year fixed effects in Column 5.

Table 4: Effect of oil palm on fertility

	(1)	(2)	(3)	(4)	(5)	(6)
			Women aged 15-49			Women aged 40-49
	OLS	OLS	IV	IV	IV	IV
Smallholder OP area (fraction of regency area)	-0.673 (0.451)	0.067 (0.339)	-3.196** (1.277) [-6.572,-1.030]	-7.908*** (2.821) [-18.480,-3.568]	-5.567** (2.445) [-14.729,-1.999]	-8.323* (4.474) [-23.326,-1.086]
Regency & year FE	Yes	Yes	Yes	Yes	Yes	Yes
Age-group FE	Yes	Yes	Yes	Yes	Yes	Yes
Initial levels * year	No	Yes	No	Yes	Yes	Yes
Region-by-year FE	No	Yes	No	No	Yes	Yes
F-stat	2.234	11.194	6.263	3.655	5.682	7.157
Kleibergen F-stat			27.576	16.302	15.793	16.020
Observations	730842	730842	730842	730842	730842	164149

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: Dep. Var.: Number of children ever born alive. Sample: Women aged 15-49 (40-49 in Col. 6). Standard errors (clustered at regency level) in parentheses. Anderson-Rubin 95% confidence intervals (robust to weak instruments) in brackets. * $p < 0.10$,

** $p < 0.05$, *** $p < 0.01$.

The results show a consistently negative effect of the oil palm expansion on fertility. The effect is always statistically significant in the instrumental-variables estimates, also when inference is based on the Anderson-Rubin confidence intervals. Column 5 is the preferred specification. In terms of magnitude, the coefficient implies that a 1 percentage point (1 standard deviation) increase in the smallholder oil palm area in a regency (relative to the regency area) reduces fertility by 0.056 (0.167) children born per woman. Between 1996 and 2016, the smallholder oil palm area (in % of regency area) increased from 0.41% to 2.62%. According to our estimates, this would lead 0.123 fewer children born per woman. In the same time period, fertility (measured as the total number of children born per woman by the time of the survey) decreased from 2.187 to 1.810 in our sample. The oil palm expansion can hence explain up to 33% of the observed fertility reduction in the last 20 years in rural Indonesia. The magnitude of the effect increases substantially when moving from OLS to our instrumental-variables approach. This could indicate a weak instrument problem. However, our first-stage Kleibergen-Paap F-statistic ranges between 15.8 and 27.5, suggesting that our instrument is sufficiently strong in all regressions. There could be three other reasons for having lower OLS

than IV estimates. First, our IV estimates capture the local average treatment effect of oil palm expansion, *i.e.* the effect in regencies in which oil palm was planted because of favorable agro-climatic conditions, and not for example because of policy interventions. Palm oil production in favorable agro-climatic conditions is likely to have higher returns, leading to higher productivity gains, and potentially stronger fertility reductions.¹ To the extent that this is true, our estimates present an upper bound to the average treatment effect. Given that this paper seeks to understand what the consequences of agricultural productivity growth could be for fertility, the LATE seems to be the more relevant magnitude here. Second, the IV approach might have corrected an upward bias in the point estimate driven by omitted variables. The Indonesian government has a long tradition of incentivizing the establishment of oil palm plantations in regions with poor economic development (Gatto et al. 2017). If the expansion of oil palm correlates with recent economic downturns, our OLS estimates would be biased towards zero. Lastly, administrative data on the expansion of oil palm could involve significant measurement error, while the instrument is based on agro-climatic conditions which may be more precisely measured. Thus, our IV approach may correct measurement error that induces attenuation bias in our OLS estimates.²

As mentioned previously, our measure of fertility captures the total number of children born by the time of survey, and as such the fertility effect we estimate might be an artifact of delays in fertility rather than actual changes in lifetime fertility. Three pieces of evidence make this explanation highly unlikely. First, when examining the magnitude of the effect by age-group,

¹ This is supported by the finding that the positive effect of the oil palm expansion on consumption expenditure and the negative fertility effect are driven by areas with high suitability for oil palm (see Table B6 in the online appendix).

² Below, we use information on the oil palm expansion available in Indonesia's village census (PODES). We expect that these data are less prone to measurement error. We find that the OLS estimates are negative and significant and the difference between the OLS and IV estimates is substantially smaller than in Table 4.

we find that the negative fertility effect peaks in the age-group 35 to 39, but remains stable thereafter, indicating that lifetime fertility is indeed substantially reduced. Lagging the oil palm variable by five years does not meaningfully change the estimates (see Figure B2). We also report the pooled estimate for the two eldest groups (women aged 40-49) in Column 6 of Table 4, and find that the effect is even larger than the average effect and statistically significant. Second, we regress the fertility of women aged 40-49 on the average oil palm area observed over the last 20 years in Table B7 to account for women's full exposure during the main childbearing years, and our results are unchanged. Because we have no regency-level oil palm data prior to 1996, we estimate this relationship in a cross-sectional instrumental variables approach, replacing the regency fixed effects in Equation 1 by province fixed effects. Third, we use fertility data from the DHS to examine if the effects we estimate overlap with changes in current fertility (number of births in the past 12 months). The DHS data are representative at the province level, which is why our estimation strategy in this exercise is limited to OLS with province and year fixed effects. We use DHS data from the years 1991, 1997, 2002-03, 2007, 2012 and 2017, and examine age-group specific effects on the number of children ever born and on current fertility. Panel A of Figure B3 shows the effect of oil palm expansion on the number of children ever born (consistent with our fertility measure in SUSENAS), while Panel B shows the effect on current fertility. Panel A closely mirrors our previous findings, providing evidence that our results are robust to the use of alternative data and identification strategies. In Panel B, we can see that effects on current fertility are negative throughout and driven by younger women (especially those aged 20 to 24) as well as by women in the age-group 30 to 34. Younger women may be reducing current fertility because they delay marriage and stay in school longer or start working, yet women in their thirties are most likely downwards adjusting the desired family size. Interestingly, the sum of all age-specific fertility effects is -5.57, which is almost identical to the estimates of Column 5 in Table 4. Taken together these findings

indicate that the fertility effect we estimate is indeed persistent, as oil palm area affects fertility over a considerable age-range and the negative current effects seem to accumulate over time.

6.2 Robustness checks

We conduct several additional checks to gauge the robustness of our findings. We test if our results are sensitive to changes in the main explanatory variable, in the study area or in the time trends included in the analysis, and test for parallel trends (*c.f.* Tables B8 to B11).

First, we use the national census of villages (PODES) to calculate the fraction of villages per regency with oil palm cultivation. While we expect this variable to be less prone to measurement error, this information is only available in 1993 and 2003. We replicate the specifications from Table 4 with this alternative measure of the oil palm expansion in Table B8 and our results are robust. We also test in Table B9 if our results change if we use the fraction of area of large-scale oil palm estates (that are identified from satellite imagery) as main explanatory variable rather than smallholder oil palm area and our results are qualitatively similar. We also compare the effect of oil palm area on fertility between different producer types using administrative data. We use data from the years 2005 and 2016 because we do not have consistent data on private estates and total oil palm area at the regency-level before 2005. We find that the fertility effect is negative across all producer types, but is generally more pronounced for smallholder oil palm expansion.

We then test if our results are sensitive to including Java, Indonesia's main island, in our sample. Close to 40% of Indonesia's population lives on Java. At the same time, Java grows oil palm only to a very small extent. As can be seen in Table B10, the effect remains highly significant, while the precision of the first stage declines, as the low levels of oil palm cultivation on Java are not driven by low suitability but rather by the limited availability of agricultural land. In Columns 2-5, we show that our results are robust to the inclusion of various alternative time trends: province-specific linear time trends (Col. 2), attainable yield for low-

input level rainfed rice – Indonesia’s most important crop – multiplied by a time trend (Col. 3), the initial levels of regency-average fertility, electrification, female labor force participation, and male agricultural wages interacted with the national oil palm expansion instead of a linear time trend (Col. 4), and each regency’s average altitude multiplied by a linear time trend (Col. 5). As discussed previously, one concern with the validity of our instrument stems from the fact that the attainable yield for oil palm correlates with other characteristics, such as the attainable yield for other crops or (inversely) with altitude (which in turn correlates with remoteness). These characteristics might generate a spurious correlation between our instrument and fertility and bias our results. However, the fact that the effect size remains stable and significant throughout, indicates that this is not of major concern.

Finally, using data from the 1971, 1980 and 1990 population censuses (we use the IPUMS subsamples throughout), we also run a placebo regression to assess the plausibility that regencies with high oil palm suitability were on similar fertility trends as regencies with low oil palm suitability. We find no evidence that the 25-year lead of oil palm area affects fertility (as reported in Table B11), while we do find a statistically significant contemporaneous effect using the 1995 Intercensal survey (SUPAS) and the 2010 population census, which underscores the validity of our empirical approach.

6.3 Understanding the mechanisms of the negative fertility effect

In this section, we seek to shed light on the mechanisms through which the oil palm expansion reduced fertility. As discussed in Section 3, we expect the oil palm expansion to be associated with income gains, sectoral reallocations (out of agriculture) for women, and – if the positive local economy effect dominates the negative labor demand effect – an increase in female non-agricultural wages and in returns to education.

In Table 5, Column 1, we show estimates of the effect of oil palm expansion on household per capita consumption expenditures. We find a statistically significant and positive effect. The

point estimate suggests that an increase in the regency area dedicated to smallholder oil palm cultivation by 1 percentage point increases consumption expenditures by 3.4%. In Columns 2-4, we disaggregate the effect by the main activity of the household head, which – in the absence of information on land-ownership in the SUSENAS and SAKERNAS – is the only possibility of distinguishing farm households from non-farm households.³ As can be seen, the positive consumption effect is largest among households whose head is self-employed in agriculture as his main job, with the effect among households whose head is agricultural laborer or works in the non-agricultural sector being positive and statistically significant, but smaller. While suggestive at best, this indicates that income gains are largest among farm households.

Table 5: Effect of oil palm on consumption expenditures per capita

	(1) All households	(2) Hh head is self- employed in agricultural sector	(3) Hh head is employed in agricultural sector	(4) Hh head works in non-agricultural sector
Smallholder OP area (fraction of regency area)	3.406** (1.446) [0.953,8.029]	4.665*** (1.708) [1.902,10.123]	2.220* (1.190) [0.013,6.492]	2.576** (1.284) [0.297,6.780]
F-stat	2.234	2.111	1.992	4.948
Kleibergen F-stat	16.539	20.334	11.741	13.251
Observations	672780	305141	51180	248741

Sources: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates reported. All regressions control for regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Consumption expenditures are in log constant 1996 IDR. Sample: All households. Standard errors (clustered at regency level) in parentheses. Anderson-Rubin 95% confidence intervals (robust to weak instruments) in brackets.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

³ As the main occupation of the household head might change due to oil palm, such differences need to be interpreted with caution. It seems that the share of households whose head is self-employed in agriculture decreased with the expansion of oil palm, while the share of households whose head is employed in agriculture increased (see Table B12), which could indicate two things: first, younger adults might now form their own household sooner (and start working on oil palm plantations), or second, in-migration. Both these groups would be initially poorer.

We then explore the effects of the expansion of oil palm on female wages, labor supply, and sector of work. In Table 6, we present estimates of the effect of oil palm cultivation on women's wages. Consistent with a rising demand for non-agricultural goods, we find that female wages in the non-agricultural sector increase (Col. 1), while remaining unchanged in the agricultural sector (Col. 2). The expansion of the non-agricultural sector also seems to be associated with an increase in the returns to education: while the oil palm expansion has no discernible effects on wages of women with primary education, the wages of women with secondary and – even more so – with tertiary education increase substantially with the cultivation of oil palm (Cols. 3-5 of Table 6). Similar results are obtained for men (*c.f.* Table B13). In terms of employment, then, we find some evidence that women reduce their labor supply in response to the oil palm expansion at the extensive margin (Col. 1 of Table 7), but not at the intensive margin (conditional on working, Col. 4), which – in light of rising non-agricultural wages – could be indicative of an increase in reservation wages (due to income gains) or of some other frictions that prevent women from switching into the non-agricultural sector. Disaggregating labor supply by the sector of work reveals that women exit the agricultural sector, as predicted, but do not necessarily switch into the services sector, as total employment in that sector remains constant (Cols. 2 and 3). We also find a decrease in working hours for women in the agricultural sector. Taken together these findings underscore that the expansion of oil palm raised prices and wages through local economy effects. However, it also decreased labor demand for women in agriculture, and the extent to which female workers were able to transition into the services sector is relatively limited.

Table 6: Effect of oil palm on women's wages

	(1) Non-agricultural sector	(2) Agricultural sector	(3) ≤Primary education	(4) Secondary education	(5) Tertiary education
Smallholder OP area (fraction of regency area)	6.055* (3.315) [1.152, 19.587]	0.790 (3.544) [-6.057, 11.550]	-2.103 (3.628) [-11.117, 8.055]	5.373* (2.872) [0.956, 16.359]	8.362* (4.377) [0.251, 21.996]
F-stat	2.133	7.078	5.017	4.705	6.346
Kleibergen F-stat	11.283	12.077	8.833	12.909	13.792
Observations	222630	64594	103407	120581	63236

Source: SAKERNAS 2001-2015.

Notes: IV estimates reported. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Log hourly wages (in constant 1996 IDR). Sample: Working women aged 15-49: Col. 1, in non-agricultural sector; Col. 2, in agricultural sector; Col. 3, with no or primary degree; Col. 4, with secondary degree; Col. 5, with tertiary degree. Standard errors (clustered at regency level) in parentheses. Anderson-Rubin 95% confidence intervals (robust to weak instruments) in brackets. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Effect of oil palm on women's labor force participation and sector of work

	(1) Work	(2) All women Work in service sector	(3) Work in agricultural sector	(4) Working women Total hours worked	(5) Work in services sector Total hours worked	(6) Work in agricultural sector Total hours worked
Smallholder OP area (fraction of regency area)	-1.358* (0.746) [-3.506,0.084]	0.144 (0.377) [-0.674,1.111]	-1.137* (0.688) [-3.063,0.192]	0.619 (0.803) [-1.188,2.553]	0.706 (0.693) [-0.743,2.701]	-2.220* (1.277) [-5.999,0.048]
F-stat	3.273	1.709	2.759	4.973	3.909	4.318
Kleibergen F-stat	15.799	15.799	15.799	17.753	12.933	19.526
Observations	730894	730894	730894	334903	128767	178180

Sources: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates reported. All regressions control for five-year age cohort fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Col. 1, work (=1), Col. 2, work in service sector (=1), Col. 3, work in agricultural sector (=1); Cols. 4-6, log total weekly hours worked. Sample: Cols. 1-3, women aged 15-49; Col. 4, working women; Col. 5, working in services sector; Col. 6, working in agricultural sector. Standard errors (clustered at regency level) in parentheses. Anderson-Rubin 95% confidence intervals (robust to weak instruments) in brackets. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

With this evidence at hand, we examine the mechanisms through which these changes could have affected fertility, that is: changes in maternal opportunity costs of time, income or in the returns to education. We presented evidence above that women reduce labor supply, rather than increasing it, which would suggest a decline in the opportunity costs of time. However, this effect does not necessarily need to be negative for all women: we have shown that returns to education increase, such that the opportunity costs of time of educated women might in fact increase. If this were driving the fertility effect, then, we should see fertility declines among well educated women and stagnating fertility among uneducated women. Yet, as shown in Table B14, the exact opposite seems to be the case: women with the lowest levels of education show stark fertility reductions, while well educated women (secondary or tertiary completed) display no changes in fertility in response to the expansion of oil palm area.

We cannot clearly distinguish between the effects of income and of returns to education. As discussed previously, the largest income effects seem to occur among households whose head is self-employed in agriculture, and the smallest income effects in households whose head is employed in agriculture (Table 5). The negative fertility effects, in turn, are largest among women in households whose head is self-employed in agriculture, about half as big but still statistically significant among women in households whose head works in the non-agricultural sector, and virtually zero among women in households whose head is employed in agriculture (Table B14). This would suggest negative effects of income on fertility in this context. Obviously, this exercise is subject to multiple caveats, as these households might differ along various other characteristics, such as age structure and migrations status. The major concern, however, would be that smallholder farmers are concentrated in different regions than large-scale oil palm plantations, where agricultural laborers would mostly find employment (Santika et al. 2019). To the extent that increases in the returns to education are largest in regions with strong local economy effects, there would be a strong spatial correlation between households whose head is self-employed in the agricultural sector, consumption effects and increases in the

returns to education. Disaggregating returns to education by the activity of the household head (as reported in Tables B15 and B16) suggests that this indeed seems to be the case: returns to education increase more strongly among households whose head is self-employed in agriculture than among households whose head works in the non-agricultural sector, and are unchanged by oil palm cultivation among households whose head is employed in agriculture. In a final exercise, we examine if parents indeed invest more in the schooling of their children, which is a key prediction of both a potential income effect and the returns to education effect. In Table 8, we show that enrollment of school-age children (5-19) increases overall, though most pronouncedly in the age-group 10-14. The enrollment effect is also strongest among households whose head is in the non-agricultural sector and (slightly smaller but still significant) among households whose head is self-employed in agriculture.

Taken together, these results indicate that the negative effects of oil palm on fertility are most pronounced in regions with income growth, local economy effects and increasing returns to education. These effects are likely linked to the strong involvement of smallholder farmers in the sector.

Table 8: Effect of oil palm on enrollment

	(1) Age 5-9	(2) Age 10-14	(3) Age 15-19	(4)	(5) Age 5-19	(6)	(7)
	All households	All households	All households	All households	Hh head is self- employed in agriculture	Hh head is employed in agriculture	Hh head works in non-agr. sector
Smallholder OP area (fraction of regency area)	-0.246 (0.436) [-1.508,0.566]	0.780* (0.449) [-0.092,2.078]	1.035 (0.993) [-1.206,3.511]	0.540 (0.502) [-0.632,1.752]	0.961* (0.581) [-0.305,2.365]	0.643 (0.592) [-0.411,2.916]	1.357** (0.589) [0.261,3.292]
F-stat	5127.973	52.480	360.502	4053.556	3842.794	1983.863	3537.897
Kleibergen F-stat	18.344	16.189	16.062	16.950	20.637	12.668	13.427
Observations	193277	322197	269692	785166	378841	56464	298749

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates are reported. All regressions control for age fixed effects, regency fixed effects, region-by-year fixed effects, gender and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: School enrollment. Sample: Col. 1, children and adolescents aged 5-9; Col. 2, aged 10-14 (Col. 2); Col. 3, aged 15-19; Col. 4, aged 5-19; Col. 5, children aged 5-19 living in households whose head is self-employed in agriculture; Col. 6, whose head is employed in agriculture; Col. 7, whose head works in the non-agricultural sector. Standard errors (clustered at regency level) in parentheses. Anderson-Rubin 95% confidence intervals (robust to weak instruments) in brackets. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6.4 Alternative explanations

Other mechanisms that are not captured by our conceptual framework could explain a negative effect of oil palm on fertility, namely changes in the returns to child labor, child mortality, infrastructure availability, female empowerment, or migration (see Section A.2 in the online appendix). These mechanisms are discussed in the following.

Lower returns to child labor in oil palm as opposed to other crops could raise the net cost of having children, and reduce fertility. And indeed, we do find that the expansion of oil palm is associated with a significant decline in child labor (Table B17). However, this effect seems to be driven by off-farm labor, as we find no effect of the oil palm expansion on child labor in family agriculture. This suggests that the drop-in child labor is related to income gains and increasing returns to education rather than to decreasing returns to on-farm child labor. We also find no evidence that the oil palm expansion reduces child mortality (measured as the fraction of children born to a woman who have died by the time of the survey), which could reduce fertility if parents optimize the number of surviving children (Table B17).

An improvement in infrastructure availability might reduce fertility by incentivizing human capital investments (at the expense of the quantity of children). Indeed, the fraction of villages with creches (kindergarten) and primary schools seems to increase with the oil palm expansion (Table B18). The increased access to kindergarten facilities and primary schools should improve the compatibility of childrearing and working, and is in itself unlikely to explain the observed decline in fertility. Also, primary schools are already available in most villages (Table 2). We do not find evidence that the fraction of villages with connection to electric grid or asphalt roads is increasing due to the oil palm expansion. The propagation of family planning through hospitals and maternity facilities (Puskesmas and Posyandu) could explain the decline in fertility, but we do not find evidence that the number of these health facilities increases with the expansion of oil palm (Hull 2005). We also do not observe any increase in the use of contraception.

We also explore the link between the oil palm expansion and female empowerment, given that an increase in women's wages might have positively impacted their bargaining-power within the household. Using DHS data, we test if the oil palm expansion influences several proxies of female empowerment, such as the gap between actual and desired fertility, an index of female autonomy, and whether women have control over their own income. We also estimate (in the SUSENAS data) if the share of food expenditures in overall expenditures is related to the oil palm expansion, which might indicate that women have a higher control over household finances. We do not find any evidence that this mechanism explains the negative effect of oil palm on fertility (Table B19).

Finally, we explore whether increased migration can explain the link between oil palm and fertility using data from the 1995 SUPAS and the 2010 population census (Table B20). In contrast to our expectations, we find evidence that oil palm is associated with lower short-term migration (*i.e.* in-migration in the last five years), and unchanged long-term migration (*i.e.* being born in a different regency). This could be because we observe changes due to the oil palm expansion of smallholder farmers but not private estates that are more depended on migrant workers. We also find that the fertility declines associated with the oil palm expansion are most pronounced among non-migrant women (*i.e.* women born in the same regency as they live in now), while migrant women exposed to the oil palm expansion have only weakly lower fertility than migrant women not exposed to oil palm. This clearly shows that increased migration does not explain the negative fertility effect of the oil palm expansion.

7 Conclusions

Low-income countries continue to exhibit fertility rates that are up to three times as high as fertility rates in high-income countries. While substantial evidence shows that technological innovation and productivity growth were paramount in spurring the fertility transition of the US and Europe in the 19th century, little is known about the relationship between productivity

growth and fertility in developing country contexts. Understanding this relationship is particularly important as many of these countries experience trajectories of economic growth that are widely different from the Industrialization in the US and Western Europe.

This paper sheds light on the relationship between agricultural productivity and fertility, and speaks to the potential effects of economic growth on fertility in the poorest countries: countries that are still at the onset of the fertility transition, and that are unlikely to experience a structural transformation away from agriculture in the near future.

In particular, we show that the oil palm boom substantially contributed to the decline in fertility in Indonesia between 1996 and 2016. While our estimates likely represent an upper bound to the average treatment effect, we find that the oil palm expansion explains up to 33% of the fertility reduction observed in the rural regions of Indonesia in that time period. In terms of mechanisms, our results suggest that the fertility reduction was triggered by income gains among smallholder farmers, which spurred local economic development and increasing returns to education, and led to higher investments in child human capital. These findings imply that productivity growth – even if it is limited to the agricultural sector – can accelerate the fertility transition.

Our results also speak to policy debates in developing countries. While we find a negative effect of oil palm expansion on fertility in Indonesia, this might depend on several preconditions. First, Indonesia has a long tradition of cash crop cultivation. People obtain a considerable part of food and non-food consumption goods from markets, and are surrounded by a relatively well established institutional and infrastructural framework. In settings with less amenable conditions for the development of a prospering non-agricultural sector, a decline in female labor productivity could lead to falling wages, potentially increasing fertility. Second, the availability of schools might matter. Our results suggest that investments in education were an important transmission mechanism. If high transaction costs impede such investments, fertility reductions might be less evident. Third, it is important to note that oil palm was widely

adopted by smallholder farmers. Agricultural productivity growth that is restricted to large-scale farms might have different effects. For instance, mechanization in large-scale agriculture might similarly increase labor and land productivity. But if income gains are concentrated among a small elite, effects on demand for non-agricultural goods and on local economic development would likely be less pronounced or absent, which would substantially reduce the scope for fertility reductions. Studying the nature of productivity growth, and its contextual effects on fertility might be an important piece of evidence in understanding the heterogeneous development paths of different countries and regions.

A number of caveats apply. While we can exclude several potential transmission mechanisms, we are not able to clearly disentangle the relative importance of the income effect and changes in the returns to education. Second, due to data limitations, the variable we use for fertility represents the number of all ever-occurred live births per woman. Our variable thus captures events which possibly happened decades ago, which limits the scope for a more detailed analysis by age groups. And finally, we want to emphasize that although we find positive effects of the oil palm expansion on consumption expenditures and on educational attainment, this does not imply that oil palm should be favored for poverty reduction. The detrimental effects of the oil palm expansion on a large set of ecosystem functions such as biodiversity, hydrological cycles and carbon storage are widely documented, as well as equity issues and land conflicts, posing serious threats to the long-term sustainability of Indonesia's oil palm sector. An assessment of the societal impact of oil palm needs to carefully weigh these different outcomes against each other.

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ONLINE APPENDIX

Agricultural productivity and fertility: Evidence from the oil palm boom in Indonesia

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Appendix A: Theoretical considerations

A.1. Oil palm expansion as increase in agricultural productivity

We consider each regency in Indonesia to behave like a small open economy, and to consist of two sectors: an agricultural sector and a non-agricultural sector. Agricultural goods can be traded (nationally or internationally), but production factors and the non-agricultural good are immobile.¹

Agricultural production is governed by the following constant elasticity of substitution (CES) production function:

$$Q_a = A_N[(A_L L_a)^\rho + (A_T T_a)^\rho]^{1/\rho} \quad (\text{A.1})$$

with Q_a being agricultural output, L_a aggregate agricultural labor, and T_a total agricultural land. A_N , A_L , and A_T are factor-neutral, labor-specific and land-specific productivity parameters, respectively. $\rho \leq 1$ is the complementarity parameter, and the elasticity of substitution $\sigma \in (0, \infty)$ is defined as $\sigma = 1/1 - \rho$.² Labor can move freely between the agricultural and the non-agricultural sector, and land is fixed initially. The non-agricultural good is produced exclusively with labor, *i.e.* $Q_n = A_n L_n$. Because we consider each regency to be a small open economy, and labor can move freely between both sectors, agricultural producers are price takers with respect to output prices and wages. They will thus choose input levels that equalize the marginal product of labor (MPL_a) to (real) wages:

$$\frac{w}{p_a} = MPL_a = A_N A_L^\rho \left[A_L^\rho + A_T^\rho \left(\frac{T_a}{L_a} \right)^\rho \right]^{1-\rho/\rho}. \quad (\text{A.2})$$

¹ The predictions of the model are the same as in a three-sector economy, where manufacturing goods can be traded, but not the service sector output.

² When $\sigma = \infty$, the two factors are perfect substitutes, and when $\sigma = 0$ the two factors are perfect complements. In line with Acemoglu (2002), we abstract from the share parameter for the sake of simplicity.

Since our interest is in fertility decisions, we model the effect of oil palm on gender-specific labor demand explicitly. We adapt the framework of Acemoglu (2002) and characterize agricultural labor L_a as CES aggregate of female (F_a) and male (M_a) labor:

$$L_a = [(A_F F_a)^\varepsilon + (A_M M_a)^\varepsilon]^{1/\varepsilon}. \quad (\text{A.3})$$

The fact that labor can move between sectors again implies that the (gender-specific) marginal product of labor MPL must equal wages. Specifically, one can write:

$$\frac{w_M}{w_F} = \left(\frac{A_M}{A_F}\right)^\varepsilon \left(\frac{M}{F}\right)^{-(1-\varepsilon)}. \quad (\text{A.4})$$

We incorporate the fact that male labor productivity in oil palm production is higher than in the production in other crops while female labor productivity is the same across crops, by modelling the effect of the expansion of oil palm in the agricultural sector as an increase in A_M . Solving for F/M and differentiating with respect to A_M reveals that an increase in the productivity of male labor reduces the share of female workers in agriculture as long as $0 < \varepsilon < 1$, *i.e.* as long as male and female workers are substitutes in the production of the agricultural good.³

The effect of a change in A_M on overall demand for labor, then, depends on the complementarity between land and labor in overall agricultural production. Bustos et al. (2016) demonstrate that an increase in the productivity of labor, A_L in eq. (A.1), is labor saving in small open economies with multiple sectors, as long as the elasticity of substitution between land and labor is smaller than the land share of output, *i.e.* $\sigma < T_a MPT_a / Q_a$. This condition is likely to be satisfied in agriculture, where land and labor tend to be highly complementary.

The model thus predicts that oil palm would reduce the demand for labor in agriculture, and the demand for female labor in particular, as long as the area used for agriculture remains fixed.

³ Note that we do not need to make any assumption about the relative productivity of male and female workers, we just need to assume that there is no minimum of female workers needed for male workers to be productive and vice versa.

But as discussed previously, the expansion of oil palm was accompanied by an increase in agricultural land, and substantial deforestation in Indonesia. A simple way to incorporate this into our framework is to model the expansion of land as a function of its marginal product (MPT_a).⁴ The effect of an increase in A_M on labor demand in agriculture is then a function of the marginal cost of deforestation. Provided the cost of deforestation is sufficiently low, labor demand in agriculture would remain constant or even increase.

The general equilibrium effect of the oil palm expansion on wages (and incomes) is then a combination of local economy and labor demand effects. Local economy effects are expected to be positive. Landowners benefit from the oil palm expansion because land productivity increases. This increases landowners' incomes, and consumption of the agricultural and the non-agricultural goods. Because the non-agricultural good is not traded, an increase in the demand would raise prices p_n and wages w_n in the non-agricultural sector. To the extent that the non-agricultural sector is characterized by higher returns to education, a growing non-agricultural sector (relative to the agricultural sector) also implies rising returns to education in the economy.

Labor demand effects within agriculture, on the other side, are expected to be negative for women, and weakly positive for men. As the demand for female labor in agriculture falls, women switch from the agricultural sector to the non-agricultural sector. The market clearing condition in the non-agricultural sector is: $w_n = p_n MPL_n$. *Ceteris paribus*, an increase in the supply of labor in the non-agricultural sector depresses prices and wages (as long as Q_n is non-tradable). Which of the two effects dominates for female wages in the non-agricultural sector is *ex ante* ambiguous. For men, the general equilibrium effect on wages in both sectors is strictly

⁴ A simple supply function of agricultural land in which there is a fixed cost of deforestation (which is increasing in T_a) is sufficient to characterize an increase in the amount of agricultural land with rising MPT_a .

positive as long as demand for male labor does not decrease in agriculture (*i.e.* as long as agricultural land can expand).

Empirically, the expansion of oil palm was associated with an increase non-agricultural wages for men and women (see Tables 6 and B13), while previous work also found positive effects on men's agricultural wages (Kubitza et al. 2018; Edwards 2019).⁵ This suggests that the positive local economy effect dominates the negative labor demand effect for women, and is consistent with our observation that smallholder farmers make up for a substantial share of the palm oil production.

A.2 Alternative explanations for effect of oil palm on fertility

In the following, we will discuss five potential alternative explanations for why fertility might decline with the expansion of oil palm: Child labor, child mortality, infrastructure, female empowerment, and migration.

Child labor. A negative relationship between fertility and oil palm cultivation might stem from differences in the returns to child labor between oil palm and alternative crops. In many countries, children contribute to household income by working on the family farm or in the labor market, thereby offsetting part of the direct cost of raising children. We are not aware of any detailed empirical analysis of child labor in oil palm cultivation. Anecdotal evidence suggests that children can be involved in picking up loose fruits, which fell off the main bunch during harvest (Koczberski 2007). However, harvesting oil palms necessitates too much physical strength to involve child labor. Rubber and rice cultivation, in contrast, involve more female labor and theoretically also more child labor. We therefore expect that oil palm has

⁵ We explore these effects empirically in Section 6.1.

reduced the returns to child labor and increased the cost of having children.⁶ This could have reduced the demand for children.

Child mortality. Another alternative mechanism could be that fertility decreases as more children survive (Kirk 1996). The idea is that families target a specific number of surviving children, and that this target can be achieved with lower overall fertility rates as child mortality declines. Since oil palm expansion improved incomes and potentially infrastructure, and this probably decreased child mortality, households might have simply adjusted the number of births but not the number of desired children.

Infrastructure. The expansion of oil palm was probably accompanied by substantial investments in infrastructure. The processing of oil palm fruit bunches requires improved road infrastructure and reliable electricity. Moreover, the government of Indonesia targeted infrastructure projects deliberately to oil palm cultivating areas to pursue its economic development agenda.⁷ Investments in roads and other infrastructure could reduce the cost of accessing (higher) education and health care services, and encourage investments in child quality, potentially at the expense of child quantity.

Female empowerment. A substantial body of literature suggests that female bargaining power within the household increases as women earn their own income (Duflo 2012). If women have *per se* lower fertility preferences than men, a reduction in fertility could stem from the fact that women's wages in the non-agricultural sector increased. The fertility reduction would then simply reflect an increased bargaining weight of women within the household.

⁶ Note that the microdata presented in Section 2 do not provide information about child labor, which by 2012 was largely abolished. This does not imply that child labor did not play a more important role in the 1990s.

⁷ Furthermore, the oil palm expansion could have directly contributed to the revenue of local governments, which could in turn lead to higher investments in health, education and transportation infrastructure.

Migration. The oil palm boom increased internal migration flows into oil palm cultivating areas through the transmigration program as well as through spontaneous migration (Euler et al. 2016). In the very short-term, migrant families might have faced increasing opportunity costs of child rearing since the establishment of a new farm and household are labor intensive tasks. On the other hand, men are more likely to be involved in internal migration, increasing the share of women in sending regions (Sukamdi & Mujahid 2015). This could have decreased fertility in sending regions compared to oil palm cultivating areas due to a reduction in the likelihood of marriage. In the long run, both these factors might be less important, and childbearing patterns might depend more whether there are selection effects, as migrants might have different fertility preferences than the local population (Kulu 2005).

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Appendix B: Supplementary Figures and Tables

Figure B1: Expansion of oil palm area in Indonesia by producer type

Source: Tree Crop Statistics.

Figure B2: Effect of oil palm on the number of children born by age group

Source: SUSENAS 2001, 2006, 2011, 2016.

Notes: Figure plots marginal effects and 90% CI of IV estimates of the effect of smallholder oil palm area on fertility in 5-year age groups, with standard errors clustered at the regency level. Each regression controls for age fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. Var.: Number of children ever born alive. Sample: Women aged 15-49.

Figure B3: Effect of oil palm expansion on fertility – DHS data

Source: DHS 1991, 1997, 2002-03, 2007, 2012, 2017.

Notes: Figure plots marginal effects and 90% confidence intervals of OLS estimates of the effect of smallholder oil palm area (fraction of province area) on fertility in 5-year age groups, with standard errors clustered at province level. All regressions control for age fixed effects, province fixed effects, and year fixed effects. Dep. var. Panel A: Number of children ever born alive; Panel B: Births in the last 12 months. Sample: Ever-married women aged 15-49.

Table B1: Summary statistics for smallholder household survey in Jambi province

	2012		2015	
	Oil palm farmers [n=238]	Non-adopters [n=441]	Oil palm farmers [n=248]	Non-adopters [n=435]
Household characteristics				
Farm size owned (ha)	5.414 (5.289)	3.337 (3.955)	5.474 (5.224)	3.208 (4.213)
Rubber area (ha)	2.324 (3.485)	3.213 (3.969)	2.170 (3.230)	3.097 (4.217)
Oil palm area (ha)	3.011 (3.656)	0.000	3.212 (3.951)	0.000
Number of household members	4.176 (1.505)	4.218 (1.563)	4.173 (1.500)	4.094 (1.587)
Number of adults in the household (>15y)	2.849 (1.064)	2.980 (1.227)	2.964 (1.125)	2.922 (1.141)
Female-headed household (=1)	0.021 (0.144)	0.068 (0.252)	0.028 (0.166)	0.103 (0.305)
Age of household head (years)	45.51 (12.18)	45.78 (12.28)	47.66 (10.98)	47.49 (11.79)
Educ. of household head (years of school)	7.752 (3.604)	7.302 (3.680)	7.335 (3.526)	7.115 (3.780)
Own business (=1)	0.231 (0.422)	0.186 (0.390)	0.335 (0.473)	0.221 (0.415)
Employed in non-farm (=1)	0.412 (0.493)	0.476 (0.500)	0.556 (0.498)	0.570 (0.496)
Migrant (=1)	0.576 (0.495)	0.374 (0.484)	0.548 (0.499)	0.379 (0.486)
Transmigrant village (=1)	0.437 (0.497)	0.236 (0.425)	0.411 (0.493)	0.248 (0.433)
Total consump. expend. (mill. IDR/year/AE)	24.53 (15.21)	20.09 (31.31)	23.96 (16.75)	17.84 (13.39)
Food consump. expend. (mill. IDR/year/AE)	12.85 (6.57)	10.93 (6.09)	11.61 (6.23)	9.402 (4.761)

Notes: Mean values with standard deviations in parentheses are reported. Monetary values from 2012 are inflation-adjusted.

To obtain data on smallholder farms we conducted an extensive survey of local farm household. Data were collected in two waves, 2012 and 2015. Sampling was based on a multi-stage framework. All five regencies in Jambi Province located in the tropical lowland areas were selected purposively. From these regencies, 40 villages in 20 districts were randomly selected. Five additional villages were selected purposively to allow for interdisciplinary collaboration with associated research groups. The sample size was adjusted to village population size to mitigate possible sampling bias. All households that owned any agricultural land in the last 5 years were included. In total 679 randomly selected households were interviewed. Between both rounds, the attrition rate was at 6%.

Table B2: Effect of education on factor productivity of oil palm and rubber

	(1) Profit per ha	(2) Profit per labor hour
Oil palm plot (=1)	-3742.059*	33.460**
	(1969.317)	(13.702)
Education of household head (years of schooling)	643.891**	-1.746
	(252.322)	(1.754)
Oil palm plot # Education of household head	-123.951	2.249
	(226.595)	(1.581)
F-Stat	34.461	12.987
Observations	1405	1398

Source: Smallholder household data, Jambi province 2012 and 2015.

Notes: OLS estimates reported. All regressions control for year and household fixed effects, a household wealth index, capital input at plot level and plot size. All monetary variables are in constant 2012 values. Sample: Plots of local smallholder farmers. Unproductive plots were excluded and tree age restricted to main productive age from 5 to 25 years. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B3: Description of data sources

Source	Variable	Data availability	Description
Tree Crop Statistics	Oil palm area	1967-2016 (national level) 1996-2016 (regency level)	We use the data published in the Indonesia Database for Policy and Economic Research (INDO-DAPOER) which is maintained by the World Bank (World Bank 2018), and update the series until 2016 with data from the Tree Crop Statistics Reports (Ministry of Agriculture, 2017). Regency-level oil palm data are only available for smallholders between 1996-2004. Starting 2005, the data contain oil palm area for smallholders, private estates and government estates, such that it is possible to calculate the total oil palm area only from 2005 onwards. Missing data (2006: private and government estates, 2008: smallholder, 2013: all, 2016: private and government estates) are linearly interpolated.
GAEZ/FAO	Attainable yield (kg/ha)	1960-1990 (baseline)	The Global Agro-Ecological Zones (GAEZ) database generates simulations of agro-climatic attainable yields and suitability indices for crops under different conditions in grid cells of 5 arc-minute and 30 arc-second (approximately 10x10km resolution). We use the agro-climatically attainable yield (in kg/ha) for low input level rain-fed oil palm in the baseline period 1961-1990. To convert grid-level data to regency-level data, we aggregate across grids using area weights (<i>i.e.</i> total area of the grid overlapping with the regency, divided by the total regency area).
SUSENAS	Fertility (number of children ever born alive), work in the past 7 days (hours, sector of work), educational attainment, school enrollment, child mortality, consumption expenditures per capita	1993, 1996, 2001, 2005, 2006, 2011, 2013, 2016	The National Socioeconomic Survey (SUSENAS) is a multi-purpose socio-economic household survey, that contains individual-level information about demographics, education, and labor market participation, and is carried out annually by Indonesia's Central Statistical Agency, Badan Pusat Statistik (BPS), albeit with altering content every year for some specific modules. The SUSENAS is representative at the regency-level. The provinces of Papua were not covered 2016 due to armed conflict and are therefore dropped from the sample. The province Aceh was not covered in 2001, but because this is an intermediate round, we leave Aceh in the sample. As with most surveys, the fertility module is only administered to women who are or were married in the past. To avoid constructing an endogenous sample, we set fertility to zero for all women who were never married. We also winsorize fertility at the 99th percentile. Sector of work is classified into three main sectors: agriculture, manufacturing, and services. The agricultural labor force consists of individuals who are employed in agriculture (such as on oil palm estates), self-employed in agriculture (<i>i.e.</i> farmers), and family workers in agriculture. We also use the main activity of the household head to (albeit imprecisely) deduce if a household owns land or not (building on the assumption that a household head who owns land is self-employed in agriculture). Person and household weights are rescaled to give equal weight to each survey year.
PODES	Villages with oil palm cultivation (1993, 2003), Village characteristics (1996, 2006, 2014)	1993, 1996, 2003, 2006, 2014	The Village Potential Statistics (PODES) collects village and urban neighborhood characteristics for all of Indonesia. It is carried out approximately every three years by the BPS. The rounds 1993 and 2003 contain information on village-level land-use. Based on this information, we calculate the share of villages that cultivate oil palm (out of all villages within a regency). We construct additional variables from the PODES rounds 1996, 2006 and 2014, including: the fraction of villages per regency with at least one kindergarten, primary school, junior high school, hospital, maternity facility, asphalt road, and at least one household with access to the electric grid. Villages are reweighted by the number of households.

Table B3: Description of data sources - cont.

Source	Variable	Data availability	Description
SAKERNAS	Wages, work in the past 7 days (hours, sector of work)	1993-2015	The National Labor Force Survey (SAKERNAS) collects labor market characteristics of working age individuals. The SAKERNAS is collected annually by the BPS and is representative at the regency-level since 2007. Regency-identifiers are available from 2000 onwards, and wage data is elicited consistently since 2001. Household identifiers are available in 2003, 2007, 2011, 2015. We construct two samples: 1) In 1993, we calculate average province-level wages for all men and women (aged 15 to 49) employed in the agricultural sector, and the share of women and men working in the agricultural sector. 2) For the years 2001-2015, we extract demographics (age, gender) and labor market outcomes (labor force participation, sector of work, hours worked, wages per hour) for all men and women in the age-range 15-49. Person weights are rescaled to give equal weight to each survey year.
Demographic and Health Surveys (DHS)	Fertility, Female bargaining power	1991, 1997, 2002/03, 2007, 2012, 2017	The Demographic and Health Survey (DHS) provides representative data on health and population at the province level (village coordinates are only available in 2002-03), including births over the past 12 months (current fertility), and number of children ever born per woman (lifetime fertility) for all ever-married women. We construct some proxies for female bargaining power: 1) the fertility gap is calculated as the difference between actual children and desired children (variable is top-coded at 6). To construct a meaningful measure, we restrict the sample to women ≥ 40 and bottom code it to zero. 2) Control over her income is a dummy which equals one if a woman earns her own cash salary and reports to decide how to spend it by herself, and zero otherwise (no own salary, or no control). 3) Autonomy is an index ranging from 0 to 1 indicating if the woman reports to be at least partly involved in decisions regarding her own health, household purchases (large and daily), visits to family and relatives and the food to be cooked. The more dimensions she is involved in decision-making, the higher the index (available from 2001-02 onwards). We exclude provinces in Papua to be consistent with the other samples.
IPUMS International Database	Migration, Fertility, Education, Household characteristics, Land-holdings	1971, 1980, 1990, 1995, 2000, 2005, 2010	From the IPUMS International database, we use the 10% subsample of the Population Census of 2000 and 2010, the 0.54% subsample of 1971, the 5% subsample of 1980, the 0.51% subsample of 1990, as well as the 0.43% and 0.51% subsamples of the Intercensal Population Surveys of 1995 and 2005, respectively. We construct three different datasets: 1) From the Census 1980, we calculate regency-level land-distribution characteristics before the onset of the oil palm expansion (median size of agricultural landholdings, number of farmers with agricultural landholdings of different sizes). 2) From the census and intercensal surveys of 1995 and 2010, we construct a sample of all women aged 15-49 that contains their age, education, fertility (number of children born by year t), migration history (permanent migration indicates if a woman was born in a different regency than her regency of residence, recent migration indicates if she moved to the regency in the last 5 years). To be consistent with the other samples, we exclude Java, Papua, and city districts (kotas). Person weights are rescaled to give equal weight to each survey year. 3) From the Census 1971, 1980 and 1990 we construct a sample of women aged 15-49 that contains their age and fertility (number of children born by year t), which allows us to conduct placebo regressions (we merge this sample to the oil palm area in 1996, 2005 and 2015). Person weights are rescaled to give equal weight to each survey year. To be consistent with the IV estimates from other samples, we exclude Java, Papua, and city districts.

Table B3: Description of data sources - cont.

Source	Variable	Data availability	Description
Badan Pusat Statistik (BPS)	Poverty line	1993-2016	Province-specific rural and urban poverty lines are published annually in the Statistic Year Book of Indonesia. We use rural poverty lines to discount wages and consumption.
NASA	Average altitude	n.a.	NASA's Shuttle Radar Topographic Mission (SRTM) digital elevation data are used to calculate the average altitude of each regency.
Austin et al. (2017)	Oil palm estates	1995, 2000, 2005, 2010, 2015	Spatial data on the expansion of industrial-scale oil palm estates relying on LandSat satellite imagery are published by Austin et al. (2017). Data are available at 250 x 250m resolution for the islands Sumatra, Papua and Kalimantan. We impute zero industrial-scale oil palm estates for Java (main island), where almost no oil palm production is taking place.

Table B4: Additional summary statistics

	Obs.	Mean	Std. dev.
SUSENAS (1996, 2001, 2006, 2011, 2016)			
<i>Households:</i>			
Hh head self-employed in agricultural sector	672780	0.454	0.498
Hh head employed in agr. sector	672780	0.076	0.265
Hh head working in non-agr. sector	672780	0.370	0.483
Household size	672780	4.142	1.821
<i>Women aged 15-49:</i>			
Number of children ever born alive (women w/ primary educ.)	394729	2.418	2.098
Number of children ever born alive (women with sec educ.)	296375	1.353	1.603
Number of children ever born alive (women with tert. educ.)	39738	1.426	1.410
Number of children ever born alive (Hh head self-employed in agr.)	329674	2.080	2.081
Number of children ever born alive (Hh head employed in agr.)	55086	1.992	1.802
Number of children ever born alive (Hh head working in non-agr.)	291460	1.874	1.817
Use of contraception (=1)	725678	0.495	0.500
Child mortality (Mortality/1000 children ever born alive)	489879	29.422	113.340
<i>Children aged 10-14:</i>			
Work (=1)	322197	0.068	0.252
Work on own farm (=1)	322197	0.045	0.206
Work (boys) (=1)	167119	0.081	0.273
Work (girls) (=1)	155078	0.054	0.227
SUSENAS (1996, 2006, 2016)			
<i>Household:</i>			
Share of food expenditures in total exp.	409108	0.636	0.139
PODES (1996, 2006, 2014)			
<i>Regencies:</i>			
Share of villages in regency with asphalt main road	416	0.681	0.188
Share of villages in regency with kindergarten	416	0.574	0.253
Share of villages in regency with primary school	416	0.957	0.084
Share of villages in regency with junior high school	416	0.498	0.173
Share of villages in regency with access to electric grid	416	0.953	0.102
Share of villages in regency with hospital	416	0.039	0.033
Share of villages in regency with maternity facility	416	0.815	0.168
PODES (1993, 2003)			
<i>Regencies:</i>			
Fraction of villages in regency with oil palm cultivation	278	0.046	0.116
SUPAS (1995), Census (2010)			
<i>Men and women aged 15-49:</i>			
Ever migrated to regency	4663220	0.175	0.380
Migrated in last 5y to regency	4652117	0.057	0.231
<i>Women aged 15-49:</i>			
Number of children ever born alive (migrant women)	383015	1.910	1.693
Number of children ever born alive (non-migrant women)	1936993	1.842	1.848
Census (1971, 1980, 1990)			
<i>Women aged 15-49:</i>			
Number of children ever born alive	2157735	2.661	2.775
SAKERNAS (2001,2006, 2011, 2015)			
<i>Men aged 15-49:</i>			
Wages in agricultural sector (IDR/Hour)	239188	1230.246	1882.810
Wages in non-agricultural sector (IDR/Hour)	428801	1499.057	2201.392
Wages with none/primary education (IDR/Hour)	265602	1111.377	1379.413
Wages with secondary education (IDR/Hour)	342992	1387.314	2044.022
Wages with tertiary education (IDR/Hour)	59395	2795.448	3806.942

Table B4: Additional summary statistics – cont.

	Obs.	Mean	Std. dev.
DHS (1991, 1997, 2002/03, 2007, 2012, 2017)			
<i>Ever-married women aged 15-49:</i>			
Age	202109	32.43	9.218
Number of children ever born alive	202109	2.355	2.015
Number of children born in past 12 months	202109	0.108	0.313
Fertility gap (women aged 40-49)	53345	0.676	1.314
Autonomy index	125651	0.868	0.244
Control over income (=1)	202109	0.201	0.401
Tree Crop Statistics (2005, 2016)			
<i>Regencies:</i>			
Smallholder oil palm area (fraction of regency area)	278	0.020	0.035
Private/ government estate oil palm area (fraction of regency area)	278	0.031	0.056
Share of total oil palm area (fraction of regency area)	278	0.051	0.084
Austin et al. (2017) (1995, 2001, 2005, 2011, 2015)			
<i>Regencies:</i>			
Industrial-scale oil palm area (fraction of regency area)	340	0.069	0.089

Notes: All monetary values are in constant 1996 IDR. For migration, multiple regencies have missing data. No data for industrial-scale oil palm area for Sulawesi, Maluku and Nusa Tenggara. One regency missing in PODES data. Autonomy questions available in DHS from 2002/03 onwards.

Table B5: Effect of oil palm on fertility – first stage results

	(1)	(2)	(3)
	Smallholder OP area (fraction of regency area)		
Attainable yield for oil palm * national oil palm area	0.345*** (0.066)	0.196*** (0.049)	0.237*** (0.060)
Regency & year FE	Yes	Yes	Yes
Woman's age cohorts	Yes	Yes	Yes
Initial levels * year	No	Yes	Yes
Region-by-year FE	No	No	Yes
Kleibergen F-stat	27.576	16.302	15.793
Observations	730842	730842	730842

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: Dep. Var.: Smallholder OP area (fraction of regency area). Sample: Women aged 15-49. Standard errors (clustered at regency level) in parentheses. The estimates presented here are the first stages to Table 4, Cols. (3)-(5). Attainable yield (in t/ha) and national oil palm area in 1,000,000 ha. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B6: Effect of oil palm on fertility – Local average treatment effect

	(1) Consumption exp. p. c.	(2) Number of children ever born alive
Smallholder OP area (fraction of regency area)	0.194 (0.372)	-0.036 (0.408)
Smallholder OP area * Attainable yield (t/ha)	1.479** (0.671)	0.206 (0.855)
F-stat	3.139	9.350
Observations	672780	730842

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: OLS estimates are reported. Dep. var.: Col. 1, Consumption expenditures per capita, Col. 2, Number of children ever born alive. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Sample: Col. 1, all households; Col. 2, women aged 15-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B7: Effect of oil palm on completed fertility – women 40-49

	(1) IV	(2) IV	(3) IV
Average 1996-2016 smallholder OP area (fraction of regency area)	-21.137** (9.764)	-8.417* (4.788)	-18.040** (6.982)
Region and age-group FE	Yes	Yes	Yes
Province FE	No	Yes	Yes
Initial levels * year	No	No	Yes
F-stat	4.686	3.090	11.122
Kleibergen F-stat	11.681	23.280	14.945
Observations	42942	42942	42942

Source: SUSENAS 2016.

Notes: Col. 3 controls for initial levels of regency-average fertility, electrification, female labor force participation, and male agricultural wages, times year. Dep. var.: Number of children ever born alive (lifetime fertility). Sample: Women aged 40-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B8: Effect of oil palm on fertility – PODES data

	(1) OLS	(2) OLS	(3) IV	(4) IV	(5) IV
Fraction of villages in regency with oil palm cultivation	-0.402*** (0.126)	-0.078 (0.147)	-0.926*** (0.331)	-1.063* (0.538)	-0.948 (0.679)
Regency & year FE	Yes	Yes	Yes	Yes	Yes
Age-group FE	Yes	Yes	Yes	Yes	Yes
Initial levels * year	No	Yes	No	Yes	Yes
Region-by-year FE	No	Yes	No	No	Yes
F-stat	10.210	3.665	7.803	6.156	3.667
Kleibergen F-stat			41.014	19.679	16.946
Observations	229194	229194	229194	229194	229194

Source: SUSENAS and PODES 1993, 2003.

Notes: Cols. 2, 4-5 control for initial levels of regency-average fertility, electrification, female labor force participation, and male agricultural wages, times year. Dep. var.: Number of children ever born alive. Sample: Women aged 15-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B9: Effect of oil palm on fertility – alternative measures of oil palm area

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Sumatra, Kalimantan, Java		Original sample					
	IV	IV	IV	IV	IV	OLS	OLS	OLS
Smallholder OP area (fraction of regency area)	-1.743 (1.250)		-3.000 (2.061)			-0.568* (0.303)		
Industrial-scale OP area (fraction of regency area)		-2.544 (1.884)						
Private/Gov. estates OP area (fraction of regency area)				-2.036 (1.511)			-0.037 (0.259)	
Total OP area (fraction of regency area)					-1.213 (0.840)			-0.162 (0.206)
F-stat	16.211	14.994	11.597	12.232	13.271	17.782	15.811	16.612
Kleibergen F-stat	8.938	9.976	12.543	8.847	16.462			
Observations	795803	795803	326375	326375	326375	326375	326375	326375

Source: Cols. 1-2, SUSENAS 1996, 2001, 2006, 2011, 2016; Cols. 3-8, SUSENAS 2005, 2016.

Notes: IV estimates are reported in Cols. 1-5. OLS estimates reported in Cols. 6-8. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial levels of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. Var.: Number of children ever born alive. Sample: Women aged 15-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B10: Effect of oil palm on fertility – alternative samples, trends

	(1)	(2)	(3)	(4)	(5)
	Original sample + Java			Original sample	
Smallholder OP area (fraction of regency area)	-9.443** (4.201)	-5.318** (2.353)	-3.162** (1.304)	-5.559** (2.449)	-5.641*** (1.765)
Regency, year & age-group FE	Yes	Yes	Yes	Yes	Yes
Initial levels * year	Yes	Yes	No	No	No
Region-by-year FE	Yes	No	No	Yes	No
Province* year	No	Yes	No	No	No
Att. yield of rice * year	No	No	Yes	No	No
Initial levels * National OP area	No	No	No	Yes	No
Average altitude * year	No	No	No	No	Yes
F-stat	8.801	10.938	3.231	5.817	5.463
Kleibergen F-stat	8.564	9.331	23.869	15.849	37.942
Observations	1078267	1078267	730842	730842	730842

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates are reported. All regressions control for five-year age-group fixed effects, regency fixed effects, and year fixed effects. Col. 1 adds region-by-year fixed effects, and initial levels of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Col. 2 adds province-specific linear time trends. Col. 3 adds attainable yield for rice times year. Col. 4 adds region-by-year fixed effects and initial levels times national oil palm area. Col. 5 adds altitude times year. Dep. var.: Number of children ever born alive. Sample: Women aged 15-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B11: Effect of oil palm on fertility – census data, contemporaneous and placebo regression

	(1)	(5)
	Contemporaneous regression	Placebo regression: oil palm area leading by 25 years
Smallholder OP area (fraction of regency area)	-5.942** (2.871)	-1.919 (4.228)
F-stat	5.748	4.275
Kleibergen F-stat	9.092	13.961
Observations	2256771	671041

Source: Col. 1, SUPAS 1995, Population census 2010; Col. 2, Population census 1971, 1980, 1990 (IPUMS subsamples).

Notes: IV estimates are reported. All regressions control for five-year age-group fixed effects, regency fixed effects and region-by-year fixed effects and for initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times the national oil palm expansion. The main regressor in Col. (1) is smallholder oil palm area in 1995 and 2010. The main regressor in Col. (2) is smallholder oil palm area in 1996, 2005 and 2015 which was merged with a 25-year lead to the population census. The instrument in col (2) is national oil palm area in 1996, 2005, 2015 times attainable yield. The national oil palm area increased from 133,298 to 294,560 hectares between 1971 and 1980 and to 1,126,677 in 1990. Dep. var.: Number of children ever born alive. Sample: Women aged 15-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B12: Effect of oil palm on main activity of household head, household size

	(1) Hh head self-employed in agricultural sector	(2) Hh head employed in agricultural sector	(3) Hh head in non-agricultural sector
Smallholder OP area (fraction of regency area)	-1.578** (0.769)	0.914*** (0.345)	0.082 (0.502)
F-stat	1.732	3.992	1.619
Kleibergen F-stat	16.539	16.539	16.539
Observations	672780	672780	672780

Sources: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates reported. All regressions control for regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Sample: All households. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B13: Effect of oil palm on men's wages

	(1) Non- agricultural sector	(2) Agricultural sector	(3) ≤Primary education	(4) Secondary education	(5) Tertiary education
Smallholder OP area (fraction of regency area)	6.195** (2.959)	0.750 (2.502)	2.615 (3.176)	4.954* (2.610)	5.158 (3.613)
F-stat	3.143	3.105	3.202	1.621	5.934
Kleibergen F-stat	11.389	8.839	8.694	11.971	12.080
Observations	428539	236003	263581	341610	59351

Source: SAKERNAS 2001-2015.

Notes: IV estimates reported. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Log hourly wages (in constant 1996 IDR). Sample: Working men aged 15-49: Col 1, in non-agricultural sector; Col. 2, in agricultural sector; Col. 3, with none or primary degree; Col. 4, with secondary degree; Col. 5, with tertiary degree. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B14: Effect of oil palm on fertility – subsample analysis

	(1) ≤Primary education	(2) Secondary education	(3) Tertiary education	(4) Hh head self- employed in agricultural sector	(5) Hh head employed in agricultural sector	(6) Hh head in non- agricultural sector
Smallholder OP area (fraction of regency area)	-9.606** (4.280)	0.444 (1.174)	1.508 (2.980)	-8.490*** (3.107)	-0.700 (2.270)	-4.143* (2.303)
F-stat	6.560	1.289	1.556	6.716	6.213	5.722
Kleibergen F-stat	14.784	15.898	13.268	19.539	12.104	12.473
Observations	394729	296375	39738	329674	55086	291460

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates are reported. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Number of children ever born alive. Sample: Women aged 15-49: Col.1, with none or primary degree; Col. 2, with secondary degree; Col. 3, with tertiary degree; Col. 4, head of household self-employed in agricultural sector; Col. 5, head of household employed in agricultural sector; Col. 6, head of household working in non-agricultural sector. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B15: Effect of oil palm expansion on women's wages - OLS

	(1) ≤Primary education	(2) Secondary education	(3) Tertiary education
Smallholder OP area (fraction of regency area)	-0.533 (0.416)	-0.095 (0.439)	1.355* (0.717)
F-stat	5.218	7.874	6.587
Observations	103407	120581	63236

Source: SAKERNAS 2001-2015.

Notes: OLS estimates reported. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Log hourly wages (in constant 1996 IDR). Sample: Working women aged 15-49: Cols. 1, with none or primary degree; Col. 2, with secondary degree; Col. 3, with tertiary degree. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B16: Effect of oil palm expansion on women's wages – subsample analysis

			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
			All households			Household head self-employed in agricultural sector			Household head employed in agricultural sector			Household head in non-agricultural sector		
			≤Primary education	Secondary education	Tertiary education	≤Primary education	Secondary education	Tertiary education	≤Primary education	Secondary education	Tertiary education	≤Primary education	Secondary education	Tertiary education
Smallholder	OP	area	-1.057	-0.344	2.286	-3.149**	-0.539	4.644	1.987	-1.646	-0.395	-1.495	1.164	2.256*
(fraction of regency area)			(0.949)	(0.836)	(1.566)	(1.352)	(1.254)	(2.943)	(1.485)	(1.596)	(4.574)	(1.122)	(0.896)	(1.314)
F-stat			1.018	4.959	5.039	4.006	2.611	6.468	1.387	0.842	1.112	1.580	6.916	3.510
Observations			30415	25741	19478	10380	8230	2955	6681	3407	379	12902	22638	14331

Source: SAKERNAS 2003, 2007, 2011, 2015.

Notes: OLS estimates reported. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Log hourly wages (in constant 1996 IDR). Sample: Working women aged 15-49: Col. 1,4,7,10, with none or primary degree; Col. 2,5,8,11, with secondary degree; Col. 3,6,9,12, with tertiary degree. Cols. 4-12, additionally split the sample by the main activity of household head. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B17: Effect of oil palm expansion on child labor, mortality

	(1) Child labor	(2) On-farm child labor	(3) Male child labor	(4) Female child labor	(5) Child mortality
Smallholder OP area (fraction of regency area)	-1.074** (0.489)	-0.547 (0.373)	-1.338** (0.631)	-0.785* (0.401)	-0.171 (0.211)
F-stat	1.822	2.696	2.809	1.305	0.653
Kleibergen F-stat	16.188	16.188	16.081	16.275	11.064
Observations	322197	322197	167119	155078	489879

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates are reported. All regressions control for age fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. Var.: Cols. 1, 3-4, work (=1), Col. 2, work in family agriculture, Col. 5, fraction of children born to woman i who died. Sample: Cols. 1-2, children 10-14; Col. 3, boys 10-14; Col. 4, girls 10-14; Col.5, women aged 15-49 with 1 or more children born alive. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B18: Effect of oil palm on infrastructure, contraception

	(1) Kindergarten	(2) Primary school	(3) Junior high school	(4) Asphalt road	(5) Electricity	(6) Hospital	(7) Maternity facility	(8) Use of contraception
Smallholder OP area (fraction of regency area)	2.515** (1.156)	0.923* (0.554)	0.080 (1.035)	-1.178 (0.932)	-1.436* (0.849)	0.288 (0.175)	-0.331 (1.262)	0.723 (0.534)
F-stat	1.672	2.325	8.623	1.942	19.987	1.110	2.577	1.140
Kleibergen F-stat	27.199	27.199	27.199	27.199	27.199	27.199	27.199	15.789
Observations	415	415	415	415	415	415	415	725678

Sources: Cols. 1-7, PODES 1996, 2006, 2014; Col. 8, SUSENAS 1996, 2001, 2006, 2011, 2016.

Notes: IV estimates are reported. All regressions control for regency and year fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. var.: Cols. 1-7, fraction of villages with respective infrastructure (0-1); Col. 8, use of contraception (=1). Sample: Cols. 1-7, regencies; Col. 8, women aged 15-49. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B19: Effect of oil palm on female empowerment

	(1) Fertility gap	(2) Autonomy	(3) Control over income	(4) Share of food expenditures in total expenditures
Smallholder OP area (fraction of regency/province area)	1.135* (0.621)	-0.107 (0.104)	-0.004 (0.089)	-0.294 (0.239)
F-stat	3.337	1.064	0.002	615.031
Kleibergen F-stat				18.122
Observations	53345	125651	202109	409108

Sources: Cols. 1-3, DHS 1991, 1994, 1997, 2002-03, 2007, 2012, 2017; Col. 4, SUSENAS 1996, 2006, 2016.

Notes: OLS estimates reported in Cols. 1-3, and IV estimates reported in Col. 4. Cols. 1-3 control for province and year fixed effects. Col. 4 controls for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Variable definitions are available in Table B3. Sample: Col. 1, ever married women aged 40-49; Cols. 2-3, ever married women aged 15-49; Col. 4, households. Standard errors (clustered at province level in Cols. 1-3 and at regency level in Col. 4) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B20: Effect of oil palm on migration, fertility by migration background

	(1) Migrated in last 5- years to regency	(2) Ever migrated to regency	(3) Fertility (non-migrant women)	(4) Fertility (migrant women)
Smallholder OP area (fraction of regency area)	-2.587** (0.997)	-0.272 (0.272)	-6.129** (2.896)	-2.591 (3.026)
F-stat	6.235	3.091	6.762	1.346
Kleibergen F-stat	9.391	9.376	8.502	8.726
Observations	4537533	4526758	1890143	366628

Sources: SUPAS 1995, population census 2010.

Notes: IV estimates are reported. All regressions control for five-year age-group fixed effects, regency fixed effects, region-by-year fixed effects, and initial values of regency-average fertility, electrification, female labor force participation and male agricultural wages times year. Dep. Var.: Cols. 1-2, migration status; Cols. 3-4, number of children ever born alive. Sample: Cols. 1-2, women and men aged 15-49; Col. 3, women aged 15-49 not migrated; Col. 4, women aged 15-49 migrated. Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.