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Agricultural Productivity and Fertility Rates: Evidence from the Oil Palm Boom in Indonesia*

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

JEL Classification: J13, O13, O14, Q10

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I. Introduction

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

At first glance, the empirical phenomenon resembles the fertility decline experienced by the US and Western Europe during the process of industrialization. This suggests that similar forces might explain the recent decline in fertility in developing countries, that is: technical change, structural transformation, and a rising demand for high-skilled labor (Galor and Weil 2000; Galor 2012).[2] However, upon closer examination, it would appear that not all development trajectories observed in developing countries since the 1960s mirror the experiences of current high-income countries during the 19th and early 20th Centuries. In many developing nations, agriculture remains an important economic sector, and employs a large share of the labor force. Some countries, such as Indonesia, India, Pakistan, Bangladesh or Myanmar, saw significant declines in fertility during time periods, during which the proportion of agricultural workers within the total workforce was largely stagnating.[3] Meanwhile, many developing countries have experienced growth in agricultural productivity, which was largely driven by the introduction of new high-yielding crop varieties as well as higher intensities in irrigation and fertilizer

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

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

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

application (Evenson and Gollin 2003), but also by mechanization (Pingali 2007), the adoption of herbicides (Haggblade et al. 2017), and the introduction of new insect-resistant and herbicide-tolerant crop varieties (Qaim 2016).

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

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

To guide our empirical analysis, we model the oil palm expansion as an increase in the productivity of land and of male (but not female) labor within agriculture in a two-sector economy. As oil palm leads to income gains among landowners, it is expected to generate local economic development (accompanied by rising wage returns to education), if demand for (non-traded) non-agricultural goods increases sufficiently. The increase in male labor productivity shifts the labor composition in agriculture towards men and raises male wages. Female wages are expected to increase in the non-agricultural sector, as long as the positive local economy effects (*i.e.* demand for non-agricultural goods) outweigh the negative labor demand effects for women in agriculture.

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

In our empirical analysis, we combine a large set of different data sources. We use Indonesia's socio-economic survey (SUSENAS) to assess changes in fertility, measured as the total number of children ever born.[4] Data on wages, labor supply and sector of work are obtained from the national labor force survey (SAKERNAS). For the oil palm expansion, we rely on administrative data published by the Indonesian Government, the Tree Crop Statistics, a data source that was also used to analyze the effects of oil palm on poverty rates (Edwards 2019a). Due to data availability, we focus on the oil palm expansion of smallholder farmers in the main analysis, and investigate effect heterogeneity across producer types as a robustness check. To complement these data, we use land-use data from Indonesia's village census (PODES), which is available for 1993 and 2003, and remote sensing data on large-scale oil palm estates, which is available from 1995 to 2015. For the robustness checks, we use data from PODES, from Indonesia's Population Census and Intercensal Survey (SUPAS), from the Demographic and Health Surveys (DHS), as well as from different administrative sources.

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

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

Using this instrumental-variables approach, we find consistently negative effects of smallholder oil palm expansion on fertility. These results are robust to controlling for region-by-year fixed effects and for differential time-trends between regencies with different initial characteristics, such as fertility, electrification, female labor force participation and male agricultural wages. The results are also robust to a broad set of alternative specifications, including the use of different measures of oil palm expansion and of fertility, of different time periods, as well as to controlling for province-specific time-trends, for time-trends that vary with the altitude of a regency, or with the suitability for other crops.

We proceed to explore the importance of different mechanisms through which the fertility effect might be operating. We show that smallholder oil palm expansion triggered income gains

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

and broader local economic development, which increased returns to education. Our results suggest that the fertility reduction is strongest in areas that experience higher income effects and where returns to education rose more pronouncedly. Interestingly, changes in returns to education are not due to new technology in agriculture. Oil palm cultivation is not more skill intensive than growing other crops in the region. Instead, the oil palm expansion induced local economic development and led to growth in non-agricultural sectors. This increased returns to education. Taken together, our findings suggest that agricultural productivity growth can accelerate a country's fertility transition, even if it does not directly affect returns to education or the opportunity costs of time, as long as income gains are large enough, and accrue to a substantial share of the population, so as to trigger local economic development and an increase in returns to education.

Our contributions are as follows. Firstly, we add to the empirical literature on the role of productivity growth, and the importance of different mechanisms, in reducing fertility (Rosenzweig and Evenson 1977; Levy 1985; Wanamaker 2012; Ager et al. 2019). For the industrialization process in the US, Wanamaker (2012) argued that structural change led to fertility reductions, because it increased maternal opportunity costs of time and induced a separation of migrant households from their extended family network. In the same context, Ager et al. (2019) attributed the decline in fertility to higher opportunity costs of raising children, as households switched into manufacturing, as well as to income declines within agriculture. Rosenzweig and Evenson (1977) and Levy (1985) analyzed the link between technological innovations, agricultural productivity and fertility in the context of India and Egypt, respectively. Both papers concentrate entirely on changes in the demand for child labor as main mechanisms. In contrast to previous work, we find no link between fertility and opportunity costs of time (either the mother's- or the child's-).

Secondly, we contribute to a literature that seeks to understand the relationship between economic growth and fertility in developed and in developing countries (Sobotka et al. 2011;

Brueckner and Schwandt 2015; Vogl 2016; Chatterjee and Vogl 2018). In line with previous work from developing country contexts, we find negative long-run effects of economic growth on fertility. We add to this literature by attempting to disentangle the mechanisms through which this negative relationship occurs.

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

The remainder of this paper is structured as follows: In Section II, 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 III presents the conceptual framework. In Section IV, we introduce the different data sources used in the analysis. Our estimation strategy is presented in Section V. Section VI reports our main results, as well as several robustness checks, and an analysis of the transmission mechanisms. Conclusions are presented in Section VII.

II. Background: Oil Palm Cultivation in Indonesia

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

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

The increasing dominance of oil palm cultivation has also had repercussions on the local economy: Previous work finds that the expansion of oil palm has been associated with substantial welfare gains, especially among smallholder farmers (Rist et al. 2010; Euler et al. 2017; Edwards 2019a). These changes can be explained by substantial differences in the cultivation of oil palm vis-a-vis other crops, particularly rice and rubber. Firstly, fresh oil palm

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

fruit bunches have to be processed in palm oil mills shortly after harvest. This necessitates improved road infrastructure to rapidly transport the fresh fruit bunches from the producer to the mill, and reliable access to electricity to run palm oil mills.[7]

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

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

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

found no evidence that female labor is less productive than male labor in rice cultivation (Feintrenie et al. 2010; Li 2015).

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

Finally, it seems important to point out that the cultivation of oil palm is no more skill-intensive than the cultivation of other crops, and of rubber, in particular. We show in Table B1 that oil palm farmers in Jambi Province are not significantly more educated than rubber farmers, and in Table B2, that the difference in land and labor productivity between oil palm and rubber is not driven by differences in the years of education of the head of the household. In Section V, we also examine if men and women living in oil palm cultivating areas have higher levels of education at the onset of the oil palm boom and find no evidence that this is the case.

III. Conceptual Framework

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

A. Agricultural Productivity and Structural Change

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

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

The increase in male labor productivity affects the gender-composition within agriculture, as well as total labor demand in the agricultural sector. Under fairly standard assumptions, the share of women working within the agricultural sector is expected to decline (see Online Appendix A.1). Total labor demand in agriculture will remain constant or even increase, as long as the agricultural area can be expanded at reasonable cost (*i.e.* through deforestation).

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

B. The Demand for Children

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

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

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

Returns to education. While cultivation of oil palm does not require higher skills than the cultivation of other crops, we expect returns to skills to increase due to the expansion of the non-agricultural sector. This increases parents' demand for child human capital, because investing in children's education is likely to seem more desirable if wages of educated workers rise. Because investing in (higher) education is costly, parents of any education level could be

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

willing to reduce fertility in response to increasing returns to education (Galor and Weil 2000). The link between increasing returns to education and decreasing fertility is empirically well established (Bleakley and Lange 2009; Becker et al. 2010; Fernihough 2017).

IV. Data

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

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

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

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

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

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

Finally, we use data from the Global Agro-Ecological Zones (GAEZ) database for our instrumental-variables approach. The GAEZ provides agro-climatically attainable yield data (in kg/ha) for different crops in grid cells of 5 arc-minutes and 30 arc-seconds (approximately 10x10km) resolution. These data are calculated by incorporating local agro-climatic conditions into agronomic models with pre-specified levels of inputs and management conditions (Fischer et al. 2012). We use the agro-climatically attainable yield for low input level rain-fed oil palm for the time period 1961-1990.[9] Regency-average attainable yield for oil palm is then calculated by averaging pixel values within 1993 regency boundaries. Figure 3 illustrates our calculations.

V. Estimation Strategy

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

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

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

agro-climatic suitability is a major determinant of land-use patterns. Importantly, we expect this instrument to be exogenous, *i.e.* to affect fertility only through its effect on oil palm expansion, and not through any other mechanisms. This is obviously a strong assumption and warrants some discussion.

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

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

A third caveat in our identification strategy could be the high regional concentration in the oil palm expansion. As depicted in Figure 2, the oil palm expansion started in Sumatra, and spread only later to Sulawesi and Kalimantan.[10] It is not unlikely that regional shocks affected the oil palm expansion as well as fertility. We address this concern by controlling for region-by-year fixed effects in all our estimations.

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

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

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

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

γ_{st} control for region-specific aggregate shocks, and the regency fixed effects μ_j control for time-invariant differences across regencies. ε_{ijst} is the error term.

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

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

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

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

VI. Results

A. The Effect of Oil Palm Cultivation on Fertility

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

The results show a consistently negative effect of the oil palm expansion on fertility. The effect is always statistically significant in the instrumental-variables estimates, also when inference is based on the Anderson-Rubin confidence intervals. Column 5 is the preferred specification. In terms of magnitude, the coefficient implies that a one percentage point (one standard deviation) increase in the smallholder oil palm area in a regency (relative to the regency area) reduces fertility by 0.056 (0.167) children born per woman. Between 1996 and 2016, the smallholder oil palm area (in % of regency area) increased from 0.41% to 2.62%. According to our estimates, this would lead 0.123 fewer children born per woman. In the same time period, fertility (measured as the total number of children born per woman by the time of the survey) decreased from 2.187 to 1.810 in our sample. The oil palm expansion can, hence, explain up to 33% of the observed fertility reduction in the last 20 years in rural Indonesia. The magnitude of the effect increases substantially when moving from OLS to our instrumental-variables approach. This could indicate a weak instrument problem. However, our first-stage Kleibergen-Paap F-statistic ranges between 15.8 and 27.5, suggesting that our instrument is sufficiently strong in all regressions. There could be three other reasons for having lower OLS than IV estimates. Firstly, our IV estimates capture the local average treatment effect of oil palm expansion, *i.e.* the effect in regencies in which oil palm was planted because of favorable agro-climatic conditions, and not, for example, because of policy interventions. Palm oil production in favorable agro-climatic conditions is likely to have higher returns, leading to higher productivity gains, and potentially stronger fertility reductions.[11] To the extent that this is true, our estimates present an upper bound to the average treatment effect. Given that this

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

paper seeks to understand what the consequences of agricultural productivity growth could be for fertility, the LATE appears to be the more relevant magnitude here. Secondly, the IV approach might have corrected an upward bias in the point estimate driven by omitted variables. The Indonesian government has a long tradition of incentivizing the establishment of oil palm plantations in regions with poor economic development (Gatto et al. 2017). If the expansion of oil palm correlates with recent economic downturns, our OLS estimates would be biased towards zero. Lastly, administrative data on the expansion of oil palm could involve significant measurement error, while the instrument is based on agro-climatic conditions that can be more precisely measured. Thus, our IV approach may correct measurement error that induces attenuation bias in our OLS estimates.[12]

As mentioned previously, our measure of fertility captures the total number of children born by the time of survey, and as such, the fertility effect we estimate might be an artifact of delays in fertility, rather than actual changes in lifetime fertility. Three pieces of evidence make this explanation highly unlikely. Firstly, when examining the magnitude of the effect by age-group, we find that the negative fertility effect peaks in the age-group 35 to 39, but remains stable thereafter, indicating that lifetime fertility is indeed substantially reduced. Lagging the oil palm variable by five years does not meaningfully change the estimates (see Figure B2). We also report the pooled estimate for the two eldest groups (women aged 40-49) in Column 6 of Table 4, and find that the effect is even larger than the average effect and statistically significant. Second, we regress the fertility of women aged 40-49 on the average oil palm area observed over the last 20 years in Table B7 to account for women's full exposure during the main childbearing years, and our results are unchanged. Because we have no regency-level oil palm data prior to 1996, we estimate this relationship in a cross-sectional instrumental variables

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

approach, replacing the regency fixed effects in Equation 1 by province fixed effects. Third, we use fertility data from the DHS to examine if the effects we estimate overlap with changes in current fertility (number of births in the past 12 months). The DHS data are representative at the province level, which is why our estimation strategy in this exercise is limited to OLS with province- and year-fixed effects. We use DHS data from the years 1991, 1997, 2002-03, 2007, 2012 and 2017, and examine age-group specific effects on the number of children ever born and on current fertility. Panel A of Figure B3 shows the effect of oil palm expansion on the number of children ever born (consistent with our fertility measure in SUSENAS), while Panel B shows the effect on current fertility. Panel A closely mirrors our previous findings, providing evidence that our results are robust to the use of alternative data and identification strategies. In Panel B, we can see that effects on current fertility are negative throughout and driven by younger women (especially those aged 20 to 24), as well as by women in the age-group 30 to 34. Younger women may be reducing current fertility, because they delay marriage, stay in school longer, or start working. Yet, women in their thirties are most likely to adjust the desired family size downwards. Interestingly, the sum of all age-specific fertility effects is -5.57, which is almost identical to the estimates of Column 5 in Table 4. Taken together, these findings indicate that the fertility effect we estimate is indeed persistent, as oil palm area affects fertility over a considerable age-range and the negative current effects appear to accumulate over time.

B. Robustness Checks

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

Firstly, we use the national census of villages (PODES) to calculate the fraction of villages per regency with oil palm cultivation. While we expect this variable to be less prone to measurement error, this information is only available in 1993 and 2003. We replicate the specifications from Table 4 with this alternative measure of the oil palm expansion in Table B8 and our results are robust. We also test in Table B9, if our results change with use of the fraction of area of large-scale oil palm estates (that are identified from satellite imagery) as the main explanatory variable, rather than smallholder oil palm area. Our results are qualitatively similar. We also compare the effect of oil palm area on fertility between different producer types using administrative data. We use data from the years 2006 and 2016, because we do not have consistent data on private estates and total oil palm area at the regency-level before 2005. We find that the fertility effect is negative across all producer types, but is generally more pronounced for smallholder oil palm expansion.

We then test if our results are sensitive to including Java, Indonesia's main island, in our sample. Close to 40% of Indonesia's population lives on Java. At the same time, Java grows oil palm only to a very small extent. As can be seen in Table B10, the effect remains highly significant, while the precision of the first stage declines, as the low levels of oil palm cultivation on Java are not driven by low suitability, but rather by the limited availability of agricultural land. In Columns 2-5, we show that our results are robust to the inclusion of various alternative time-trends: province-specific linear time-trends (Column 2), attainable yield for low-input level rainfed rice (Indonesia's most important crop), multiplied by a time-trend (Column 3), the initial levels of regency-average fertility, electrification, female labor-force participation, and male agricultural wages, interacted with the national oil palm expansion instead of a linear time-trend (Column 4), and each regency's average altitude multiplied by a linear time trend (Column 5). As discussed previously, one concern with the validity of our instrument stems from the fact that the attainable yield for oil palm correlates with other characteristics, such as the attainable yield for other crops, or (inversely) with altitude (which, in turn, correlates with remoteness). These characteristics could generate a spurious correlation between our instrument and fertility and could bias our results. However, the fact that the effect size remains stable and significant throughout, indicates that this is not of major concern.

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

C. Understanding the Mechanisms of the Negative Fertility Effect

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

In Table 5, Column 1, we show estimates of the effect of oil palm expansion on household per capita consumption expenditures. We find a statistically significant and positive effect. The point estimate suggests that an increase in the regency area dedicated to smallholder oil palm cultivation by one percentage point, increases consumption expenditures by 3.4%. In Columns 2-4, we disaggregate the effect by the main activity of the household head, which – in the absence of information on land-ownership in the SUSENAS and SAKERNAS – is the only possibility of distinguishing farm households from non-farm households.[13] As can be seen, the positive consumption effect is largest among households, in which the head of the household is self-employed in agriculture as his main job, with the effect among households, in which the

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

head of the household is an agricultural laborer or works in the non-agricultural sector, being positive and statistically significant, but smaller. While suggestive at best, this indicates that income gains are largest among farm households.

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

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

We cannot clearly distinguish between the effects of income and of returns to education. As discussed previously, the largest income effects seem to occur among households, in which the head of the household is self-employed in agriculture, and the smallest income effects in households, in which the head of the household was employed in agriculture (Table 5). The negative fertility effects, in turn, are largest among women in households, in which the head of the households is self-employed in agriculture, about half as big, but still statistically significant among women in households, in which the head of household is employed in non-agricultural sectors, and virtually zero among women in households, in which the head of the household is employed in agriculture (Table B14). This would suggest negative effects of income on fertility in this context. Obviously, this exercise is subject to multiple caveats, as these households could differ along various other characteristics, such as age structure and migrations status. The major concern, however, would be that smallholder farmers are concentrated in different regions than large-scale oil palm plantations, where agricultural laborers would mostly find employment (Santika et al. 2019). To the extent that increases in the returns to education are largest in regions with strong local economy effects, there would be a strong spatial correlation between households, in which the head of the household is self-employed in the agricultural sector, consumption effects and increases in the returns to education. Disaggregating returns to education by the activity of the household head (as reported in Tables B15 and B16) suggests that this indeed seems to be the case: returns to education increase more strongly among households, in which the head of the household is self-employed in agriculture, than among households in which the head of the household was employed in the non-agricultural sector, and are unchanged by oil palm cultivation among households, in which the head of the household is employed in agriculture. In a final exercise, we examine if parents indeed invest more in the schooling of their children, which is a key prediction of both a potential income effect and the returns to education effect. In Table 8, we show that enrollment of school-age children (5-19) increases overall, though most pronouncedly in the age-group 10-14 years-old. The enrollment effect is also strongest among households, in which the head of the household is employed in non-agricultural sectors and (slightly smaller but still significant) among households, in which the head of the household is self-employed in agriculture.

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

D. Alternative Explanations

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

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

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

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

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

VII. Conclusions

Low-income countries continue to exhibit fertility rates that are up to three times as high as fertility rates in high-income countries. While substantial evidence shows that technological innovation and productivity growth were paramount in spurring the fertility transition of the US and Europe in the 19th Century, little is known about the relationship between productivity growth and fertility in developing country contexts. Understanding this relationship is particularly important, as many of these countries experience trajectories of economic growth that are widely different from the industrialization process experienced in the US and Western Europe.

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

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

Our results also speak to policy debates in developing countries. While we find a negative effect of oil palm expansion on fertility in Indonesia, this might depend on several preconditions. Firstly, Indonesia has a long tradition of cash-crop cultivation. People obtain a considerable part of food and non-food consumption goods from markets, and are surrounded by a relatively well established institutional and infrastructural framework. In settings with less amenable conditions for the development of a prospering non-agricultural sector, a decline in female labor productivity could lead to falling wages, potentially increasing fertility. Secondly, the availability of schools might matter. Our results suggest that investments in education were an important transmission mechanism. If high transaction costs impede such investments, fertility reductions might be less evident. Thirdly, it is important to note that oil palm was widely adopted by smallholder farmers. Agricultural productivity growth that is restricted to large-scale farms might have different effects. For instance, mechanization in large-scale agriculture might similarly increase labor and land productivity. However, if income gains are concentrated among a small elite, effects on demand for non-agricultural goods and on local economic development would likely be less pronounced or absent, which would substantially reduce the scope for fertility reductions. Studying the nature of productivity growth, and its contextual effects on fertility might be an important piece of evidence in understanding the heterogeneous development paths of different countries and regions.

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

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Figures

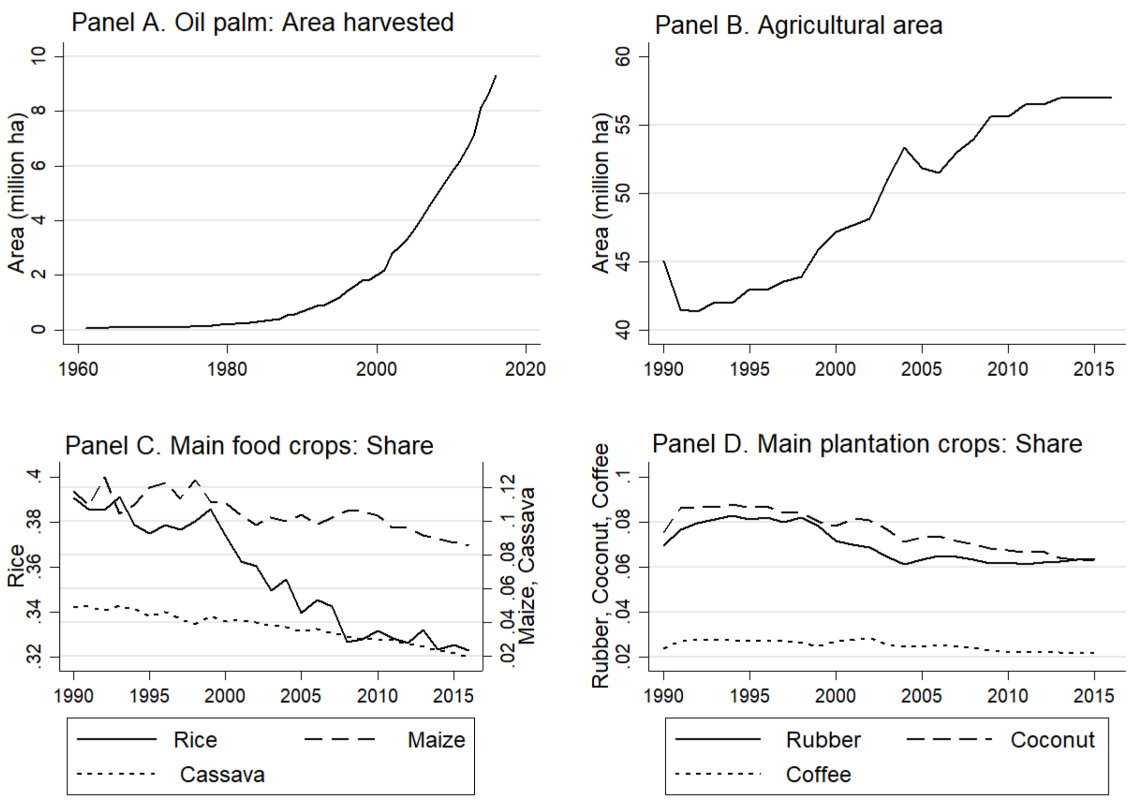

Figure 1: Cultivation area of oil palm and other main crops in Indonesia

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

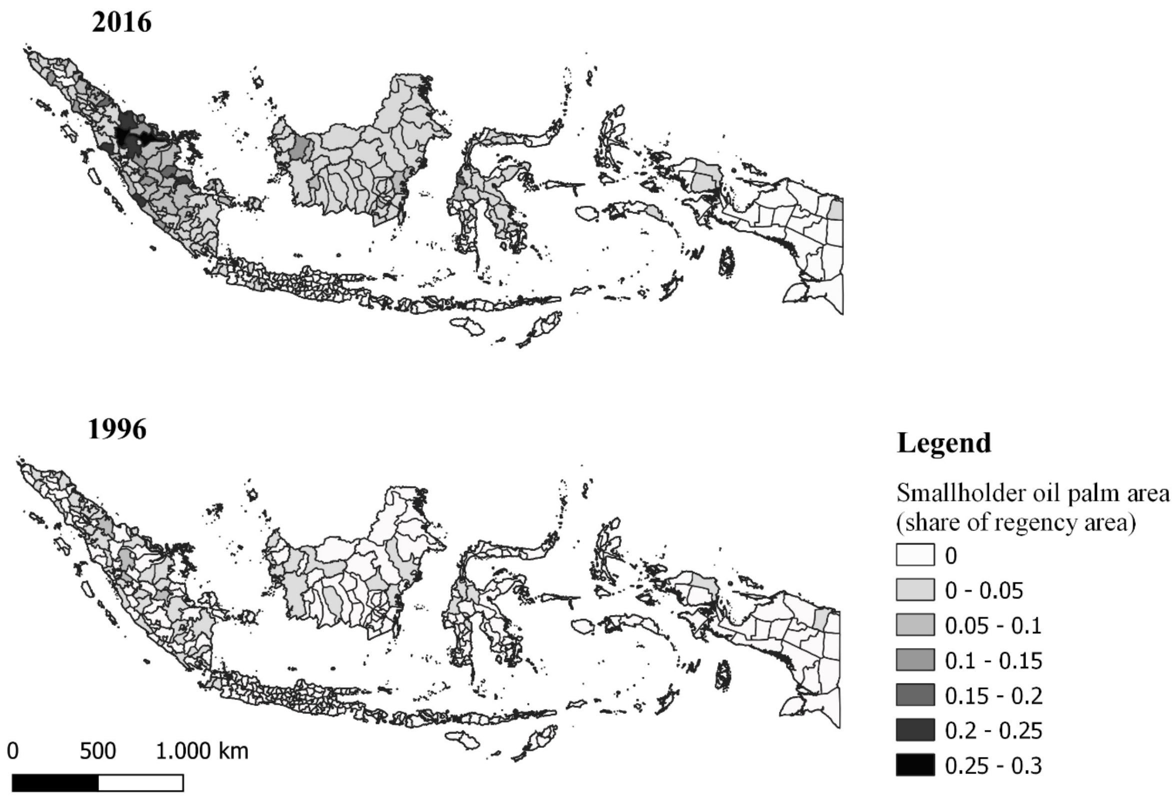

Figure 2: Smallholder oil palm area (fraction of regency area) in 1996 and 2016

Source: Tree Crop Statistics.

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

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

Tables

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

	Oil palm		Rubber		OLS estimates (Oil palm =1)
	Obs.	Mean (Std. dev.)	Obs.	Mean (Std. dev.)	Beta coeff. (Std. err.)
Profit per hour [000 IDR/hour]	435	61.956 (94.516)	969	13.146 (17.872)	39.725*** (6.582)
Profit per ha [000 IDR/ha/year]	439	10718.073 (10729.864)	972	8857.845 (12468.901)	296.358 (1133.671)
Variable inputs [000 IDR/ha/year]	439	2653.118 (2662.383)	973	651.996 (1021.978)	1358.937*** (191.010)
Male labor input [Hours/ha/year]	439	237.696 (211.090)	973	854.687 (997.983)	-574.337*** (48.534)
Female labor input [Hours/ha/year]	439	25.764 (65.350)	973	313.761 (471.624)	-268.782*** (37.107)

Source: Smallholder household data, Jambi province 2012 and 2015.
Notes: Regressions control for year and household fixed effects. Labor input includes family, as well hired wage labor. All monetary variables are in constant 2012 values. Profits are calculated as plot revenues minus expenditures for variable inputs and labor (family labor priced at province level agricultural wages). Sample: Plots of local smallholder farmers. Unproductive plots were excluded, and tree age restricted to main productive age from 5 to 25 years. Standard errors (clustered at household level) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Summary statistics

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

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

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

Table 3: Initial characteristics

	Summary statistics			Regression coeff.
	Obs.	Mean	Std. dev.	Independent var.: Attainable yield (t/ha)
Number of children ever born alive, women aged 15-49 (SUSENAS 1993)	139	2.29	(0.30)	0.070* (0.041)
Share of households with access to electricity (SUSENAS 1993)	139	0.31	(0.19)	-0.073** (0.029)
Consumption expenditures per capita (SUSENAS 1993)	139	37783.2	(9023.9)	1056.930 (1355.785)
Log Consumption expenditure per capita (SUSENAS 1993)	139	10.4	(0.20)	0.037 (0.033)
Share of women aged 15-49 with less than primary education (SUSENAS 1993)	139	0.40	(0.12)	0.011 (0.017)
Labor force participation rate, women aged 15-49 (SUSENAS 1993)	139	0.55	(0.17)	-0.061*** (0.019)
Share of labor force working in agriculture, women aged 15-49 (SUSENAS 1993)	139	0.63	(0.18)	0.005 (0.024)
Share of men aged 15-49 with less than primary education (SUSENAS 1993)	139	0.30	(0.10)	-0.013 (0.014)
Labor force participation rate, men aged 15-49 (SUSENAS 1993)	139	0.86	(0.05)	-0.001 (0.006)
Share of labor force working in agriculture, men aged 15-49 (SUSENAS 1993)	139	0.65	(0.13)	-0.012 (0.019)
Log hourly female agricultural wage, current values (SAKERNAS 1993)	135	5.87	(0.33)	0.152*** (0.054)
Log hourly male agricultural wage, current values (SAKERNAS 1993)	139	6.19	(0.25)	0.177** (0.042)
Median landholding (ha) (Census 1980)	139	0.53	(0.32)	0.024 (0.047)

Notes: The last column reports the coefficients from regressing the respective variable in the first column on attainable yield for palm oil (in t/ha). The dependent variables are obtained from SUSENAS 1993, SAKERNAS 1993, and the 1980 population census. All variables are measured at the regency-level based on 1993 boundaries, and computed using the sampling weights needed to recover regency-level population summary statistics (except the SAKERNAS data, which are computed at province level). Robust standard errors (clustered at the province level with SAKERNAS data) in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Effect of oil palm on fertility

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

Source: SUSENAS 1996, 2001, 2006, 2011, 2016.
Notes: Dep. Var.: Number of children ever born alive. Sample: Women aged 15-49 (40-49 in Column 6). Standard errors (clustered at regency-level) in parentheses. Anderson-Rubin 95% confidence intervals (robust to weak instruments) in brackets.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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

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

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

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

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

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

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

Source: SAKERNAS 2001-2015.

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

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

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

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

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

Table 8: Effect of oil palm on enrollment

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

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

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