Why does a labor-saving technology decrease fertility rates?
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Evidence from the oil palm boom in Indonesia

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EFForTS discussion paper series Nr. 22

Kubitza, Christoph ; Gehrke, Esther : Why does a labor-saving technology decrease fertility rates? : Evidence from the oil palm boom in Indonesia
Göttingen : GOEDOC, Dokumenten- und Publikationsserver der Georg-August-Universität, 2018
(EFForTS discussion paper series 22)

Verfügbar:
PURL: http://resolver.sub.uni-goettingen.de/purl/?webdoc-3983

Bibliographische Information der Deutschen Nationalbibliothek

Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliographie; detaillierte bibliographische Daten sind im Internet über <http://dnb.dnb.de> abrufbar.

Erschienen in der Reihe
EFForTS discussion paper series

ISSN: 2197-6244

Herausgeber der Reihe
SFB 990 EFForTS, Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems (Sumatra, Indonesien) - Ökologische und sozioökonomische Funktionen tropischer Tieflandregenwald-Transformationssysteme (Sumatra, Indonesien)

Georg-August-Universität Göttingen
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May 2018

Funded by the German Research Foundation (DFG) through the SFB 990
"EFForTS, Ecological and Socioeconomic Functions of Tropical Lowland
Rainforest Transformation Systems (Sumatra, Indonesia)"

https://www.uni-goettingen.de/de/about+us/413417.html

SFB 990, University of Goettingen
Untere Karspüle 2, D-37073 Goettingen, Germany

ISSN: 2197-6244

Why does a labor-saving technology decrease fertility rates? Evidence from the oil palm boom in Indonesia*

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*We thank the Matin Qaim, Krisztina Kis-Katos, Jean-Marie Baland, Jean-Philippe Platteau, Catherine Guirkinger, as well as seminar participants in Goettingen and Namur for their helpful comments. We also thank Robert Sparrow, Michael Grimm and Krisztina Kis-Katos for sharing their data. Christoph Kubitza acknowledges financial support from Deutsche Forschungsgemeinschaft (DFG) as part of the Collaborative Research Center (CRC 990): Ecological and Socioeconomic Functions of Tropical Lowland Rainforest Transformation Systems (Sumatra, Indonesia).

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1 Introduction

There are many good reasons why reducing fertility is important. At the individual level, the health burden for women (including the risk of dying in childbed) as well as their socio-economic wellbeing are directly associated with fertility declines (Chen et al. 1974; Campbell & Graham 2006; Miller 2010). At the macroeconomic level, low fertility rates are often associated with higher incomes, and more generally with higher and more sustained economic growth (Barro 1991; Lee & Mason, Andrew 2006). Globally, population growth has been identified as an important factor contributing to environmental degradation and global warming (Bongaarts 1992; Dietz & Rosa 1997; York et al. 2003; Luck 2007).

Different theories exist about what triggers decreasing fertility rates. Technological change is generally seen as one key driver of the historical fertility transition in the US and Europe (Galor & Weil 2000; Guinnane 2011).[1] Galor & Weil (2000) argue in their theoretical model that technological change increases returns to education which leads to a substitution away from child quantity to child quality, building on Becker's quantity-quality model (Becker & Lewis 1973; Becker 1981).[2] Other theoretical arguments for the linkage between technological change and fertility reductions are increasing maternal opportunity costs of time due to rising wages and work opportunities (Brown & Guinnane 2002), decreasing compatibility of work and child rearing (Rindfuss & Brewster 1996), and the diminishing value of child labor (Doepke 2004). Only few papers have studied possible transmission mechanisms empirically. For the fertility transition in the US, Wanamaker (2012) argues that industrialization led to fertility reductions in South Carolina between 1880 and 1900 due to increasing maternal opportunity costs of time and a separation of migrant households from

[1] Clearly, technological progress is not the only explanation for the observed demographic transition. Other prominent reasons are: declining child mortality, innovations in contraceptive methods, increases in the direct costs of children, increases in the opportunity costs of child bearing, reductions of the cost of child quality, and the expansion of social insurance. See Guinnane (2011) for a detailed review.

[2] The linkage between increasing returns to education and decreasing fertility was mostly backed up by empirical findings (Bleakley & Lange 2009; Becker et al. 2010; Fernihough 2017), although the results are not unambiguous (Black et al. 2005).

their extended family network. Ager et al. (2017) show for the American South in the same time period that households switching to manufacturing face higher opportunity costs of raising children. Their results also suggest that rising returns to education and diminishing returns to child labor led parents to invest rather in child quality than child quantity.

For developing countries, empirical evidence on the relationship between technology and fertility is largely inexistent. For one, employment is still largely dominated by agriculture, and attempts to trigger industrialization processes often failed, limiting potential effects on fertility. Moreover, new technologies such as mechanization in agriculture are often concentrated on large farms, restricting direct income effects to a rather small elite. Consequently, only few studies have looked at the relationship between mechanization and fertility in low-income settings, or at the mechanisms underlying this relationship. Rosenzweig and Evenson (1977) and Levy (1985) are notable exceptions. However, these two studies concentrate entirely on changes in the demand for child labor and its effects on fertility.

This paper explores the effect of a different technology - the expansion of oil palm in Indonesia.[3] We argue that oil palm is rather unique since it is - similarly to mechanization - labor-saving compared to alternative crops in the region, and can free up substantial amounts of labor from agriculture (Rist et al. 2010; Euler et al. 2017). Moreover, it affects not only large-scale farms but also smallholder farmers. Unlike factor-neutral technologies that only raise productivity and thus income, we hypothesize that the labor savings induced by the expansion of oil palm play an important role in determining fertility decisions. Our research question is therefore if and through which mechanisms a labor saving technology such as oil palm affects fertility decisions in a developing country context.

[3] Although oil palm identifies as a technology only in a wider sense, we use this term to emphasize the changes in factor productivity and its comparability with mechanization.

We use Becker's quantity-quality model (henceforth Q-Q model) to identify different causal mechanism through which the expansion of oil palm could affect fertility rates. Our conceptual framework highlights five main mechanisms. The first mechanism is an income effect. While increases in income could generally increase the demand for children, it is generally assumed that the income elasticity of child quality is greater than the income elasticity of child quantity, thereby reducing fertility via a substitution effect. The second mechanism is an effect on the price of child quantity via a reduction in child labor. The third mechanism is also related to the price of child quantity: we expect the expansion of oil palm to affect maternal opportunity costs of time. The fourth and fifth mechanisms relate to the price of child quality: returns to education could rise, and infrastructure development could reduce the price of investing in child quality. We also discuss three alternative mechanisms that are not in line with the Q-Q model: female empowerment, migration patterns, and child mortality.

In our empirical analysis, we focus on the oil palm expansion in Indonesia since the mid-1990s. and explore a large set of different data sources. We use the National Socioeconomic Survey (SUSENAS) to assess changes in fertility, measured as the total number of children born per woman. Changes in wages, labor supply and sector of work are observed in the Indonesian Labor Force Survey (SAKERNAS). For the oil palm expansion, we rely on administrative data gathered 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 2017). To complement this data source, we use land-use data from the Village Potential Statistics (PODES), which was collected in 1993 and 2003. Finally, we use Census data, the Demographic and Health Survey (DHS), as well as different administrative data sources to explore a number of causal mechanisms.

Our identification strategy builds on the fact that agro-ecological characteristics affect a regency's suitability for oil palm cultivation.[4] Similarly to Duflo & Pande (2007), we exploit two sources of variation in a fixed effects instrumental variables (IV) approach: First, we explore differences across space in terms of the maximum agro-climatically attainable yield for oil palm from the Global Agro-Ecological Zones (GAEZ) data. Second, we explore 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 oil palm. 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.

Using this instrumental variables approach, we find consistently negative effects of the oil palm expansion on fertility. These results are robust to controlling for island-year fixed effects and differential time trends between regencies with different initial characteristics, such as fertility, share of agricultural employment in total employment, agricultural wages and electrification. The results are also robust to using different measures for the oil palm expansion and for fertility, to using different time periods, and to using a number of alternative specifications.

Our results on the different transmission mechanisms suggest that the bulk of the negative effect can be explained by an income effect at the household level, as well as by the local economic development that was induced by the oil palm expansion. Oil palm expansion increased income at the household level, which induced a substitution away from child quantity to child quality. The income growth also triggered broader local economic development, leading to a growing non-agricultural sector and increasing returns to education.

[4] In Indonesia provinces are the highest tier of the local government. At the next level provinces are divided into regencies (kabupaten) and city districts (kotas). Since the decentralization in 2001, regencies (and city districts) are mainly responsible for providing public services.

This induced parents to substitute child quantity for child quality, as well as women to invest more into their own education, thus reducing their fertility. We conclude that labor saving technologies in agriculture can reduce (rather than increase) fertility as long as income gains are shared by the majority of the population and high enough to trigger local economic development.

Our results contribute to two different strands of literature. We add to the literature on the role of technology in determining fertility choices (Rosenzweig & Evenson 1977; Levy 1985; Wanamaker 2012; Ager et al. 2017) by showing the impact and transmission mechanisms of a labor-saving agricultural technology, which unlike mechanization is also rapidly adopted by smallholder farmers. [5] We also contribute to the growing literature on the effects of oil palm in Indonesia. Previous research has documented negative environmental effects such as a drastic loss of biodiversity (Wilcove & Koh 2010; Clough et al. 2016), reduction of water resources (Merten et al. 2016) 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. 2017a; Edwards 2017). 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 to test our hypotheses. Our estimation strategy is presented in Section 5. Section 6 reports main results as well as several

[5] Our research differs substantially from research using an exogenous shock on for example price of child quality (Bleakley & Lange 2009; Becker et al. 2010) or quantity (Black et al. 2005) to confirm model predictions, since we focus on a technology with a wide range of potential effects. To test these effects a broad set of data is necessary. The data demands might also explain why this literature is rather limited, yet.

robustness checks and an analysis of the transmission mechanisms. Conclusions are presented in Section 7.

2 Background: Oil palm in Indonesia

Global palm oil production rose steeply by 300% between 1990 and 2010 with Indonesia emerging as the world's largest producer around 2009 (Byerlee et al. 2017). Although oil palm has been cultivated in Indonesia since the 1930s (Verheye 2010), the expansion only accelerated in the 1970s with the central government supporting the establishment of large-scale plantations in the outer islands. In so-called Nucleus Estate and Smallholder (NES) schemes, large estates surrounded by smallholder plantations were built up, tying the smallholder farmers via contract farming to the estates. In sparsely populated regions, laborers and farmers were often recruited from the central islands such as Java. With the decentralization process starting in 1998, market liberalizations 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). Although large private estates still dominate oil palm cultivation in Indonesia, smallholders cultivated roughly 40% of the total oil palm area in the country in 2016 (see Figure S1 in the Appendix).

Positive welfare gains of oil palm have been documented for smallholders by Euler et al. (2017) and Rist et al. (2010). These welfare gains seem to be driven by the low labor intensity of oil palm compared to alternative crops such as rubber and rice, which allows for farm expansion and additional off-farm work.[6] In order to provide more detailed evidence on the factor productivity of oil palm compared to other crops, we explore farm household data

[6] At the national level, PODES data suggests that rubber and rice are the main alternatives to oil palm cultivation. In 53% of the villages where oil palm was the first or second most important plantation crop in 1993, rubber was either the first or second most important crop. In 63% of the oil palm villages, rice was also mentioned as important food crop. More recent data from Sumatra also shows that oil palm is increasingly replacing rubber as the dominant plantation crop, and to a lesser extent rice (Feintrenie et al. 2010; Gatto et al. 2015; Euler et al. 2016). Evidence from Kalimantan also suggests that oil palm mainly replaced labor-intensive crops such as rubber and rattan (Belcher et al. 2004).

collected in Jambi province (Sumatra) in 2012 and 2015.[7] The data contains detailed plot input and output information for farmers involved in the cultivation of oil palm and rubber.[8] In addition, we cite evidence from the literature concerning rice cultivation.

Plot level estimates in Table 1 show that labor productivity per hour is significantly higher in oil palm compared to rubber. This is also reflected in higher wages paid in both activities: wages are higher for men in oil palm than in rubber cultivation. However, the difference in wages is smaller for women and not significant. The finding that labor productivity is higher in oil palm relative to rubber is generally confirmed in the literature (Rist et al. 2010; Euler et al. 2017). The labor productivity gap between oil palm and rice is even larger with 47.33 to 2.27 $ per men's labor day (Rist et al. 2010). In contrast, land productivity of oil palm is lower than in rubber cultivation. This is not true in comparison to rice: Rist et al. (2010) report a significantly lower land productivity for inundated rice compared to rubber and oil palm (2846.36$ per ha for oil palm and 264.61$ per ha for rice). Switching from a food crop such as rice to a cash crop thus increases welfare by raising labor (and partly land) productivity.

Our data also suggests that the gains in labor productivity largely translate into a reduction of labor inputs. As can be seen in Table 1, labor hours per hectare of women and men are substantially lower in the cultivation of oil palm than in the cultivation of rubber. Male labor hours are by 72% lower in oil palm compared to rubber. Female labor hours are even by 92% lower. The low labor input in oil palm in particular for women was also reported 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 is mainly done by men. Women are mainly involved in the collection of loose oil

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

[8] A multi-stage sampling framework was used to obtain a representative sample of 700 local farm households in 45 villages in the tropical lowlands of Jambi. For more details on the sampling framework, see Krishna et al. 2017b.

palm fruits and maintenance work (Koczberski 2007; Li 2015). Typically, food crops such as rice also involve comparably more female labor than cash crop cultivation, and rice cultivation in Indonesia is no exception. Rice has a low labor productivity in general, and there is no evidence that female labor is more or less productive than male labor in rice cultivation (Feintrenie et al. 2010; Li 2015).

While welfare gains from oil palm cultivation among smallholder farmers seem to be driven by increases in labor productivity, expansion of farm land and the reallocation of working hours towards other sectors, these effects are expected to look quite differently for wage workers. The majority of palm oil is still produced by large private estates, which rely entirely on wage work, and also farm households employ significant amounts of wage labor (Euler et al. 2017). The wage labor is partly drawn from migrants, but evidence from Kalimantan suggests that local population groups that lack the financial means to establish their own plantations are also employed (Li 2015). Higher labor productivity in oil palm cultivation could increase wages. However, if land is scarce, the demand for agricultural labor might decrease and thus also decrease wages, or limit welfare gains to a very small group of farm workers. While the welfare effect of the oil palm expansion for wage workers is found to be positive on average (Edwards 2017), this might mask substantial regional heterogeneity.

In addition to the welfare gains documented above, one important aspect of oil palm that might drive broader economic development is the need to process fresh oil palm fruit bunches shortly after harvest in palm oil mills. This necessitates improved road infrastructure in order to quickly transport the fresh fruit bunches from the producer to the mill, and reliable access to electricity to run palm-oil mills. Finally, some high-skilled labor is needed to operate the mills (Edwards 2017). In general, welfare gains and infrastructure development might have contributed to broader local economic development through increased consumer demand and reduced costs in transportation and production, thereby increasing wages and creating job opportunities outside the oil palm sector.

3 Conceptual framework

The previous Section highlighted a range of mechanisms through which oil palm could raise household welfare. This Section builds on the Q-Q model developed in Becker and Lewis (1973) to derive testable predictions of the effect of the oil palm expansion on fertility. In particular, we seek to highlight the mechanisms through which this effect might be operating. Possible extensions of the Q-Q model are discussed in Section 3.2.

3.1 A simple model on oil palm expansion and demand for children

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

$$p_n n + p_q q + p_c nq + \pi_Z Z = I \qquad (1)$$

In this budget constraint, I is the full income of the household. p_n is the cost of having one additional child, thus the opportunity cost of time of pregnancy and individual child rearing, and all other monetary costs of having children that are largely independent of child quality. The net cost of having children p_n falls if children contribute to farm income, and falls with increasing costs of avoiding pregnancies. p_q is the cost of child quality which is independent of number of children, such as reusable school books and clothing, or accessing information on the school system. p_c is the cost of augmenting the quality of any child, such as school fees, and the respective price of other commodities is π_Z.

We now consider how the adoption of a new agricultural technology, such as oil palm, affects the demand for children. We assume that the crop is adopted because it increases farm income and do not model the agricultural production function explicitly. Furthermore, we assume that the positive income effect dominates in all population segments. Given the effects on labor productivity, income and infrastructure development cited above, we expect oil palm to affect fertility mainly through five mechanisms, which will be discussed in the following.

Income. If oil palm raises farm income and potentially also income from agricultural employment, households can invest this additional income in increasing the number of children, in increasing child quality or both. The number of children could hence decrease or increase. However, following Becker and Lewis (1973), we assume that the income elasticity of child quality is higher than the income elasticity of child quantity. Because increasing the quality of each child affects the shadow price of child quantity through the interaction term between quality and quantity, even a small increase in q could have a large and negative effect on n.[9] This is why we generally expect the income effect on child quantity to be negative.

Child labor. A price effect of child quantity might stem from differences in the returns to child labor between oil palm and alternative crops. In many countries children generate income through family work or wage work, thereby offsetting some of their direct costs such as clothing and food. 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 and cutting of oil palm necessitates too much physical strength to involve child labor. Rubber and rice cultivation, in contrast, involve more family labor and theoretically also more child labor. We therefore expect that oil palm would rather decrease the returns to child labor.[10] If returns to child labor fall, this increases the cost of child quantity p_n, thereby reducing the demand for children.

Maternal opportunity costs of time. The price of child quantity also shifts with changing maternal opportunity costs of time. As noted in the previous Section, oil palm cultivation is less labor intensive, and employs considerably less women than alternative crops. If female

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

[10] 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.

shadow wages in agriculture fall, women could either stop working or shift to other sectors. However, as the oil palm expansion might go hand-in-hand with income growth and local economic development, wages for women in other sectors than agriculture could even increase, thus drawing more women into the labor force and out of agriculture. This provides two possible scenarios: If female labor is not sufficiently demanded, we would expect that female labor force participation and female wages decrease. This implies a reduction of p_n and *ceteris paribus* an increase in the demand for children. In the second scenario, the income gains in the agricultural sector spur broader economic development and while women still leave the agricultural sector, they now enter an increasingly more profitable non-agricultural sector. Then, we would expect p_n to increase due to higher wages, and women reallocating their time from child rearing to income earning activities. If the non-agricultural sector is less suitable to combine child rearing and income generation due to the distance between dwelling and workplace or less amenable working environment, we would expect additional increases in the opportunity costs of time, and fertility reductions. Also, if local economic development creates more jobs in the high education sector, then the wage gap between low education and high education jobs might widen and returns to education increase. This might again affect maternal opportunity costs of time and thus the price of child quantity p_n, as we would expect that women reallocate their time away from child rearing to schooling.

Returns to children's education. Not only the price of child quantity, also the price of quality is expected to change with the oil palm expansion. Building on the second scenario mentioned above, we assume that higher returns to education not only increase maternal opportunity costs of time, but also the returns to children's education. Investing into children's education is likely to pay off more if profitable jobs in the high education sector exist. If returns to education increase, parents are more likely to substitute away from child quantity to quality, thus decreasing their demand for children.

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

3.2 Alternative explanations

While the Q-Q model highlights a range of important mechanisms, it imposes a set of assumptions which might not necessarily be true. For one, the assumption of a unitary household has been subject to a lot of debate recently. Furthermore, fertility might respond more strongly to social preferences rather than household choice. In the following, we will discuss three potential alternative explanations, which seem particularly relevant in the context of oil palm cultivation: Migration, child mortality and female empowerment.

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 the decreasing likelihood of marriage. In the long run both these factors might be less important and childbearing patterns might depend more on the question if there was a selection of migrants by fertility preference and if migrants' fertility preferences differed from the local population (Kulu 2005).

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

Female empowerment. A substantial body of literature suggests that female bargaining power within the household increases as women earn their own income (Atkin 2009; Heath & Mobarak 2015). If women have *per se* lower fertility preferences than men, a reduction in fertility could stem from the fact that women leave the agricultural sector (and on-farm work) and start earning their own income over which they have higher control than farm income. The fertility reduction would then simply reflect the increased bargaining weight of women within the household that is associated with the oil palm expansion.

4 Data

We combine different datasets to assess the effect of the oil palm expansion on fertility and to analyze the underlying mechanisms. We merge all datasets at the regency level using 1993 boundaries. This was necessary due to Indonesia's decentralization process, which involved a continuous division of regencies over the past 20 years. A detailed list of all data sources can be found in Table S1 in the Appendix. Table 2 presents summary statistics.[11]

Administrative data on the oil palm expansion at regency level is available since 1996. The Tree Crop Statistics are published annually by the Indonesian government (Ministry of

[11] Additional summary statistics are reported in Table S2 in the Appendix.

Agriculture 2017), and can be accessed through the Indonesia Database for Policy and Economic Research (INDO-DAPOER) which is maintained by the World Bank (World Bank 2018a).[12] The data provides information on the area under oil palm cultivation, and distinguishes between four producer categories, smallholder, government estate, national private estate, and foreign private estate. However, time series at regency level dating back to the 1990s are only available for smallholder producers, and not for private or government estates. As can be seen in Figure S1 in the Appendix, the expansion of oil palm over time in the smallholder sector is fairly parallel to the expansion in the private estates. Government estates are less important. Also, the expansion of the large-scale plantation sector and the smallholder sector are likely to correlate regionally, since the smallholder sector depends on access to palm oil mills which are often established within the large-scale plantations (Euler et al. 2016). Figure 1 illustrates the expansion of smallholder oil palm area on the different islands of Indonesia. It shows a strong concentration of oil palm on Sumatra, but also the growing importance of Kalimantan and to some extent of Sulawesi.

The PODES – Indonesia's village census – provides the earliest data on oil palm expansion that is nationally representative and can be disaggregated by regency. The PODES data covers all villages and urban neighborhoods in Indonesia. It collects information on village-level land use in the years 1993 and 2003. Based on this information, we calculate the share of villages within a regency that cultivate oil palm. We use this variable for additional robustness checks. The PODES dataset also provides additional controls such as the share of villages with schools, hospitals and asphalt roads within a regency, as well as the share of households with access to the public electricity grid.

[12] We update the database with more recent data from the Tree Crop Statistics to complete the time series until 2015. We do not have consistent data for oil palm expansion on regency level for 2016 and thus use 2015 data if necessary.

We use Indonesia's socio-economic survey (SUSENAS) to construct individual fertility.[13] The SUSENAS collects demographic and socioeconomic characteristics of individuals in annually repeated cross sections. Since 1993 the sample size increased to more than 200.000 households from formerly around 65.000, being representative at the regency-level. The SUSENAS provides information on the number of all ever occurred live births per woman, including all women older than 10 years. We use this variable as our measure of fertility, and restrict the sample to women aged 15 to 49. Our 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 based on current age-specific fertility rates, assuming constant age-specific fertility rates over time and no premature deaths of women. Our measure of fertility, in contrast, has no reference period and is therefore sensitive to fertility changes that already happened in the past. These differences are also reflected in differential time trends: Between 1996 and 2016, fertility decreased from 2.11 to 1.70 children born per woman in Indonesia, while the TFR only fell from 2.6 to 2.4 in the same time period (World Bank 2018c). Figure 2 presents the fertility trends based on SUSENAS for different islands in Indonesia.[14] The figure shows that the fertility rate decreased until 2005, stagnating in some islands in subsequent years. Additional variables derived from SUSENAS are age, age at marriage, education, consumption expenditure, labor supply, and type of work.[15]

We use the National Labor Force Survey (SAKERNAS) to capture labor market characteristics of working age individuals. The SAKERNAS provides information on labor supply, the sector of activity, as well as on wages of men and women in different sectors. The

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

[14] Although we speak of islands, these are the main islands of Sumatra, Kalimantan, Java and Bali and Sulawesi, including their adjacent islands. All islands which do not belong to these regions are included in the fifth category "other islands".

[15] We deflate all monetary values to 1996 values using the province-level poverty lines for rural and urban regions.

SAKERNAS has 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 controls since 1996, and to test for the effects of oil palm on labor market outcomes at regency level in the time period 2001 to 2015.

Additional control variables are derived from the Demographic and Health Surveys (DHS), the Census, as well as from different administrative data sources. We use the DHS to control for child mortality, which is defined as the number of child deaths between the ages of one to five years per 1000 live births. Furthermore, we use the DHS to estimate the effect of the oil palm expansion on current fertility, in addition to the total number of live births per woman. Finally, the DHS provides a number of interesting outcomes that proxy for female bargaining power, such as the difference between actual and desired fertility, her influence on household and personal decisions, and her control over her own income. Since neither SAKERNAS nor SUSENAS provide detailed information on internal migration, we use data from the Indonesian Census to calculate the share of individuals who ever migrated as well as the share of individuals who migrated in last 5 years at the regency level.[16] Administrative data, such as poverty lines, are retrieved from Badan Pusat Statistik (BPS), and public revenue data are retrieved from the Ministry of Finance, Information System for Sub-National Budget. We also calculate average altitude at regency level from the NASA Shuttle Radar Topographic Mission (SRTM) digital elevation data.[17]

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 for different crops under specific levels of inputs and management conditions. It uses information on agro-climatic conditions to predict attainable yield based on agronomic models in grid cells of 5 arc-minute and 30 arc-second (approximately 10x10km) resolution

[16] We use the subsample of the census from the IPUMS database.
[17] Country-specific data can be downloaded from http://www.diva-gis.org/gdata.

(Fischer et al. 2012). We use the maximum attainable yield of palm oil under rain-fed conditions and low-input management for the average climate in the baseline period 1961-1990. The low-input level was chosen since its predictions yield the highest correlation with 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). Low-input levels may be not adequate by definition since fertilizer use is common in oil palm cultivation, however, the usage may not be optimal, especially in the case of smallholder farming. The GAEZ data is used to calculate the average attainable yield of oil palm within a regency by aggregating the pixel values within 1993 regency boundaries. Figure 3 illustrates our calculations.

5 Estimation strategy

Eliciting a causal effect of oil palm expansion on fertility involves two major challenges: First, we cannot observe a lot of regency characteristics such as cultural and political traits, as well as time variant macro shocks such as the transmigrant program, which may correlate with the proliferation of oil palm as well as the fertility transition.[18] Second, reverse causality, such as high or low population growth which may induce oil palm expansion, could be driving our results.

We therefore use an instrumental variables approach combined with regency-fixed effects to identify causal effects. Our instrument combines time-invariant agro-climatic suitability for oil palm with the national expansion of oil palm, and is inspired by Duflo & Pande (2007). We interact the suitability of oil palm at regency level with the annual expansion of oil palm at national level. We assume that national expansion is driven by world market prices and policies of the central government and is not affected by idiosyncratic regional developments which could be correlated with both fertility and oil palm expansion.

[18] The importance of cultural and linguistic boundaries for fertility patterns is shown *inter alia* by Munshi & Myaux (2006) and Cleland & Wilson (1987).

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 delivers an instrument which highly correlates with the actual expansion, since next to access to land and transport costs agro-ecological suitability is a major determinant of 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.

A couple of possible threats to identification remain. The first is that other crops have similar agro-ecological requirements as oil palm and have a similar expansion patterns over time. This would imply that our instrument captures very different levels of initial agricultural and probably also economic activity, which also suggests different trends in fertility outcomes. A second 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. It seems fairly plausible that differences in initial levels in development and fertility also imply differential trends of fertility reduction. In order to address these concerns, we allow time trends between regencies to vary based on initial values of fertility, electrification, share of agricultural employment in total employment, and agricultural wages.[19] Our results are not affected by the inclusion of these controls. A third caveat in our identification strategy could be the high regional concentration in the oil palm expansion. As depicted in Figure 1, the oil palm expansion started in Sumatra, and spread only later to Sulawesi and Kalimantan. The fact that these regions also had very different initial levels of fertility could indicate cultural and regional differences in underlying preferences towards children, and consequently very different trends in fertility declines absent the oil palm expansion. Also higher initial fertility could lead to a more rapid decline in

[19] We do not control for differential trends based on attainable yield, since the oil palm expansion is fairly linear through time and the regression would suffer from high collinearity. We also control for differential trends based on altitude as a robustness check and our results are robust to this control.

subsequent years, when regions start to catch up with the development of the central regions, introducing a spurious negative correlation. It is thus not unlikely that these islands were on different fertility trends, or that regional shocks affected both the oil palm expansion as well as fertility. Therefore, we control for island-year fixed effects in all our estimations.

Our first stage is then:

$$OP_{jst} = \alpha_o + \alpha_1(AY_{js} * OPA_t) + \alpha_2 X_{ijst} + \alpha_3 (M_{js} * y_t) + y_t + \gamma_{st} + \mu_j + \omega_{ijst}, \quad (2)$$

where OP_{jst} is the share of smallholder oil palm area in regency j, island s and time t. AY_{js} is the attainable yield of oil palm in regency j and OPA_t is the oil palm area in hectare at national level in year t. X_{ijst} is a vector of individual controls, such as a woman's age. M_{js} are initial characteristics, such as regency-average fertility, share of workers in agriculture, share of households with access to electricity, and province-average agricultural wages. These initial characteristics are multiplied with a time trend y_t. We also control for year fixed effects y_t, island-year fixed effects γ_{st} and regency fixed effects μ_j.

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

$$FR_{ijst} = \beta_o + \beta_1 \widehat{OP}_{jst} + \beta_2 X_{ijst} + \beta_3 (M_{js} * y_t) + y_t + \gamma_{st} + \mu_j + \varepsilon_{ijst}, \quad (3)$$

where FR_{ijst} is the number of children born to each woman aged 15 to 49 in regency j, island s and year t. All remaining variables are defined as in equation (2), and ε_{ijst} is an individual error term. We use household survey weights in all our estimations and cluster standard errors at regency level.

Despite having annual data on the oil palm expansion from administrative sources, we use a long-differences approach, and concentrate on the changes in oil palm cultivation and fertility over 10-year periods (1996, 2006 and 2016). This is because we expect the effect of oil palm on fertility to work through different mechanisms, which materialize over different time periods, and which might feed back into each other. By using 10-year differences we hope to account for the full impact on fertility.[20]

In order to test for the relative importance of different causal mechanisms, we employ a mediating analysis. That is, we first test if the oil palm expansion has a significant effect of the mediating variable of interest (i.e. consumption), and then test if controlling for this variable in equation (3) affects the point estimate on the share of oil palm area.

6 Results

6.1 Effect of oil palm expansion on fertility

In Table 3 we present our main results for equation (3). In column (1) we use ordinary least squares (OLS) with regency and time fixed effects. Column (2) additionally includes island-year fixed effects and initial level of fertility, electrification, share of agricultural labor in total employment, and wages in agriculture multiplied with a time trend. In columns (3) to (6) we use the instrumental variables approach described in Section 5. To assess the robustness of our findings, we subsequently add different controls. We add island-year fixed effects in column (4). In column (5) we then additionally control for differential time trends based on initial levels of fertility, electrification, share of agricultural employment, and agricultural wages. In column (6) we add a woman's age to the controls. The age control is included because the age structure in a regency strongly determines fertility and it is not unlikely that regencies with different age structure are on different fertility trends.

The results show a consistently negative effect of the oil palm expansion on fertility. The effect is always statistically significant in the instrumental variables estimations. Column (6) is the preferred specification, as it presents the most conservative estimates that allow for differential fertility shocks between islands, and between regencies with different levels of initial fertility and economic development.

[20] We test for the importance of time-lags as additional robustness check.

Between 1996 and 2016 the average share of oil palm area at regency level increased from 0.26% to 1.57%. This would lead to a decrease of 0.088 children born per woman over a period of 20 years. Between 1996 and 2016 fertility decreased from 2.133 to 1.63 in our sample, the oil palm expansion could hence explain up to 17% of the observed fertility reduction.

The estimated effect size is increasing significantly when moving from OLS to our instrumental variables approach. This could indicate a weak instrument problem; however, our first-stage Kleibergen-Paap rk Wald F-statistic suggests that our instrument is reasonably strong in most regressions ranging between 8.192 and 15.352. 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. We thus show an effect for regencies where oil palm was planted because of favorable agro-ecological conditions and not for example because of policy regulations. Plantations in favorable agro-ecological conditions are likely to have higher returns, leading to higher income effects, and potentially stronger fertility reductions. We caution hence that our estimates present an upper bound to the average treatment effect. Second, the IV approach might have corrected endogeneity biases. Oil palm plantations which were incentivized by government policies rather than agro-ecological suitability have been targeting regions with low population density and poor economic development in order to pursue the national development agenda, filling the demand for labor with migrants from densely populated islands (Gatto et al. 2017). Migrants from densely populated regions could have had lower fertility preferences, which could have reduced the initial level of fertility and possibly the subsequent decrease. This could explain an upward bias in OLS. Lastly, administrative data on the expansion of oil palm could involve significant measurement error, while the suitability index is based on agro-climatic, soil and terrain conditions which may be more precisely measured. Thus, our IV approach may correct measurement errors, which induce an attenuation bias in our OLS estimates.

We do not expect effects to be uniform across the population. Figure 3 reports the result disaggregated by age groups based on the specification in column (6) in Table 3. The figure shows that the negative effect is only statistically significant in the age groups between 25 and 39, peaking for the age-group 30 to 34. The apparent zero effect for younger age groups is likely to be driven by our long-difference estimation strategy, combined with a relatively static fertility measure. The 25 to 29 age cohort, for which we observe a significant effect, was only 15 to 19 years old 10 years earlier. The negative fertility effect of oil palm could have hence taken place anywhere between the age of 15 to 29. The insignificant effect for older women is in line with our expectations.

6.2 Robustness checks

We conduct several additional checks to gauge the robustness of our findings. First of all, we use the PODES dataset to measure oil palm expansion at the village level. Unfortunately this information is only available in 1993 and 2003. We replicate the specifications used in Table 3 with the new variable on oil palm expansion in Table S3 in the Appendix. The results show a consistent negative and significant effect of oil palm expansion on fertility, confirming our previous results.

In the next step, we test in the 1996 to 2016 sample if our results are sensitive to our choice of specification. Results are reported in the Appendix, Table S4. First, we run the same regression without survey weights. The change in effect size is negligible, but the Kleibergen F-Statistic increases. Second, we include province-time trends instead of island-year fixed effects. Again, our results remain robust and of the same magnitude, although the first stage F-Statistic decreases. Third, we use attainable yield of oil palm under rain-fed conditions and medium-input management instead of low-input management as cross-sectional component of our instrumental variable. Again, the results are not affected. Fourth, we test if our results are sensitive to excluding Java, Indonesia's main island, from 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. We find in column (4) that the effect remains highly significant and the precision of the first stage increases, since the low levels of oil palm cultivation in Java are not driven by low suitability but little available land. Fifth, we control for each regency's average altitude multiplied by a time trend. As discussed previously, one concern with the validity of our instrument stems from the fact that the attainable yield of oil palm changes with altitude. Since regencies with high altitude are generally more remote, they might also be on different trends of economic development and fertility compared to low-land regencies. If this effect is not picked up by any of our trends, this could possibly bias our results. As can be seen in column (5), the effect size remains stable and significant. Only the Kleibergen F-stat drops to 7.7, which is to be expected given that we substantially reduce the variation in our instrument. Finally, in columns (6) and (7), we compare the effect of oil palm on fertility between producer types. We use the sample of 2005-2011-2016 since we do not have consistent data for total oil palm area before 2005 and no data in 2006. We find that the effect on fertility is lower when using total oil palm area rather than smallholder oil palm area as explanatory variable, but the effect remains statistically significant. One possible explanation could be that the income effect is more pronounced for smallholders compared to agricultural wage laborers. We also show in Table S5 that our results are robust to using 5-year differences rather than 10-year differences.

One weakness of our measure of fertility is that it captures the total number of children born per woman, rather than current fertility. This variable is sensitive to past changes in fertility and, given serial correlation in the expansion of oil palm, might capture changes in fertility that happened some time ago. Moreover, the full effect of oil palm expansion on income might only be realized after some years since oil palm trees are only productive two to three years after being planted. We therefore split our sample by age groups and test if lagging the oil palm expansion by two or five years affects the observed pattern by age group. Results are reported in the Appendix, Figure S2. We find that the effect of oil palm on fertility is now more pronounced for the older cohorts. This is expected since the lagged oil palm expansion is restricted to fertility decisions which occurred at least two or five years ago, limiting the effect on young cohorts.

As additional robustness check, we use fertility data from the DHS to illustrate differences between our fertility variable and current fertility. The DHS data is only representative at the province level, which is why our identification strategy has to rely on controlling for province and time fixed effects. We use DHS data from the years 1997, 2002, 2007 and 2012. Figure S3 in the Appendix reports the results. The figure on the left shows the effect on total fertility (consistent with our fertility measure in SUSENAS), while the figure on the right shows the effect on current fertility. Current fertility is defined as number of births for each woman in the last 12 months, and is the standard measure used to construct the TFR. The figure on the left overlaps 1:1 with our results from SUSENAS, which shows that our results are robust to the use of alternative data and identification strategies. In the figure on the right, we can see that current fertility reductions are driven by two age groups: First, the 20-24 year olds, and, second, women aged 35-44. Younger women may be reducing current fertility because they delay marriage and stay longer in school. Consistently, the observed positive effect on fertility in the 25-29 age group might be a catch-up effect. However, the fact that 35-44 year old women also reduce their current fertility could indicate changing preferences towards very large families. While the DHS data confirms our results, it also indicates that our fertility variable limits the scope for detailed cohort analyses.

6.3 Transmission mechanisms

6.3.1 Income

In Section 2, we cite evidence that the oil palm expansion induced positive income effects. Increasing income would lead to decreasing fertility rates in Becker's Q-Q model. We test this proposition using consumption expenditure per capita as proxy for income, calculated at the household level in the SUSENAS data. Table 4 presents the results. In column (1), we show that oil palm expansion has a significantly positive effect on consumption expenditures. Columns (2) and (3) show that this effect is driven by households whose head is involved in agriculture as his main job. In the subsequent columns, we test if the effect of oil palm expansion on fertility declines when controlling for changes in per capita consumption expenditure. We find in column (4) that the point estimate on oil palm decreases from -6.7 to -4.9 after controlling for household-level consumption expenditure per capita. In columns (4) and (5), we split the sample by the primary occupation of the household head. While the income effect seems to be driven by households who are engaged primarily in agriculture, fertility effects can be observed in both groups. Taken together these results suggest that part of the effect on fertility can be explained by an income effect, but that other mechanisms must be at work, too.

6.3.2 Child labor

As discussed in Section 3, decreasing returns to child labor could increase the price of child quantity. We therefore test if the oil palm expansion is associated with changes in child labor, and if average child labor at the regency level mediates the effect of oil palm on fertility.

Child labor can be calculated only for children between 10 and 14 years.[21] Results are reported in the Appendix, Table S6. In summary, we find no evidence that child labor explains the negative effect of oil palm on fertility. Oil palm does not seem to affect total child labor, nor on-farm or gender-specific child labor. Likewise, controlling for child labor or on-farm child labor does not change the effect of oil palm on fertility. Since schooling and child labor are substitutes in time use, the finding that oil palm does not affect child

[21] We do not have any data on working activities of children below the age of ten.

enrollment in Table S7 gives additional support to our findings. We conclude that changes in child labor are not an important mechanism in explaining the negative effect of oil palm expansion on fertility.

6.3.3 Maternal opportunity costs of time

We argue in our theoretical model that maternal opportunity costs of time might decrease or increase depending on whether the oil palm expansion triggers local economic development and how this affects wages. In the absence of such effects, oil palm may only induce labor savings, which would reduce the opportunity costs of child rearing. We therefore start by estimating the effect of oil palm on wages and labor supply. Columns (1) and (2) of Table 5 show a positive and significant effect of oil palm on wages in the non-agricultural sector, and a negative (albeit not statistically significant) effect of oil palm on women's wages in the agricultural sector in the SAKERNAS dataset from 2001 to 2015.[22]

In Table S8 in the Appendix, we use a set of different control variables to identify the drivers of the increase in non-agricultural wages for women. We find that changes in average consumption expenditures at the regency level as well as government revenues from own sources explain the positive wage effect of the oil palm expansion. In contrast, changes in women's educational attainment or in the sectoral composition of the workforce do not seem to explain the increase in wages. This suggests that local economy effects driven by income growth are primarily responsible for increasing women's non-agricultural wages.

We proceed by testing if increased wages led to higher labor supply. In columns (3) and (4) of Table 5 we show that women do not change their labor supply either at the extensive margin or at the intensive margin. Little surprisingly, controlling for labor supply does also not change the effect of oil palm on fertility, as reported in columns (5) to (7). Interestingly, however, increases in women's wages seem to mediate the effect of oil palm on fertility

[22] The reason for restricting the sample to 2001 is that older SAKERNAS rounds do not contain regency identifiers and the questionnaire is only consistently eliciting all variables starting from 2001.

strongly (columns 8 and 9). And as can be seen by comparing column (9) to Table 4, col. (4), this cannot be explained by an income effect.[23]

In order to analyze how wage increases affect fertility if not via changes in labor supply, we proceed by testing if oil palm affects the sector in which women work (Table 6, cols. 1 and 2). Consistent with the finding of rising non-agricultural wages, we find that women shift out of agriculture, and into the services sector. However, we do not find that controlling for the sector in which a woman works changes the coefficient of oil palm on fertility substantially. Controlling for whether a woman works in agriculture reduces the coefficient on oil palm for working women from -8.1 (Table 5, col. 6) to -7.5 (Table 6, col. 1).[24] Sectoral shifts alone are thus not able to explain the strong mediating effect of women's wages.

To understand what else could drive the relationship between increasing wages and fertility reductions, we regress wages at different educational levels on oil palm in Table 7. Again, we use wage data from SAKERNAS. We find that the oil palm expansion mostly increased wages for more highly educated individuals, in particular for men and women with tertiary education, as shown in column (3) and (6).[25]

Rising returns to education might have induced a reallocation of time away from child rearing to education. In Table 6 columns (3) and (4), we show that the educational attainment of women in the age groups 15-25 and 26-35 increased significantly due to the oil palm expansion. The latter group is included because we work with 10-year differences and therefore this group is also likely to be affected by changes in oil palm expansion. In column

[23] The SAKERNAS 1996 does not provide regency identifiers. We thus control for average province-level wages in columns (8) and (9). We merge SAKERNAS data from 2015 with SUSENAS data from 2016.

[24] The effect of oil palm on labor supply, and sector of work is robust to using SAKERNAS instead of SUSENAS data, see Table S8.

[25] These results do not necessarily imply that there are no income effects for low education households. Although wages are reported individually, wages obtained in family work are not reported and most likely included in the wage reported by the household head. Since women left family work (see Table S9), this might have decreased the contribution of family labor to own farm work and sharecropping and therewith the wage men reported. Multiple jobs are also more likely in the low education sector. By only measuring the wage from the main job, we might also miss the income effects stemming from reallocating working time between jobs.

(6), we add controls for the educational attainment of a woman to the regression of fertility on oil palm. This decreases the point estimate of oil palm on fertility from -6.7 to -5.6.

Taken together, these results indicate that oil palm triggered local economic development, which raised average wages as well as the returns to education. This increased the opportunity costs of child rearing, and women opted to change into the service sector and to invest more time in their education, both of which then led to reductions in fertility.

6.3.4 Returns to children's education

Changes in returns to education also affect the price of child quality, encouraging parents to invest more in the education of their children and to reduce fertility. In Table 8 columns (1) and (2), we regress the educational attainment of boys and girls between the age of 12 and 14 on oil palm.[26] We use the age of 12 as cutoff point since children are unlikely to have finished primary school before the age of 12. We observe a positive effect, which, however, is only significant for girls in column (2). One reason could be that since the educational attainment of girls is in general lower, investing in their education provides higher returns. Although the increase is only small, literature argues that even small shifts in child quality can induce major reductions in child quantity. In column (3), we test if investing in the quality of children explains part of the effect of oil palm on fertility by including the average educational attainment of girls and boys between the age of 12 and 14 in a regency as controls. We restrict the variable to below 14 years in order not to confound the effect on an increase in women's education with that of children. We find that the oil palm effect is decreasing from -6.7 to -5.4. We find similar results when expanding the sample to children aged 12-19 (as reported in Table S11 in the Appendix). In column (4), we add consumption expenditures to control for the income effect, and all controls which are related with increasing maternal opportunity

[26] We also estimate the effect of oil palm on enrollment rates in Table S7 in Appendix, and find no significant effects. The reason could be that enrollment does not necessarily imply effectively attending school or investing time and effort into achieving a higher degree.

costs of time such as labor force participation, working hours, sector dummies and women's educational attainment. We additionally add women's wages in column (5), and find that this only reduces the coefficient oil palm from -3.8 to -2.9, which implies that the major part of the wage effect found in Table 5 column (8) can be explained by an income effect, by changes in returns to education and to limited extent by sectoral shifts.

6.3.5 Infrastructure

The infrastructure effect suggests that the oil palm expansion might reduce the cost of child quality through better infrastructure. We use a wide range of variables as controls for infrastructure such as share of households with access to electricity from the public grid, share of villages with kindergarten, primary school, junior high school, asphalt main road and hospital. Table 9 reports the results in columns (1)-(6). We find a negative effect of oil palm on the share of villages with an asphalt road as main road, which is contrary to our expectations. However, initial oil palm expansion might have involved rather low quality roads and roads might have been asphalted only later with increasing income generation from oil palm. When using a three-year lag of the oil palm expansion, the effect is not statistically significant.[27] Of all infrastructure indicators tested, we only find a positive and significant effect of oil palm for the share of villages with a hospital. We then proceed to testing if controlling for these infrastructure variables mediates the effect of oil palm on fertility in columns (7) to (10).[28] We do not find any evidence that reductions in the price of child quality – via infrastructure development - explain part of the observed negative effect of oil palm on fertility.

[27] Results are available from authors on request.
[28] We merge PODES 2014 on SUSENAS 2016.

6.3.6 Alternative explanations

As mentioned in Section 3, other mechanisms that are not captured by the Q-Q model could explain a negative effect of oil palm on fertility, namely migration, changes in child mortality or female empowerment. These mechanisms are addressed in the following.

Columns (1) and (2) in Table S12 (in the Appendix) report the effect of oil palm on migration. We find that oil palm increases short-term migration (i.e. in the last five years), but not long-term migration. The data on migration is derived from the Indonesian Census and only available for 1995, 2000, 2005 and 2010. We thus merge the migration data with a one year lead on the SUSENAS dataset.[29] Columns (3) to (5) assess the role of migration on fertility. We do not observe a significant change in the magnitude of the oil palm coefficient after controlling for either of the two migration variables. This suggests that migration does not explain the negative effect of the oil palm expansion on fertility.

We also control for changes in child mortality at province level. Unfortunately, the DHS data does not match well with our fertility data. We match DHS data form 1997, 2006 and 2012 with SUSENAS data from 1996, 2006 and 2011. Results are reported in the Appendix, Table S13. While we find that the expansion of oil palm is associated with decreasing child mortality, controlling for this variable again does not seem to affect the observed effect of oil palm on fertility. We therefore conclude that reductions in child mortality were no major transmission mechanism.

Finally, we explore the link between the oil palm expansion and female empowerment. Since we only have a few proxies for female empowerment in SUSENAS, we also use the DHS data to test if our results could be driven by an empowerment effect. One indication for female empowerment could be an increase in investments in children's education, in particular for girls, assuming that women have a higher a preference for investing in their children (and in their daughters relative to their sons) than men. However, while we find that

[29] Census data is not available for some regencies.

educational investments in children increase, the magnitude of the effect is almost identical for boys and girls, and could be explained equally well by the changes in returns to education (cf. Table 8). Therefore, we also test if the share of food expenditures in total household expenditures is increasing due to the oil palm expansion, assuming that women have a higher preference to spend money on food than men. Results are reported in Table S14 in the Appendix. We do not find any significant effect. Moreover, we test using DHS data if the oil palm expansion has an effect on several proxies of female empowerment such as the gap between desired and actual fertility, an index of female autonomy, and if women have control over their labor income. The results in Table S14 do not show any evidence that the oil palm expansion increased female empowerment. We also do not find any evidence that controlling for these variables changes the observed effect of oil palm on fertility (cf. Table S15).

We conclude that none of these mechanisms provide an alternative explanation for the negative effect of oil palm on fertility, and that the income effect as well as increasing wages and returns to education have a greater potential in explaining the negative effect of oil palm on fertility.

7 Conclusions

We contribute to the literature by disentangling the effect of a labor saving technology on fertility. Using the oil palm expansion in Indonesia as empirical example, we show that a labor saving technology does not necessarily lead to higher fertility. Rather positive income effects coupled with broader local economic development eventually decreased fertility in the context of oil palm production in Indonesia.

This paper presents evidence that oil palm induced labor savings under the condition of land scarcity, but also income gains in particular in the smallholder sector. Based on these observations, we develop testable hypotheses using Becker's Q-Q framework. Using an instrumental variables approach with regency-fixed effects, we find that the oil palm expansion significantly reduced fertility. This effect is persistent even after controlling for island specific time fixed effects and for differential trends depending on initial values of fertility, electrification, agricultural wages and sectoral shares. While our estimates likely represent an upper bound to the average treatment effect, they suggest that the oil palm expansion explains up to 17% of the fertility reduction observed in rural Indonesia in the time period between 1996 and 2016.

We then explore different transmission mechanisms, and find evidence that the negative effect of oil palm on fertility is largely driven by income effects, as well as by local economy effects, which led to increasing wages in the non-agricultural sector as well as to higher returns to education. Our results suggest that increasing returns to education increased maternal opportunity costs of time resulting in a reallocation of time from child rearing to education. In addition, increasing returns to education induced higher investments in children's education, leading to further reductions in fertility. We conclude that the income growth coupled with local economic development outweighed the potential fertility increasing effects of the oil palm expansion.

While we find a negative effect of a labor saving technology on fertility, we argue this might depend on several preconditions. 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, labor force participation as well as wages could decrease, potentially decreasing maternal opportunity costs of time. 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 reduction might be less evident. Lastly, it is important to note that oil palm is also largely adopted by smallholder farmers. Since oil palm adoption was voluntary, we have good reasons to expect that it was adopted due to expected income gains. A technology that is labor saving but not increasing the incomes of the majority of the population might have different effects. For example mechanization in large-scale agriculture might increase labor productivity; however, an abundant labor supply might still depress wages, or restrict income gains to a minority. The income and local economic development effects might therefore be less pronounced or absent, which would substantially reduce the scope for fertility reduction. While our results indicate that a labor saving technology in the smallholder sector might be beneficial to fertility reduction, labor savings technologies in other sectors where income effects are smaller might not lead to the same reduction in fertility rates.

A number of caveats apply. 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. While our results are robust to using lags and 5-year differences, the potential serial correlation in oil palm expansion combined with our fertility variable limits the scope for a more detailed cohort analysis. Second, our data includes only a limited number of good indicators for child quality, as we can only observe variables related to schooling. And finally, we want to emphasize that although we find positive effects of oil palm expansion on consumption expenditures and on educational attainment, this does not imply that oil palm is to be favored as means of reducing poverty. 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 oil palm. An assessment of the societal impact of oil palm needs to carefully weigh these different outcomes against each other.

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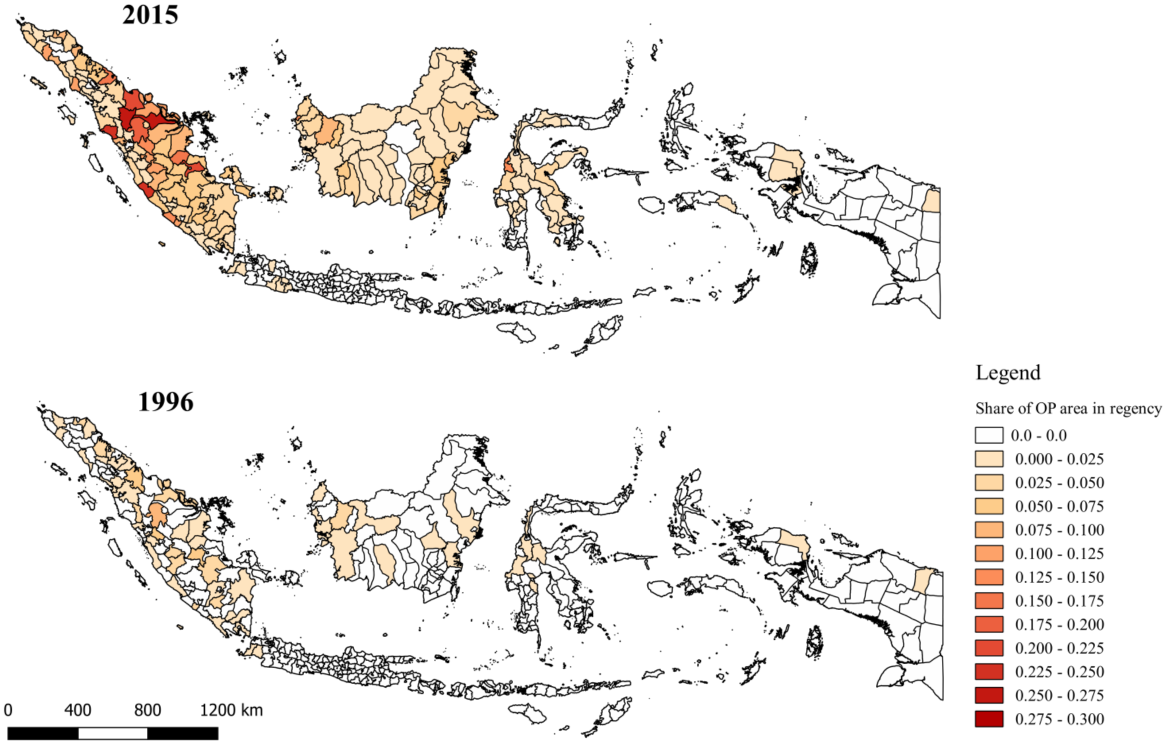
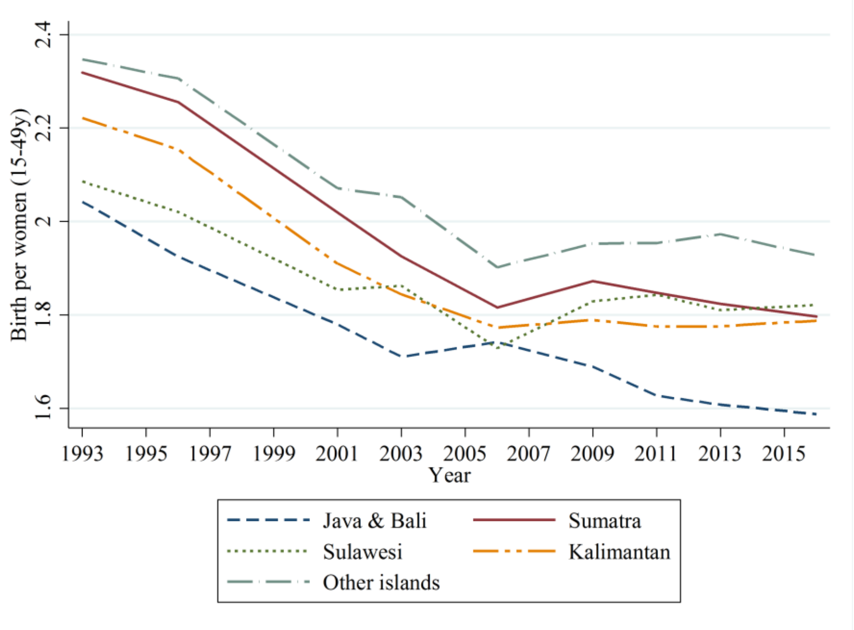
Figures

Figure 1: Regional oil palm expansion of smallholders in Indonesia in 1996 and 2015



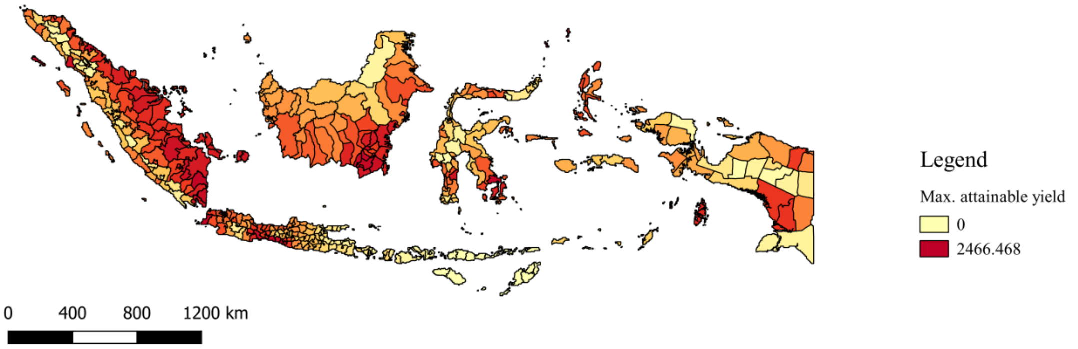
Source: Tree crop statistics, INDO-DAPOER.

Figure 2: Regional fertility trends in Indonesia



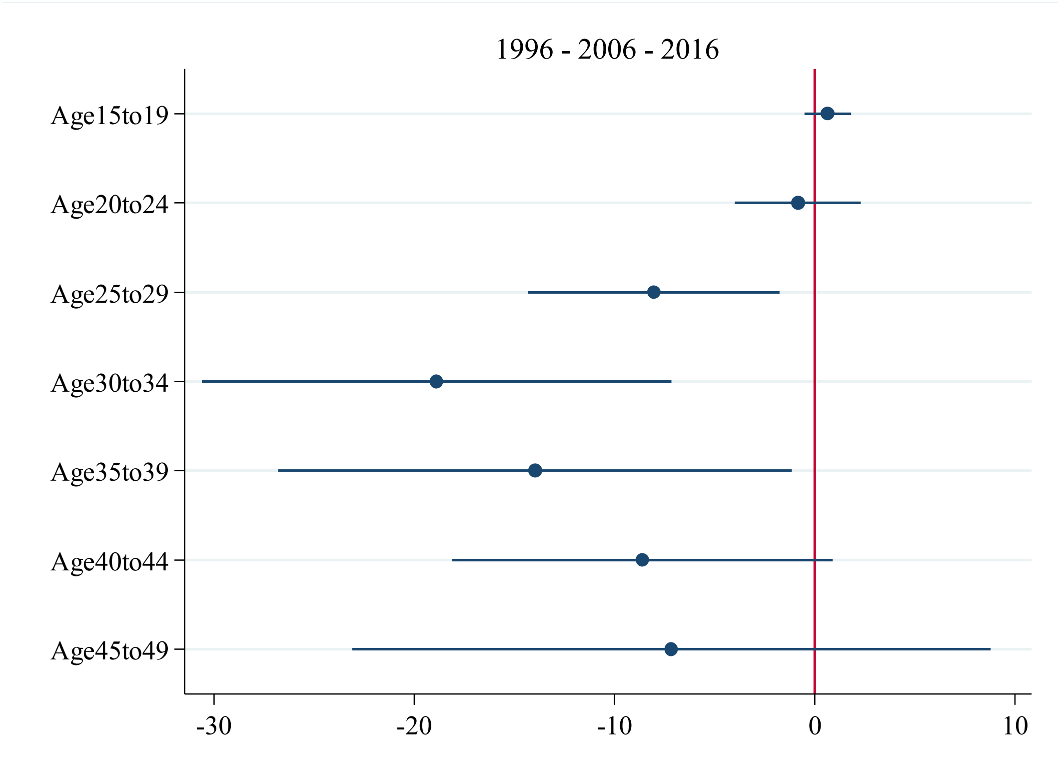
Source: SUSENAS data from 1993, 1996, 2001, 2003, 2006, 2009, 2011, 2013 and 2016.

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



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

Figure 4: Effect of oil palm on fertility by age cohorts



Notes: Marginal effects and 90% CI are reported. Standard errors are clustered at regency level. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Tables

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

	Oil palm		Rubber	
	Obs.	Mean (Std. dev.)	Obs.	Mean (Std. dev.)
Labor productivity [000 IDR/hour]	437	88.066^{***} (110.483)	967	22.752 (25.192)
Land productivity [000 IDR/ha/year]	437	16333.14^{***} (11889.91)	967	18157.01 (12108.73)
Capital input [000 IDR/ha/year]	439	2653.118^{***} (2662.383)	973	651.995 (1021.978)
Female labor input [Hours/ha/year]	439	25.764^{***} (65.35)	973	313.761 (471.624)
Male labor input [Hours/ha/year]	439	237.696^{***} (211.089)	973	854.687 (997.983)
Female wages [000 IDR/hour]	17	12.442 (11.353)	27	10.437 (1.751)
Male wages [000 IDR/hour]	167	18.227^{***} (17.222)	319	14.411 (15.580)

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

Table 2: Summary statistics (1996-2006-2016)

	Obs.	Mean	SD
For women 15-49:			
Number of children born alive	604159	1.875	1.927
Age	604219	30.745	9.885
Age at first marriage	447766	19.772	3.783
Ever married (=1)	604219	0.741	0.438
Working (=1)	604218	0.465	0.499
Working hours	604219	16.042	21.239
Working in agriculture (=1)	604219	0.217	0.412
Working in family agriculture (=1)	604219	0.138	0.345
Working in service sector (=1)	604219	0.187	0.390
HH head self-employed in agri. (=1)	604219	0.385	0.487
HH head employed in agri. (=1)	604219	0.080	0.271
Monthly expenditures per cap. (IDR)	604219	69899.75	65353.81
Share of food expenditures of total exp.	604219	0.623	0.140
Living in rural area (=1)	604219	0.709	0.454
Educational attainment			
Primary school (=1)	604219	0.364	0.481
Secondary junior school (=1)	604219	0.190	0.392
Secondary high school (=1)	604219	0.194	0.395
Tertiary schooling (=1)	604219	0.050	0.218
Regency level:			
Share of smallholder OP area in regency	626	0.009	0.025
Share of villages in regency with asphalt main road	626	0.721	0.187
Share of villages in regency with kindergarten	626	0.692	0.260
Share of villages in regency with primary school	626	0.984	0.031
Share of villages in regency with junior high school	626	0.511	0.164
Share of villages in regency with hospital	626	0.040	0.039
Share of HH in regency with access to public grid	626	0.638	0.254
Share of girls 12-14y with primary degree	626	0.568	0.111
Share of boys 12-14y with primary degree	626	0.523	0.115
Share of individuals ever migrated to regency	569	0.084	0.112
Share of individuals migrated in last 5y to regency	569	0.045	0.029
Province level:			
Female wage in non-agr. employment (IDR/hour)	66	774.734	171.636
Female wage in agr. employment (IDR/hour)	66	528.272	215.961
Male wage in non-agr. employment (IDR/hour)	66	947.589	198.003
Male wage in agr. employment (IDR/hour)	66	669.341	249.506
Child mortality (per 1000 births)	66	14.526	9.050

Notes: Data is available for 209 regencies. We miss data for one regency in 2016. For migration multiple regencies have missing data. Indonesia had 26 provinces in 1996. However, we do not have data for Maluku, Papua and Aceh and Jakarta is exclusively urban, ending up with 22 provinces. No data on child mortality and migration in 2016, we use data from 2012 and 2010 instead. All monetary values are in constant 1996 IDR. Exchange rate was at 2342 IDR/US$ in 1996 (World Bank 2018b).

Table 3: Effect of oil palm expansion on fertility

	1996-2006-2016					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	IV	IV	IV	IV
Share of smallholder	-0.422	-0.278	-6.421**	-14.841**	-4.614**	-6.707**
OP area in regency	(0.414)	(0.376)	(2.572)	(7.167)	(2.117)	(2.727)
Regency & year FE	Yes	Yes	Yes	Yes	Yes	Yes
Island-year FE	No	Yes	No	Yes	Yes	Yes
Initial levels * year	No	Yes	No	No	Yes	Yes
Woman's age	No	No	No	No	No	Yes
F-stat	377.129	413.431	218.526	81.247	289.315	564.73
Kleibergen F-stat			15.352	8.192	10.586	10.586
Observations	602758	602758	602758	602758	602758	602758

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Transmission mechanisms - Income effect

	1996-2006-2016					
	(1)	(2)	(3)	(4)	(5)	(6)
	Consumption Exp. p. c.	Consumption Exp. p. c. HH in agr.	Consumption Exp. p. c. HH in non-agr.	Fertility	Fertility HH in agr.	Fertility HH in non-agr.
Share of smallholder	3.376*	3.822**	1.611	-4.887*	-6.222**	-8.488**
OP area in regency	(2.046)	(1.902)	(2.537)	(2.797)	(2.627)	(3.800)
Consumption				-0.513***		
expenditures p. c.				(0.016)		
F-stat	161.573	172.506	170.022	630.011	365.880	551.342
Kleibergen F-stat	10.706	12.995	8.481	10.577	13.209	8.276
Observations	2294491	1102206	1192285	602758	280546	322212

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. Consumption expenditures are in log constant 1996 values.

Table 5: Transmission mechanisms - Opportunity costs of time

	2001-2006-2011-2015				1996-2006-2016				
	(1) Women's non-agr. wages	(2) Women's agr. wages	(3) Work	(4) Working hours	(5) Fertility	(6) Fertility (Working women)	(7) Fertility (Working women)	(8) Fertility	(9) Fertility
Share of smallholder OP area in regency	16.127*	-7.902	-0.476	14.344	-6.800**	-8.114**	-8.057**	-3.894*	-2.284
	(9.239)	(6.769)	(1.256)	(47.436)	(2.704)	(3.293)	(3.331)	(2.171)	(2.355)
Work (=1)					-0.195***				
					(0.015)				
Working hours							-0.004***		
							(4.E-4)		
Women's non-agr. wages								-0.371***	-0.382***
								(0.084)	(0.093)
Women's agr. wages								0.069	0.117
								(0.078)	(0.077)
Consumption expenditure p. c.									-0.513***
									(0.015)
F-stat	43.680	5.182	134.651	45.525	551.033	377.703	350.224	612.908	650.996
Kleibergen F-stat	9.296	14.476	10.588	10.822	10.585	10.818	10.818	10.460	10.452
Observations	72585	14624	602817	280152	602757	280113	280113	602758	602758

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. All monetary values are in log constant 1996 values, and wages calculated per hour.

Table 6: Transmission mechanisms - Opportunity costs of time II

	1996-2006-2016					
	(1) Work in agriculture	(2) Work in service sector	(3) Education women (15-25y)	(4) Education women (26-35y)	(5) Fertility (Working women)	(6) Fertility
Share of smallholder OP area in regency	-2.793**	2.600**	5.235*	10.036**	-7.514**	-5.601**
	(1.307)	(1.160)	(2.820)	(4.957)	(3.192)	(2.736)
Work in agriculture (=1)					0.215***	
					(0.019)	
Women's education level	No	No	No	No	No	Yes
F-stat	51.713	52.839	357.177	262.315	382.410	719.396
Kleibergen F-stat	10.822	10.822	10.349	10.614	10.812	10.578
Observations	280152	280152	211238	181646	280113	602758

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. Education level is a categorical variable. Categories are no degree, primary, junior secondary, senior secondary and tertiary schooling.

Table 7: Effect of oil palm on wages - Returns to education

	2001-2006-2011-2015					
	(1)	(2)	(3)	(4)	(5)	(6)
	Women's wages			Men's wages		
	<Primary	Secondary	Tertiary	<Primary	Secondary	Tertiary
Share of smallholder OP area in regency	-0.476	1.508	38.828***	-10.141	13.110*	31.250**
	(8.761)	(8.415)	(14.035)	(6.641)	(7.570)	(14.574)
F-stat	13.300	57.607	72.715	37.428	272.367	67.720
Kleibergen F-stat	8.877	9.568	12.212	9.335	9.851	9.817
Observations	31653	37951	17605	73130	97042	17038

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. All monetary variables are in log constant 1996 values. Dep. var.: Log hourly wages.

Table 8: Transmission mechanisms - Returns to children's education

	1996-2006-2016				
	(1) Education level boys (12-14y)	(2) Education level girls (12-14y)	(3) Fertility	(4) Fertility	(5) Fertility
Share of smallholder OP area in regency	2.152	2.358^{*}	-5.444^{*}	-3.827	-2.948
	(1.409)	(1.352)	(3.048)	(3.247)	(3.890)
Education level of 12-14y in reg.	No	No	Yes	Yes	Yes
All control variables except wages	No	No	No	Yes	Yes
Women's wages	No	No	No	No	Yes
F-stat	767.839	1379.357	393.164	631.100	608.982
Kleibergen F-stat	10.777	11.061	10.748	10.738	9.474
Observations	78388	74235	602758	602757	602757

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. Education level is a categorical variable. Categories are no degree, primary, junior secondary, senior secondary and tertiary schooling. In columns (3) to (5) we use the share of the age group having attained the respective degree as control.

Table 9: Transmission mechanisms - Infrastructure

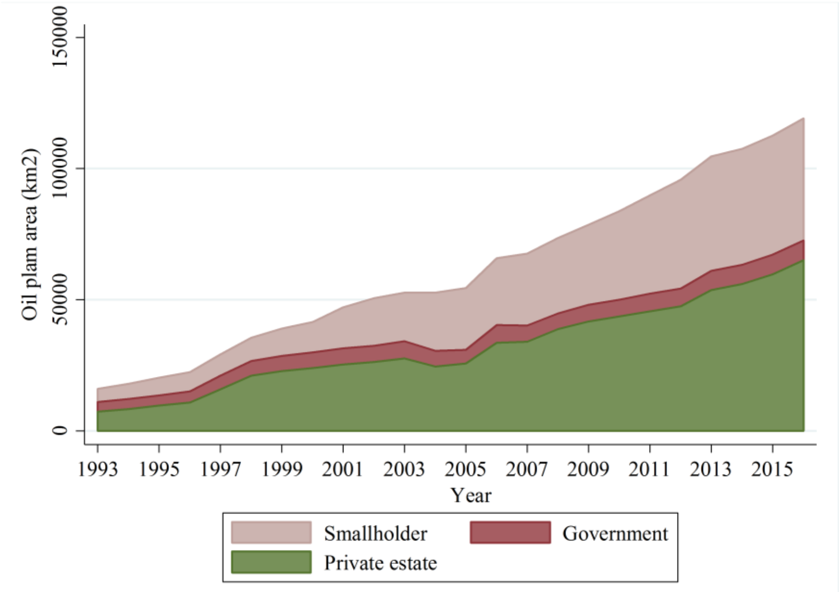
	1996-2006-2014							1996-2006-2016		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Kindergarten	Primary school	Junior high school	Asphalt road	Hospital	Electricity	Fertility	Fertility	Fertility	Fertility
Share of smallholder OP area in regency	-0.468	0.327	-2.418	-2.380*	0.879**	0.004	-7.725**	-7.710***	-7.707***	-8.450**
	(1.988)	(0.274)	(1.509)	(1.366)	(0.438)	(1.327)	(3.004)	(2.852)	(2.905)	(3.440)
Share of villages with kindergarten in regency							0.112	0.104	0.104	0.113
							(0.127)	(0.129)	(0.130)	(0.136)
Share of villages with primary school in regency							0.908	1.032	1.031	1.110
							(0.813)	(0.802)	(0.794)	(0.865)
Share of villages with junior high school in regency							-0.223	-0.214	-0.214	-0.234
							(0.166)	(0.166)	(0.167)	(0.182)
Share of households with electricity in regency								0.201**	0.200**	0.236**
								(0.083)	(0.084)	(0.097)
Share of villages with asphalt road in regency									0.001	0.004
									(0.128)	(0.131)
Share of villages with hospital in regency										0.301
										(0.423)
F-stat	93.850	15.264	44.833	12.460	5.632	474.933	458.137	487.045	470.665	439.641
Kleibergen F-stat	16.485	16.485	16.485	16.485	16.485	16.485	11.638	11.513	11.257	8.945
Observations	620	620	620	620	620	620	601025	601025	601025	601025

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

SUPPLEMENTARY APPENDIX

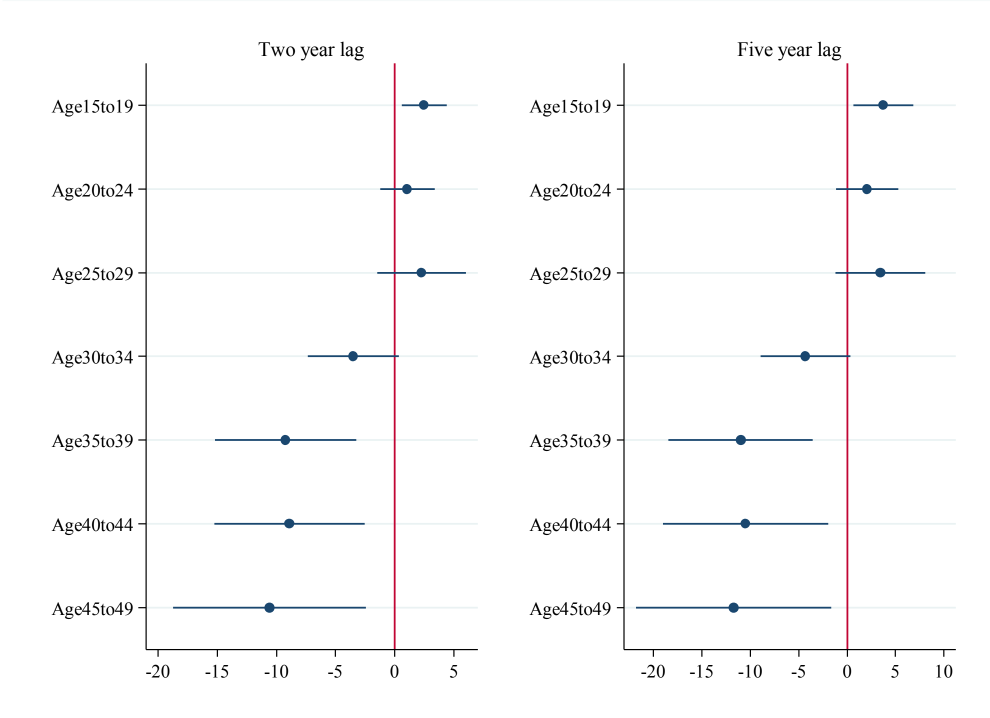
Supplementary Figures

Figure S1: Expansion of oil palm in Indonesia by producer type



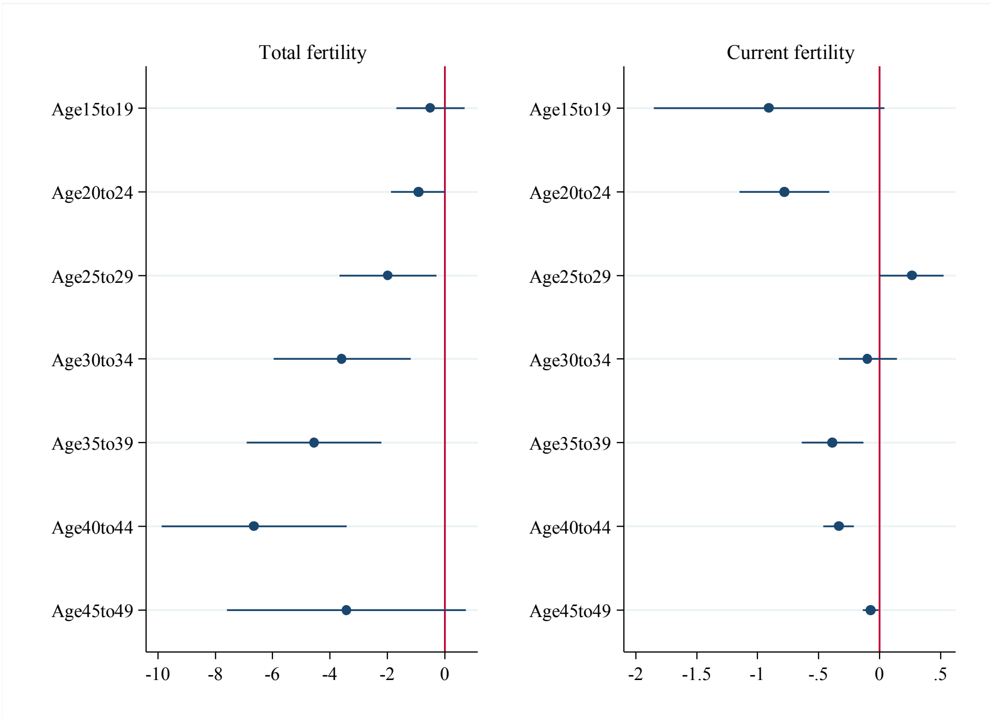
Source: Tree crop statistics.

Figure S2: Effect of oil palm expansion on fertility using lags



Notes: First figure uses a two year lag and second figure a five year lag for oil palm expansion both using the SUENAS data from 2001, 2006, 2011, 2016. IV estimates and 90% CI are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Figure S3: Effect of oil palm expansion on fertility using DHS data



Notes: Marginal effects and 90% CI are reported. All regressions include national oil palm area, province fixed effect and year dummies.

Supplementary Tables

Table S1: Description of data sources

Data-source	Data availability	Description
SUSENAS	1993, 1996, 2001, 2003, 2006, 2009, 2011, 2013, 2016	The National Socioeconomic Survey (SUSENAS) is a multi-purpose socio-economic survey at the individual level. The SUSENAS is representative at the regency-level.
PODES	1993, 1996, 2003, 2006, 2014	The Village Potential Statistics (PODES) collects village and urban neighborhood characteristics for all of Indonesia.
SAKERNAS	1993-2015	The National Labor Force Survey (SAKERNAS) collects labor market characteristics of working age individuals. SAKERNAS is representative at the regency-level starting from 2007.
GAEZ	1960-1990 (baseline)	The Global Agro-Ecological Zones (GAEZ) database provides simulations on agro-climatic attainable yield and suitability indices for crops under different conditions.
Tree Crop Statistics & INDO-DAPOER	1967-2016 (national level) 1996-2016 (regency level)	The Indonesia Database for Policy and Economic Research (INDO-DAPOER) and Tree Crop Statistics of the Ministry of Agriculture provide data on smallholder oil palm area. Data is available at the regency level starting 1996. Total oil palm area at regency level is available since 2005.
DHS	1997, 2002, 2007, 2012	The Demographic and Health Survey (DHS) provides representative data on health and population at the province level, including details on child mortality, TFR, and number of live births per woman. Proxies for female bargaining power include the difference between actual and desired fertility, a woman's influence on household and personal decisions and her control over her own income.
Indonesian Census	1995, 2000, 2005, 2010	From the IPUMS International database, we use the 10% subsample of the Population Census of 2000 and 2010, as well as the 0.43% and 0.51% subsamples of the Intercensal Population Surveys of 1995 and 2005, respectively. We calculate permanent migration as share of individuals aged 15-49 who were born in a different regency than regency of residence. Recent migration is the share of migrants who moved to the regency in the last 5 years. The data is aggregated at the regency level.
Badan Pusat Statistik (BPS)	1993 – 2016	Rural and urban poverty lines are published annually in the Statistic Year Book of Indonesia. Regional GDP by sector is available since 2000.
Ministry of Finance	1994- 2016	Public revenue data by source are available from the Information System for Sub-National Budget.
NASA Shuttle Radar Topographic Mission (SRTM)	n.a.	The SRTM digital elevation data is used to calculate average altitude for each regency.

Table S2: Additional summary statistics

	Obs.	Mean	SD
SUSENAS (1996-2006-2016):			
For Children (10-15y):			
Child labor (=1)	256332	0.059	0.236
Child labor on own farm (=1)	256332	0.037	0.189
For Children (6-14y):			
Enrollment rate boys	233809	0.895	0.307
Enrollment rate girls	220537	0.902	0.297
SAKERNAS (2001-2006-2011-2015):			
Individual level (15-49y):			
Female labor force participation	372425	0.511	0.500
Share of working women in non-agr. sector	179482	0.593	0.491
Share of working women in agr. sector (family work)	179482	0.274	0.446
Share of working women in agr. sector (wage work)	179482	0.060	0.237
Male labor force participation	368477	0.841	0.365
Share of working men in non-agr. sector	295608	0.573	0.495
Share of working men in agr. sector (family work)	295608	0.079	0.270
Share of working men in agr. sector (wage work)	295608	0.103	0.303
Ministry of Finance (2001-2006-2011-2015):			
Regency level:			
Own revenue of regency government (mil. IDR)	832	36788.59	31317.13
Transfers from central government (mil. IDR)	832	29183	27551.28
Transfers from province government (mil. IDR)	832	4544.316	5122.167
DHS (1997-2002-2007-2012):			
Women (15-49y):			
Control over income (=1)	28836	0.650	0.477
Autonomy index	73488	4.112	1.110
Fertility gap	91330	-0.534	1.642

Notes: All monetary values are in constant 1996 IDR.

Table S3: Effect of oil palm expansion on fertility – 1993-2003

	1993-2003					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	IV	IV	IV	IV
Share of villages with OP	-0.467***	-0.315**	-3.056***	-5.143**	-2.804***	-1.902**
	(0.117)	(0.159)	(0.736)	(2.046)	(1.052)	(0.897)
Regency & year FE	Yes	Yes	Yes	Yes	Yes	Yes
Island-year FE	No	Yes	No	Yes	Yes	Yes
Initial levels * year	No	Yes	No	No	Yes	Yes
Woman's age	No	No	No	No	No	Yes
F-stat	371.677	154.411	148.439	69.810	97.262	787.982
Kleibergen F-stat			25.996	8.905	10.664	10.663
Observations	366496	366496	366496	366496	366496	366496

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table S4: Robustness checks

	1996-2006-2016					2005-2011-2016	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	No weights	Province trends included	IV with inter-mediate input level	Excluding Java	Including altitude x time trend	Small-holder OP area	Total OP area
Share of smallholder OP area in regency	-6.256***	-7.315**	-7.025**	-4.354**	-6.393*	-5.778*	
	(2.419)	(2.900)	(2.900)	(1.851)	(3.333)	(3.484)	
Share of total OP area in regency							-2.755*
							(1.548)
F-stat	589.720	178.269	561.969	1033.998	567.656	313.331	311.721
Kleibergen F-stat	12.389	8.603	10.586	15.711	7.719	9.815	18.993
Observations	602758	602758	602758	332373	602758	658100	658100

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Table S5: Effect of oil palm expansion on fertility - Five year differences

	1996-2001-2006-2011-2016					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	IV	IV	IV	IV
Share of smallholder OP area in regency	-0.214	-0.304	-6.063**	-14.005**	-3.657**	-6.642**
	(0.446)	(0.414)	(2.478)	(7.094)	(1.808)	(2.588)
Regency & year FE	Yes	Yes	Yes	Yes	Yes	Yes
Island-year FE	No	Yes	No	Yes	Yes	Yes
Initial levels * year	No	Yes	No	No	Yes	Yes
Women's age	No	No	No	No	No	Yes
F-stat	226.705	564.779	148.756	100.667	465.440	521.266
Kleibergen F-stat			15.046	7.482	9.719	9.719
Observations	1006039	1006039	1006039	1006039	1006039	1006039

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table S6: Transmission mechanisms – Child labor

	1996-2006-2016					
	(1) Child labor	(2) On-farm child labor	(3) Male child labor	(4) Female child labor	(5) Fertility	(6) Fertility
Share of smallholder OP area in regency	0.392 (0.807)	0.627 (0.665)	0.399 (0.897)	0.386 (0.782)	-6.929** (2.880)	-7.056** (2.818)
Share of child labor in regency					0.501** (0.197)	
Share of on-farm child labor in regency						0.541** (0.231)
F-stat	59.995	36.020	56.162	42.155	539.516	546.300
Kleibergen F-stat	10.876	10.876	10.847	10.919	10.703	10.814
Observations	255708	255708	131987	123721	602758	602758

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Table S7: Effect of oil palm on enrollment rates

	1996-2016-2016		
	(1) School enrollment boys (6-14y)	(2) School enrollment girls (6-14y)	(3) Fertility
Share of smallholder OP area in regency	0.063 (0.840)	-0.271 (0.789)	-6.743** (3.009)
Share of 6-14 year olds enrolled in regency	No	No	Yes
F-stat	123.715	121.733	475.657
Kleibergen F-stat	10.915	10.872	11.188
Observations	233283	219973	602758

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Table S8: Effect of oil palm on women's non-agricultural wages

	2001-2006-2011-2015						
	(1) Women's non-agr. wages	(2) Women's non-agr. wages	(3) Women's non-agr. wages	(4) Women's non-agr. wages	(5) Women's non-agr. wages	(6) Women's non-agr. wages	(7) Women's non-agr. wages
Share of smallholder OP in regency (%)	16.127* (9.239)	15.559* (9.019)	15.810* (9.069)	13.107 (8.411)	17.607* (9.383)	14.535* (8.506)	12.724 (8.389)
Women's educational attainment		0.301*** (0.008)	0.299*** (0.010)				
Own revenue of regency government				0.772*** (0.084)			0.752*** (0.088)
Transfers from province government					0.032** (0.015)		
Transfers from central government					0.825*** (0.093)		
Average consumption exp. p.c. in regency						0.456*** (0.090)	0.132 (0.090)
Sector dummies	No	No	Yes	No	No	No	No
F-stat	43.680	250.615	219.492	40.306	45.935	46.922	38.361
Kleibergen F-stat	9.296	9.297	9.288	9.270	8.908	9.133	9.251
Observations	72585	72585	72585	72505	72161	72585	72505

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. All monetary values are in constant 1996 Indonesian Rupees. Dependent variable: log hourly wages in non-agricultural activities.

Table S9: Effect of oil palm on sectoral shifts

	2001-2006-2011-2015							
	(1) Female labor force participation	(2) Share of women in non-agricultural work	(3) Share of women in agricultural family work	(4) Share of women in agricultural wage work	(5) Male labor force participation	(6) Share of men in non-agricultural work	(7) Share of men in agricultural family work	(8) Share of men in agricultural wage work
Share of smallholder OP area in regency	-1.986	3.905	-5.181**	1.308	0.212	0.751	-1.235	2.865*
	(2.008)	(2.476)	(2.622)	(1.077)	(0.938)	(1.844)	(1.020)	(1.477)
F-stat	45.802	51.767	21.117	11.149	819.621	36.130	22.793	8.323
Kleibergen F-stat	10.892	12.033	12.033	12.033	11.206	11.710	11.710	11.710
Observations	371458	178948	178948	178948	367473	294740	294740	294740

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Table S10: Effect of oil palm on wages - Returns to education

	2001-2015					
	(1)	(2)	(3)	(4)	(5)	(6)
		Women's wages			Men's wages	
	<Primary	Secondary	Tertiary	<Primary	Secondary	Tertiary
Share of smallholder	-1.767	6.734	25.756***	-2.231	12.638**	29.466**
OP area in regency	(5.318)	(4.423)	(9.804)	(3.910)	(6.340)	(11.942)
F-stat	37.982	75.811	89.707	67.473	337.881	104.867
Kleibergen F-stat	9.136	7.974	9.885	8.666	8.221	8.646
Observations	137131	144666	61671	312686	375286	62201

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. All monetary values are in constant 1996 Indonesian Rupees. Wages are reported as log hourly wages. 2008 and 2013 data are not included due to inconsistent data for oil palm expansion.

Table S11: Transmission mechanisms - Returns to children's education II

	1996-2006-2016			
	(1) Education level boys 12-19	(2) Education level girls 12-19	(3) Fertility (>19y)	(4) Fertility (>19y)
Share of smallholder OP area in regency	1.959 (1.382)	2.732* (1.502)	-8.300** (3.404)	-6.885** (3.432)
Education level of 12-19 year old in regency	No	No	No	Yes
F-stat	1302.717	1273.496	480.203	387.524
Kleibergen F-stat	10.834	10.810	10.553	10.646
Observations	190581	177484	499521	499521

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. Education level is a categorical variable. Categories are no degree, primary, junior secondary, senior secondary and tertiary schooling. In column (4) we control for the share of the children in the age group having attained the respective degree.

Table S12: Transmission mechanisms – Migration

	1995-2000-2005-2010		1996–2001-2006-2011		
	(1) Share migrated in last 5y to regency (%)	(2) Share ever migrated to regency (%)	(3) Fertility (baseline)	(4) Fertility	(5) Fertility
Share of smallholder OP area in regency	0.844* (0.472)	0.513 (0.584)	-6.723** (3.112)	-6.895** (3.454)	-6.424** (3.030)
Share ever migrated to regency				0.162 (0.501)	
Share migrated in last 5 years to regency					-0.327 (0.354)
F-stat	5.825	8.484	290.006	278.255	287.211
Kleibergen F-stat	8.614	8.614	7.264	6.382	7.381
Observations	778	778	750076	750076	750076

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Table S13: Transmission mechanisms – Child mortality

	1997-2002-2007-2012	**1996-2001-2006-2011**	
	(1)	(2)	(3)
	Child mortality (province level)	Fertility (baseline)	Fertility
Share of smallholder OP area in province/regency	-109.888*	-7.477**	-8.214**
	(55.954)	(3.379)	(3.500)
Child mortality (province level)			0.004
			(0.003)
F-stat	6.824	302.543	286.543
Kleibergen F-stat		7.460	8.389
Observations	80	794267	794267

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS estimates reported in col (1) and IV estimates reported in cols. (2) and (3). Column (1) controls for national oil palm area, province and year fixed effects. Columns (2) and (3) control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year.

Table S14: Transmission mechanisms – Female empowerment

		1997-2002-2007-2012 (DHS)		**1996-2006-2016** (SUSENAS)
	(1)	(2)	(3)	(4)
	Fertility gap	Autonomy	Control over income	Share of expenditures for food
Share of smallholder OP area in province/regency	-0.201	2.551	0.350	-0.807
	(0.951)	(1.968)	(0.706)	(0.655)
F-stat	210.909	399.465	5.233	765.523
Kleibergen F-stat				10.579
Observations	91330	73488	28836	602818

Notes: Standard errors (clustered at province level in cols. (1) to (3) and at regency level in col. (4)) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS estimates reported in cols. (1) to (3) and IV estimates reported in col. (4). Columns (1) to (3) control for national oil palm area, province and year fixed effects. Column (4) controls for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year as well as consumption expenditure. All monetary values are in log constant 1996 values.

Table S15: Transmission mechanisms – Female empowerment II

	2001-2006-2016	2001-2006-2011			1996-2001-2006-2011	
	(1) Fertility	(2) Fertility (baseline)	(3) Fertility	(4) Fertility	(5) Fertility (baseline)	(6) Fertility
Share of smallholder OP area in regency	-4.935* (2.793)	-5.501 (4.201)	-5.005 (3.982)	-6.628 (4.713)	-7.395*** (2.172)	-8.644*** (2.524)
Share of expenditures for food	-0.059* (0.032)					
Consumption expenditure p. c.	-0.519*** (0.014)					
Autonomy			0.167** (0.078)			
Control over income				-0.276* (0.153)		
Fertility gap						-0.222*** (0.084)
F-stat	640.976	240.163	254.516	250.456	319.620	292.408
Kleibergen F-stat	10.580	5.254	5.375	4.928	17.236	16.586
Observations	602758	531606	531606	531606	668945	668945

Notes: Standard errors (clustered at regency level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. IV estimates are reported. All regressions control for national oil palm area, woman's age, regency and year fixed effects, island-year fixed effects, and initial values of fertility, electrification, share of agriculture in total employment and agricultural wages times year. All monetary values are in log constant 1996 values.