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Curse of the Good Rains
The Long-Run Impacts of Locust Infestations

Evidence from the 1986-89 Locust Plague in the Sahel

by

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Abstract

This thesis estimates the long-run impacts of a desert locust plague, which lasted from 1986 to 1989. It considers the effect of in utero exposure and during young ages for both men and women. The analysis is based on DHS surveys from the Sahel countries Senegal, Mali and Chad and data on locust infestations to derive the impact of the plague on adult education and height outcomes. The focus of this thesis is on rural individuals born between 1980 and 1990. Results initially show no negative impact of the locust plague on both men and women. After stratifying by education levels, though, there is a significant negative impact of the locust plague on men from below-median education clusters. The evidence is clearest for those affected during the first two life of years. The results for women are mixed with no apparent negative impact on education levels. However, height outcomes indicate towards a persistent negative effect of the plague, in particular for those affected in utero and during their first year of life. The obtained results add to the yet sparse evidence on the economic and social impacts of locust plagues and implies that further efforts to prevent the occurrence of locust plagues are important. Particularly in the context of the Sahel region, which is object to a variety of climatic and man-made disasters, adverse income shocks can have persistent effects.

Keywords: Income Shocks, Child Health, Education, Natural Disasters, Sahel

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“Hear this, you elders;

listen, all who live in the land.

Has anything like this ever happened in your days

or in the days of your ancestors?

Tell it to your children,

and let your children tell it to their children,

and their children to the next generation.

What the locust swarm has left

the great locusts have eaten;

what the great locusts have left

the young locusts have eaten;

what the young locusts have left

other locusts have eaten.

Wake up, you drunkards […]”

(Joel 1:2-5)

1 Introduction

The very first years of life are crucial for the development of young children, and any nutritional deprivation experienced during that time can have long-lasting consequences. Barker & Osmond (1986) have coined the term “fetal origin hypothesis”, which basically proposes that undernutrition in utero has a permanent adverse effect on health, even in adult stages. In recent years the long-term impact of adverse shocks on affected children has received a lot of attention. The main interest lies on their effect on people’s levels of education, health outcomes or income among others. There is indeed plenty of recent evidence indicating that economic and nutrition shocks have large impacts on health outcomes for children that were in utero or during early childhood (Abiona, 2017; Beuermann & Pecha, 2020; Groppo & Kraehnert, 2016; Lo Bue, 2019). Similar evidence was found for education outcomes (Hyland & Russ, 2019; Nguyen & Minh Pham, 2018).

The topic of this thesis is the long-term impact of a particular kind of plant pests, desert locust plagues in the Sahel. During major infestations large amounts of desert locusts can devour farmers’ crops and leave vast stripes of bare land. Under favourable weather conditions the normally solitarious desert locusts can reproduce rapidly and become gregarious. They then start moving in larger groups and form marching bands on the ground or flying swarms that migrate frequently in search for food. They can cover up to 1,700 metres and more than 100 kilometres per day, respectively. These accumulations of locusts can reach sizes of 1,200 square kilometres for a single swarm. A swarm of one square kilometre in size is capable of consuming an amount of vegetation, which approximates the daily food consumption of 35,000 people, per day. They are a clear example of an adverse shock, particularly to rural households dependent on agricultural outputs as their main source of income. Locusts have been a common threat to humans for thousands of years and been mentioned in the Quran and Bible. Indeed, at the time of the writing of the thesis a major desert locust upsurge is devastating considerable parts of land at the horn of Africa and threatening the livelihood of large parts of the mostly rural populations in several countries. However, unlike other natural disasters such as earthquakes or droughts, locust plagues can to a certain degree be prevented and tackled. Thus, an analysis of their long-run impact can contribute to evidence supporting (or not) further efforts that can be taken to improve desert locust prevention mechanisms.

The overall research question is to what extent a major locust plague from 1986 to 1989 affected children living in rural areas. More specifically, I ask whether the occurrence of the plague led to lower education levels as well as worse health measured in terms of heights for those who were affected in utero or during their first four years of life. Also, I analyse if differences by gender can be observed. Taking both education and height indicators into consideration might give us more robust findings, especially since health outcomes are evidentially associated with educational attainments (Martorell et al., 2010; Behrman, 1996). To my knowledge, this research project is the first to directly assess the persistent impacts of locust infestations on adult outcomes. I make use of data on both men’s and women’s educational levels and women's heights using nationally representative data from Demographic and Health Surveys (DHS). I design a pooled cross-section of ten nationally representative surveys conducted between 2008 and 2018 and covering nearly 145,000 individuals from three Sahel countries: Chad, Mali and Senegal. Data on desert locust activity during that time period was provided by the FAO, which continuously updates a geo-referenced dataset based on reported observations of locust infestations. The basic model that is used in this research analyses the impact of desert locust infestations on education outcomes and height, controlling for weather factors, administrative areas and birth years.

The Sahel countries are among the poorest countries in the world and thus have a more limited capacity to react to locust infestations compared to wealthier North African and South-West Asian countries (Showler, 2019). The region has been affected by a number of droughts, famines and wars over the past century and is thus particularly vulnerable to and affected by income shocks.

My results imply that the analysed locust plague had a long-lasting effect on adults who were young children at the time of the plague. Effects can mostly be shown for people from areas with comparatively low levels of education. Also, the evidence suggests that men might be more severely affected than women. The strongest effect was seen on men from below-median education regions in their first and second year of life but not those in utero. The locust plague might have reduced total years of schooling by 0.42 years for those in their first year of life. When taking a more restricted definition of treatment, the evidence suggests a reduction of education by around six months for new-born male babies until two years old. The likelihood of ever attending school might have been reduced by ten percentage points. For women the results are mixed and no clear negative effect on education can be seen. On the other hand, we observe an impact on height levels for females from areas with low levels of education who were in utero or until one year old with a height reduction of 1.58 and 0.97 centimetres, respectively. Using the more restricted treatment, results also indicate towards a negative effect on women from above-median education levels.

The structure of the thesis is as follows. In Chapter 2, I provide background information and review the existing literature. First, I explain the biology of desert locusts. Furthermore, information on the history and impact of locust infestations and particularly the plague from 1986 to 1989 is provided. After that, the link between early-life shocks and educational and health outcomes in the short and long run are explained. Finally, I present current empirical literature on the impact of natural disasters and weather shocks on those outcomes. In a next step, Chapter 3 provides a first overview of the methodology used and gives a precise description of the data and its limitations. In Chapter 4, I present my empirical strategy in more detail and address possible concerns that might arise. Next, Chapter 5 lays out my results as well as a discussion of the findings. Chapter 6 concludes and gives an outlook to future research opportunities.

2 Background & Literature Review

2.1 Desert Locusts

2.1.1 General Terms & Biological Background

The desert locust, or *Schistocerca Gregaria*, is a species of locusts that is common in desert regions from Western Africa to India. They usually live as solitarious individuals[1] in remote areas and pose no threat to human beings. However, these harmless insects can convert into arguably one of the most dangerous agricultural pests in the world. Although locusts are part of the grasshopper family, one key feature that distinguishes them is their capability to alter behaviour, colour and shape when population densities increase following weather conditions that favour their reproduction (WMO & FAO, 2016). This is referred to as density-dependent phase polyphenism and has received broad attention from a number of scientists (Ayali, 2019; Pener & Simpson, 2009; Cullen et al., 2017). In the case of high rainfall intensity, combined with the development of green vegetation, desert locusts are capable to rapidly reproduce. With augmenting density, they tend to start moving in groups and become gregarious. This is accompanied by a change of their body colour from pink/brownish to yellow (WMO & FAO, 2016; Showler, 2019; Cullen *et al.*, 2017). Gregarious desert locusts are characterised by increased migration patterns. When confronted with a shortage of food they travel to areas with more abundance of food. They can live on numerous types of cereal crops, trees and coffee and thus pose a considerable danger to agricultural outputs (Le Gall, Overson & Cease, 2019).

There are four different important terms that are crucial to describe desert locusts' development: hoppers, bands, adults and swarms. Hoppers are juvenile wingless larvae, which in general can be found in low numbers. For the reasons pointed out above though, hoppers tend to start becoming gregarious when locust density increases and form so-called bands. Dependent on availability of green vegetation, bands can march between 200 and 1,700 metres a day. After several moultings (shedding of skin) the hoppers become adults. A decisive difference to the hopper-stage is that adult locusts have wings, which largely increases their mobility. Gregarious adults then can form swarms, which travel downwind up to ten hours a day and can cover more than 100 kilometres a day. An average locust swarm on the ground usually has a density of around 50 million locusts per square kilometre and 50 percent of swarms reach an enormous size of 50 square kilometres (WMO & FAO, 2016). That is to say,

[1] The term ”solitarious” means that locusts avoid other locusts, whereas gregarious locusts are attracted to each other and accumulate to bigger groups.

a swarm containing 2.5 billion locusts is not uncommon, capable of eating the same amount of food as 1.75 million people.

2.1.2 Desert Locust Areas and Infestations

The FAO distinguishes between locust infestations depending on the duration and extent of it. First, an outbreak occurs when small groups of bands or swarms are spotted inside a limited area (ca. 5,000 square kilometres). Further spreading and reproduction of locusts lead to a regional upsurge. Finally, a plague can develop if several regions experience upsurges at the same time (Cressman, 2016). The scale of the infestations highly depends on the continuity of favourable weather conditions and to a certain extent the intervention capacity of states.

Usually, desert locusts can be found in isolated desert regions in around 25 countries in Africa, the Middle East and India. During plagues this area can vastly expand and one fifth of the world's land mass can potentially be affected by locust infestations (WMO & FAO, 2016). The frequency as well as duration of desert locust plagues has considerably declined over the past 60 years. Whereas there were several locust plagues which lasted for ten years or more until the 1960s this has changed since then (Cressman, 2016). This can likely be linked to improvements in the desert control capacities (Lecoq, 2003).

2.1.3 Impact of Locust Plagues

There is a particular feature that makes locust plagues different to other natural disasters or weather shocks. They usually occur in times when rainfalls are high, favouring overall crop production (WMO & FAO, 2016). For this reason, they are commonly referred to as the "curse of the good rains". This might in parts explain why despite the comparatively frequent occurrence of locust infestations, their economic and social impact has been barely studied. Whereas many farmers are highly affected by the disaster, the overall macroeconomic impact might be marginal. This is due to the fact that the favourable weather conditions enable high crop production in unaffected parts of the country. Also, a quantification of the locusts' impact usually does not take into account the potential long-term loss generated in terms of education and health outcomes of babies born during and being infants at the time of it.

The previous figure might seem to suggest that locust activities since the 1960s are more or less under control and pose no serious threat anymore. However, there were several upsurges over the past years, of which two reached the plague status. The plague from 1986 to 1989, which is in the focus of this thesis, affected over 65 countries. The geographic spread of locust swarms and bands is shown in Figure 1. A total amount of 274 to 310 million US dollars, which involved the contributions of international donors, was spent on measures to control it (Belayneh, 2005; Skaf, Popov & Roffey, 1990). The speed at which the plague developed and the number of countries it affected were remarkable. Skaf, Popov & Roffey (1990) point out that just before the plague, in 1984 and 1985 locust populations were arguably at their lowest level in fifty years, which underlines the sudden and rapid spread of locusts. In a plague from 2003 to 2005 costs for measures were as high as 400 million US dollars (Brader et al., 2006).

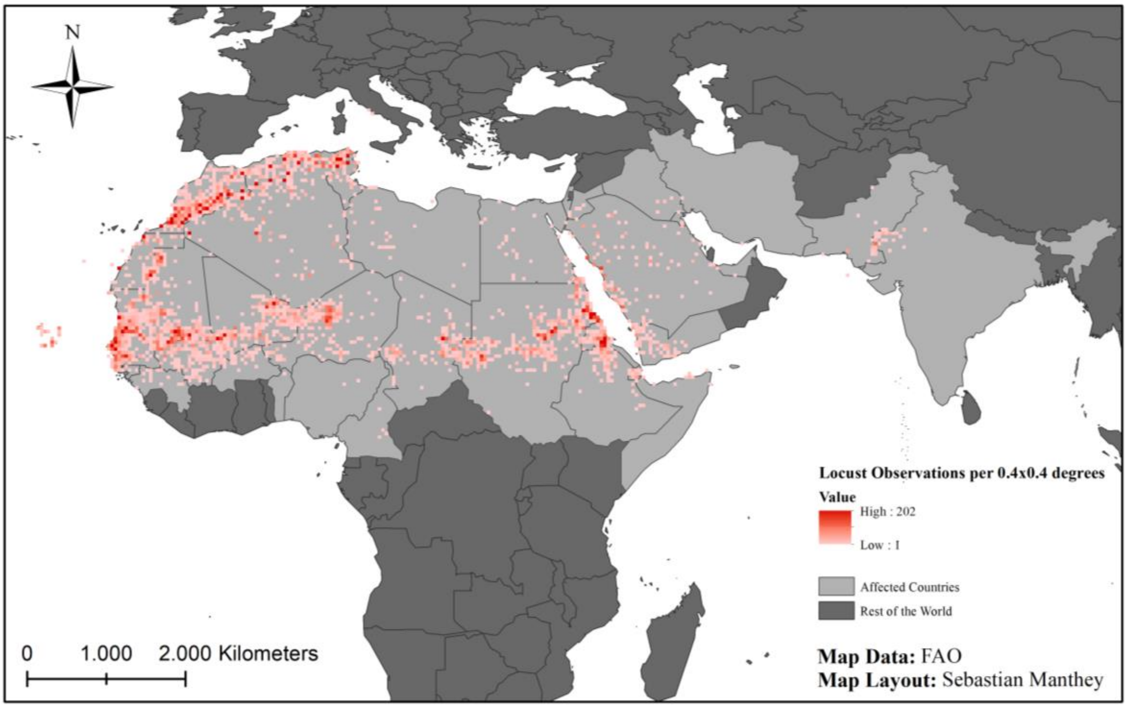

Figure 1: Locust plague 1986-1989

Calculating the economic impact of locust plagues is challenging for a variety of reasons. First, there are practical reasons why the calculation of economic damages results difficult, namely ongoing wars and inaccessibility of regions. On top of that, social disruptions are often not taken into account and the economic damage of the destruction of grazing lands is usually not quantified (Lecoq, 2003). Similarly, as explained above, locust plagues are highly related to above-average rainfall and increases in vegetation, which usually boosts overall agricultural production, and arguably national levels of production increase (Thomson & Miers, 2002). Recent case studies from Mauritania and Eritrea show little impact of locust infestations on national crop production. In general, locust pests were seen as a smaller threat than droughts or other plant pests. Nonetheless, in both studies, locust infestations, although less likely, are described as considerably more destructive than other pests. People affected by locust infestations mentioned they lost the majority of their crops and that they could not rely on conventional informal insurance mechanisms (Thomson & Miers, 2002). Figure 2 shows that overall food production in all studied countries did not markedly decrease during the locust plague from 1986 to 1989. Rather, continuous cyclical production patterns, with particularly strong variations in Senegal, can be observed, perhaps due to rainfall patterns. It is in Senegal where we observe a fall in the overall production. Looking at previous and subsequent variations this does not show an abnormality. However, it might indicate that the locust plague had a stronger impact there compared to Chad and Mali.

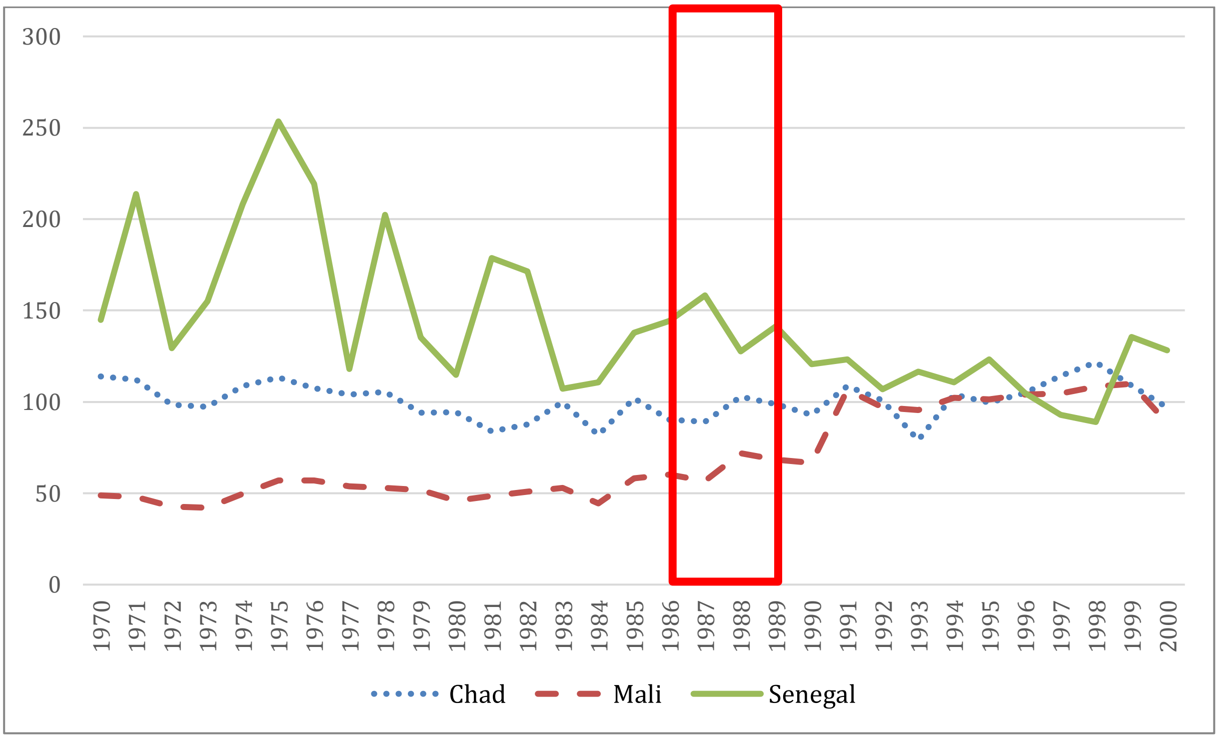

Figure 2: Gross per capita food production index number (2004-2006 = 100)

Data Source: FAO (2020)

Estimations show that the desert locust plague from 1986 to 1989 has gravely affected crop production and grazing lands in several West African countries. Losses in affected areas possibly were 70 percent of the rain-fed crops, half of irrigated crops and around 60 percent of grazing land in Mauritania. In Niger, half of the grazing land and a third of rain-fed crops were lost. Estimates for Mali, though are way less precise an range between five to 75 percent of rain-fed crops and 65 to 90 percent of grazing land (Lecoq, 2003). Evidence presented by Brader *et al.* (2006) shows that nearly 8.4 million people in the Sahel might have been affected by the plague in 2003-2005 and losses being between 80 and 100 percent of cereal production and staple leguminous crops.

The presented findings underline two key facts: First, correctly identifying the damage locust plagues cause is a considerable hurdle, which also impedes states' capacity to request more funds from international donors. Second, the impact of desert locust infestations is not evenly spread, and it is indisputable that on the household level locust plagues can lead to the destruction of entire harvests and sources of income for people living in rural areas.

2.2 Impact of Early-Life Shocks

Income shocks, e.g. generated by natural disasters and weather shocks, can affect children in utero and young age in various ways. The focus of my thesis is on the impact malnutrition can have on the physical health and development of children.[2] Although my analysis focuses on adult outcomes, a prior theoretical explanation of the origins of these outcomes is crucial. As shall be explained, the course for the future is in large parts set during infancy.

2.2.1 Responses of households to income shocks

Research shows that after the occurrence of income shocks households tend to adjust their expenditure patterns. In general, less money is spent on human capital investments (Jensen, 2000) as well as food with high nutritional values (Jensen & Miller, 2007; Hsiang & Jina, 2014). When thinking about the impact of the locust plague, the most direct effect one would expect is the one it has on the access to food. Rural households are often dependent on crop yields and their livestock for food consumption, or alternatively income derived from selling agricultural products. Particularly in the absence of savings or appropriate insurance mechanisms, the sudden destruction of crops and grazing grounds can have an immediate and large effect on the access affected households have to food. Indeed, besides the livestock's importance for food consumption it also might serve as a way to store wealth (see also Linnros, 2017). Thus, if livestock perishes due to a lack of access to food, this also affects household's ability to react to income shocks. It is particularly difficult to design formal financial products such as insurances and credits in poor rural areas (Viganò & Castellani, 2020). Consequently, severe shocks might constrain households' possibilities to invest in children's nutrition and health.

2.2.2 Malnutrition in Infant Stages and Effect

The base for a variety of studies is the "fetal origin hypothesis". The principal argument is that undernutrition in prenatal stages can be linked to a significantly higher risk of coronary heart disease. During the growth process, the foetuses adapt to and their cells are programmed to the environment they find inside the mothers' womb. If the circumstances in the "outside" world then do not match with the ones encountered in the womb this seriously harms the infants' development (Barker & Osmond, 1986). It has been shown that lesser heights or low weights at birth are reliable predictors of such maladjustments (Barker, 1995). Brown & Pollitt (1996) point out that malnutrition can have a variety of effects on children's mental health. One of them is brain damage, which in certain cases might be reversible. However, there

[2] Another possible way how income shocks can affect children is via their effect on mental health, principally through post-traumatic stress disorder (Caruso & Miller, 2015).

are additional effects like higher probabilities of becoming ill linked to a delay in the development of motoric skills. This, on the other hand, might trigger a less explorative behaviour of children and lower parents' expectations because the child seems younger than it actually is. All of this is thought to result in a delay of intellectual development. Grantham-McGregor, Fernald & Sethuraman (1999) assemble evidence from other papers and point out that the nutritional intake of children during the first two to three years is crucial for children's cognitive development measured by literacy, IQs and school grades. Likewise, Pollitt (1990) concludes that malnourished (protein and energy deficiency) children are found to have a disadvantage in terms of intelligence. Also, measures for early life body development in terms of height and weight can be related to performance in school. The author puts forward that comparatively small and underweight children are more likely to enrol to school later as well as drop out earlier. Sánchez (2017) illustrates that indicators of height-for-age are significantly related to cognitive skills in developing countries. A similar study by Martorell *et al.* (2010) links lower birth weight to less schooling and a higher risk of grade failure in Brazil, Guatemala, India, the Philippines and South Africa. Thus, there is a variety of evidence pointing towards a significant impact of malnutrition during early childhood on the development of motoric and intellectual abilities.

2.2.3 Impact of Adverse Shocks – Childhood Outcomes

Following the causation channels described above, a number of empirical studies directly links adverse income shocks to children's outcomes at early ages. Abiona (2017)'s study finds that negative rainfall shocks (droughts) in Malawi lead to a decrease of 15 to 43 percent in weights and 14 to 27 percent in height (both standardized by age) for children who experienced the shock while in utero until two years old. Similarly, Groppo & Kraehnert (2016) focus on the impact of a particularly severe winter in Mongolia in 2009/2010 and point out that height-for age scores are usually around 1.3 standard deviations lower in affected regions compared to others. The effects found by the authors are strongest for children who were in utero. Nguyen & Minh Pham (2018) in a comparative study of natural disasters in Ethiopia, India, Peru and Vietnam have varying results. Their results show a strong adverse impact of floods on outcomes such as completed grades and school enrolment. For other disasters (droughts, frost, hailstorms) the evidence is less clear. Lo Bue (2019) illustrates how forest fires in Indonesia in 1997 negatively affect height scores, and how these then reduce educational attainments. Beuermann & Pecha (2020) use data on tropical storms in Jamaica between 1987 and 2011. Importantly, they discover a strong negative impact of particularly strong hurricanes, reducing weight-for age scores by around 2.6 standard deviations. Evidence on milder storms is inconclusive.

All this evidence suggests that adverse shocks, including weather shocks and natural disasters, can affect early-life outcomes such as weight- and height-for-age. Also, we observe indications that enrolment rates are affected. The next logical step then is to see if these impacts are likely to be prolonged over time and if adults who were exposed to the shocks in early life are still affected.

2.2.4 Persistence of Childhood Malnutrition Effects into Adulthood

The persistence of the effects caused by early-life shocks is still highly controversial. One crucial aspect which is in the focus of many studies is to what extent the caused damages can still be reverted. One extraordinarily influential and thorough analysis by Victora et al. (2008) concludes that early-life shocks, especially undernutrition, have permanent effects on human capital accumulation and height. Grantham-McGregor, Fernald & Sethuraman (1999), however, provide mixed evidence on the possibility that stunted children can catch up in terms of height and weight during later stages of their childhood. They indicate that catch-up can be achieved if children receive nutritional supplements combined with psychosocial stimulation, which in a natural environment is unlikely to happen. Similarly, Pollitt (1990) implies that initial malnourishment can be corrected for when nutrition is provided after the deficit in the early childhood period.

In general, it appears that to a certain level there might be ways to generate a "catch-up" to non-affected children. Nonetheless, this is often linked to certain organizational and financial capacities to provide supplements to affected children. Even relatively mild shocks like weather shocks are found to potentially impact a foetus' and child's development with long-lasting consequences. Importantly, the severity of consequences is likely increasing with the constraints to a household's budget (Almond, Currie & Duque, 2018). This can be a major problem in developing countries. Indeed, Currie & Vogl (2013) name three reasons for why early-life health shocks are likely to have long-term consequences in developing countries. First, the frequency of shocks is expected to be high, making e.g. malnutrition a rather consistent instead of once-in-a lifetime phenomenon. Also, there are more interactions between health shocks during infancy, where malnutrition could be combined with disease, so that the capacity of the child to recover from both shocks is lower. Finally, mitigation strategies and the capacities of households to react to shocks and compensate for losses are arguably less effective than in developed countries, making it more likely that a shock has a persistent effect (Currie & Vogl, 2013).

2.2.5 Impact of Adverse Shocks – Adult Outcomes

The arguments presented indicate that we would mostly expect that adverse income shocks could lead to long-run impact on educational and health outcomes. Below I present some empirical studies to investigate if this is the case.

The possibly most complete study to this date was done by Alderman (2006), which received broad attention inside the scientific community. His unique longitudinal survey contains data on anthropometrics as well as education for 400 households in rural areas in Zimbabwe. These households were repetitively interviewed between 1983 and 2001. Over this time period there were shocks such as civil war (roughly until the mid-80s) and droughts from 1982 to 1984. The author presents evidence that the adverse shocks have a negative impact on pre-school heights. Likely important, these deficiencies caused by a lack of nutritional inputs are shown to be persistent, and the impacted individuals are, on average, shorter and less educated at adult stages than non-affected counterparts. Another highly relevant study for this thesis is the one done by Hyland & Russ (2019), which extensively analyses the long-run impacts that droughts have on women in 19 Sub-Saharan countries. Their outcomes show a substantial impact of droughts on wealth levels, education and, in the case of severe droughts, heights of adults. It is of particular relevance in the sense that, apart from its implications for the effect of natural disasters in general, it clearly highlights that households in the Sahel zone are exposed to a variety of environmental shocks on a continuous basis. Neelsen & Stratmann (2011) study the impact a famine in Greece in 1941-42 has on long-run education and labour market outcomes and find that those people that were exposed to the famine while being an infant or foetus have on average between 1.6 and 2.9 months less of education and are between 2.1 and 3.3 percent less likely to finish upper secondary school. Caruso & Miller (2015) study the impact of an earthquake in 1970 in Peru. Their empirical study demonstrates that women are stronger affected than men, with an average reduction in schooling of 0.8 and 0.5 years, respectively.

Conclusively, most evidence points towards a lasting effect of malnutrition on people's education and health. Thus, adult outcomes can clearly serve as a measure to assess the severity of a particular shock and the degree to which it affected households. Similarly, a lack of findings might be an indicator that either the shock was not as severe as one might expect and/or perhaps additional nutritional intake led to a catch-up of affected children.

2.2.6 Differences by Gender

There is no clear consensus on whether impacts in early childhood have a stronger effect on boys/men or girls/women. Whereas Caruso & Miller (2015) find a stronger negative impact on women, Groppo & Kraehnert (2016) show higher and more significant negative effects on boys' outcomes.

Most research points towards girls' higher resilience to nutritional shocks experienced in early life (Fukuda, Fukuda, Shimizu & Møller, 1998; Stevenson et al., 2000). However, other scientific evidence indicates that girls might be more affected than boys because female foetuses are more gravely affected by a deficit of iodine (Currie & Vogl, 2013). Importantly, besides the biological resilience to shocks, it is important to take into account how households' decisions differ between boys and girls. For example, boys might be valued higher than girls so that in the case of income shocks the resources inside a family might be rather allocated to male offspring. In addition to that, the birth order possibly plays a role, too. All these factors might highly depend on cultural norms and customs. A big overall gap in education outcomes between men and women would point towards a higher overall spending on education for boys. Thus, differences in gender might highly depend on the context and particularly, the statistical significance of outcomes may be driven by the heterogeneity in outcomes, with boys usually having significantly higher education outcomes than girls. For the West African context, there are clear indications that the formal as well as informal social institutions are discriminatory to women and hinder their access to education (Bouchama et al., 2018). Kuépié (2016) argues that women in Senegal and Mali have considerable less education levels than men and labour market inequalities are high. This can in parts be explained by the role of women to raise large families (the so-called "fertility burden").

2.2.7 Studies on Impact of Locust Infestations

To my knowledge there are only three studies that analyse the potential impact of locust infestations on education and health outcomes. Vreyer, Guilbert & Mesple-Somps (2015)'s analysis focuses on the impact of the locust plague from 1986 to 1989, which is also the subject of this study, on enrolment rates and educational attainment of children in Mali. They find a significant negative impact in rural areas. The authors show that the locust plague might have led to a reduction in school enrolment of 7.5 percent for boys and 5 percent for girls. Girls see a decrease of one grade in schooling, whereas boys' educational attainment is shown to be reduced by less than half a grade. A recent publication of Conte, Piemontese & Tapsoba (2020) finds a significant negative impact of the locust plague from 2003 to 2005 on children who were in utero at the time of the plague. Interestingly, no evidence was shown for children already born. On average, height-for-age Z-scores are reduced by 0.33 compared to those children that were not exposed to the locusts. The authors show that these effects are not only due to the individual losses of crops. They argue that speculative price effects because of the anticipation of the locust plague might have had a similar effect (Conte, Piemontese & Tapsoba, 2020). In another study, Linnros (2017) investigates how locust infestations between 1985 and 2015 impact children's height levels in West Africa. Her results imply a causal impact of the degree of exposure to locusts on health, particularly in rural areas. The author designs an indicator taking into account the number of infestations a child is affected by during childhood standardized by age and distance of the locust infestations. She demonstrates that an increase by one standard deviation in the yearly exposure leads to a decrease of the height-for-age Z-score by 0.084. Thus, the impact of locust infestations on early life development has been investigated in depth. However, up to this date no study has derived the persistence of effects into adulthood. My analysis fills this gap by providing estimates on educational attainment and adult heights.

3 Methodology & Data

3.1 Methodology

The methodology applied in this thesis highly depends on a preceding understanding of the data that is used. Large parts of the method used build on a prior setup of connections of various datasets based on spatial and temporal information. Thus, I only roughly outline the methodological strategy at this point and go into more depth in the next chapter.

The identification strategy used in this paper targets at deriving the long-run impact of the locust plague from 1986 to 1989 on education and health of people who were in utero and until four years old at the time of the infestation. As pointed out above, the most severe impact can be expected on infants until two years but also at slightly later ages. Including children until four can add to the literature by investigating how these age groups can possibly be affected. The model used is a linear fixed effects model with locust infestations as a treatment to certain individuals. This analysis focuses on the direct impact of locust infestations, that is to say crop losses and the loss of livestock.[3] A clear link between locust infestations and individuals can be created thanks to the precise spatial and temporal information available. I further control for deviations from average rainfall and temperature levels to disentangle the effect of higher crops yields due to favourable conditions from that of the devastating impact of locust infestations. Following the evidence of heterogeneous effects by gender presented above, I carry out my analysis separately for males and females.

3.2 Sampling

Only a specific sample of all individuals from the DHS surveys are included in the analysis. Given that shocks caused by locust infestations are principally caused by the destruction of crops and grazing lands and that the evidence does not point towards a major macroeconomic food crisis, I restrict my analysis to rural households. Included individuals are born between 1980 and 1990. There are several reasons for the choice of these years and two opposing requirements. On the one hand, we want a sample that is big enough to have sufficient observations to capture regional patterns and create internal as well as external validity. On the other hand though, we need a control group which is comparable to the treated group. The Sahel

[3] Conte, Piemontese & Tapsoba (2020) for example also consider the indirect effect of a locust plague via price changes.

countries are object to continuous changes in education infrastructure and climatic environment. The levels of education in the sample have dramatically changed over the past years. Thus, having a reasonably small sample, I can keep the changes between the different cohorts minor. On top of that, disasters such as famines, droughts and wars are frequent and recurrent issues in the region. A major drought in the Sahel, which lasted between 1968 and 1973, led to famines in all the countries included in the sample and possibly caused the death of over 100,000 people. Choosing a lower bound of 1980, I exclude those children that were affected most heavily by the famine itself and the uncertain environment. The upper bound of 1990 was chosen because it is the last year with individuals that were affected by locust infestations. Furthermore, including more recent years would contain an increasing amount of individuals that are not fully grown yet and did not have the time to finish their education.

3.3 Data

My analysis builds on three main data sources. The ten surveys from the Demographic and Health Surveys (DHS) contain socioeconomic information on the individual level. The desert locust data from the Desert Locust Information Service (DLIS) shows locations and types of locust infestations. Weather data between 1901 and 2018 is taken from the Standardized Precipitation-Evapotranspiration Index (SPEI).

3.3.1 Demographic and Health Surveys

The outcome variables of interest of this thesis come from one principal data source, the DHS. The DHS Program was initiated in 1984 and since then frequently has collected standardized data on a variety of indicators, principally related to health and education outcomes.[4] The nationally-representative DHS survey women aged 15-49 years, also containing data on their children, and men between 15 and 49 or up to 59 years old. One factor, which makes DHS surveys appealing is that the majority of them collects geo-referenced data on a cluster level, which allows researchers to do more precise analyses by not having to rely on the assignment of households to broader geographic units. This is particularly useful in analyses of developing countries, which usually have less availability of geo-referenced data.

All DHS surveys included are pooled. Given that this analysis focuses on adults that were affected by the plague, only surveys from 2007 on were considered. Earlier surveys would possibly contain data of children (from 15 years on) that were affected by the plague. This leaves me with a pooled cross-section of ten surveys from three countries (Chad, Mali and

[4] A description of the questionnaires and variables used in this analysis can be found at https://dhsprogram.com/publications/publication-dhsg4-dhs-questionnaires-and-manuals.cfm.

Senegal) shown in Table 1.[5] A minor part of the clusters from the different surveys has no information on geographical location and was thus dropped from the sample. The remaining pool contains information on 35,100 individuals who were born between 1980 and 1990. Although the DHS surveys are standardized, not all the surveys necessarily include the same number of questions and target groups. Indeed, data availability on women's heights or residence status highly varies between countries and surveys. Nonetheless, I decide on keeping the maximum number of observations that is available for each step taken to create the most representative picture possible.

There are two main outcomes of interest taken from the DHS surveys: education and health. For education, I use a wider array of indicators. The first one is education in years. Second, a variable on educational achievement[6] is considered. Based on that variable I create a dummy variable indicating whether an individual has never attended school or has had some education. Height measurements were only available for a subset of women in some of the surveys. I use two variables: Height in centimetres and the allocation of people in a height/age percentile based on an international reference group.

Some observations are dropped due to missing information on education. The remaining sample consists of 29,883 women and 5,217 men. The overrepresentation of women can be explained by the nature of DHS surveys, which have a focus on maternal and child health. Three of the surveys focus explicitly on women. In total there is height data for 7,343 women (see Table 1).

Table 1: Included DHS surveys

Country	Survey Year	Observations	Included Observations	Male	Female	With Height Data	With Migration Data
Mali	2012/13	14,822	3,806	803	3,003	1,559	0
Mali	2015	7,758	2,230	0	2,230	0	0
Mali	2018	14,371	3,109	833	2,276	1,158	3,109
Chad	2014/15	22,861	5,922	998	4,924	3,219	0
Senegal	2008/09	19,441	5,775	0	5,775	0	5,775
Senegal	2010/11	20,306	4,816	865	3,951	1,407	0
Senegal	2012/13	8,636	2,014	0	2,014	0	0
Senegal	2014	11,680	2,332	523	1,809	0	0
Senegal	2015	12,585	2,594	651	1,943	0	0
Senegal	2016	12,392	2,502	544	1,958	0	0
Total	2008-2018	144,852	35,100	5,217	29,883	7,343	8,884

[5] I originally considered adding DHS surveys from Ethiopia to the sample. However, the country was struck by one of the worst famines the continent has seen between 1983 and 1985. This would highly influence my reference group as well as treatment group and create biases. For that reason the country was left out.

[6] The educational achievement variable is originally coded to: none, incomplete primary, complete primary, incomplete secondary, complete secondary, higher education.

The locations of each DHS cluster are set independently of previous rounds and thus vary for each survey. In order to guarantee confidentiality, the GPS position of individuals within DHS clusters are randomly displaced. Clusters in DHS data are composed of geographically closely located villages in rural areas. Thus, the position of rural clusters is displaced by up to five kilometres, and in one percent of the cases ten kilometres (Burgert, Colston, Roy & Zachary, 2013). This is crucial for the process of spatial joins to locust observations, which is further discussed in Chapter 3.4.

3.3.2 Desert Locust Data

The FAO, or more precisely the Desert Locust Information Service (DLIS), has been gathering geo-referenced data on desert locust infestations in highly affected areas since the 1950s (Cressman, 2013). A description of that data and predictions on possible future locust movements is regularly published in bulletins which are publicly available.[7] This data is collected by ground teams scanning vast areas for possible locust infestations based on previous analyses using remote sensing (Cressman, 2016). However, during the time of the locust plague at the end of the 80s, the use of spatial data was still in its infancy. Showler & Potter (1991) point out that spatial data and the analysis of greenness maps were used to improve the process of selection of areas to be checked. In large parts, though, reports came from scouts and nomadic herders amongst others. The reporting scouts tended to stay on main roads and could often not access remote areas plagued by a lack of infrastructure, difficult terrain or war (Showler & Potter, 1991). On top of that, reports of locust observations were largely based on phone calls made by people who spotted locusts at their or close to their homes, which then were confirmed (or not) by ground teams (Vreyer, Guilbert & Mesple-Somps, 2015).

Upon correspondence with Keith Cressman, Senior Locust Forecasting Office at the FAO, I received several datasets containing locust observations (swarms, bands, adults, hoppers) and further indicators for the years 1986 to 1989. Since the 15th of April 2020 all locust data from 1985 on until the present day is publicly available at the newly set-up Locust Hub.[8]

For my analysis I use both swarms and bands as indicators of the presence of gregarious locusts, which are seen as indicators of widespread and heavy infestations (Cressman, 2013). As explained earlier, in this state desert locusts potentially have a disastrous impact on vegetation, whereas single adults or hoppers can be considered mostly harmless and might be of more value to predict locust populations. One might argue that the extremely mobile swarms that can reach impressive sizes have a larger impact than the localized bands that are easier to treat. Given their limited migration patterns though, bands could provide more exact localizations of an infestation. I consider only those cases that were marked as confirmed by ground teams. All desert locust observations divided by observations of bands and swarm can be seen in Figure A. 1.

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[7] http://www.fao.org/ag/locusts/en/info/info/index.html

[8] https://locust-hub-hqfao.hub.arcgis.com/

3.3.3 Weather Data

Weather data estimates come from the Standardized Precipitation-Evapotranspiration Index (SPEI). This index is based on the joint effects of rainfall levels and potential evapotranspiration based on data from the Climatic Research Unit of the University of East Anglia (Vicente-Serrano, Beguería, López-Moreno, Angulo & El Kenawy, 2010). The dataset contains monthly standardized data[9] on a global scale from 1901 to 2018. The data is provided at grid cell level and the spatial resolution is 0.5 x 0.5 degrees, which roughly equals 50 x 50 kilometres close to the equator. I use this data to create variables indicating the average yearly climatic conditions during the time in utero and until four years old. In order to derive the weather values on the cluster level, clusters are joined to the grid cell they are in.

3.4 Locust Treatments

My main variable of interest is the effect that the adverse shocks caused by locusts have on people who were infants or in utero at the time of the plague. The DHS data used in this thesis is geo-referenced. This enables me to match cluster locations of the DHS surveys to the position of locust observations. In a first step, I link the cluster location to locust observations within a radius of ten kilometres.

As argued above, the cluster location provided does not essentially represent the exact location of the individual due to geographical displacements. There are two opposing effects that need to be considered for the choice of radius. The closer households are to the observation, the higher one would expect the locusts' impact to be on agricultural outputs on average. Arguably, a reasonably small radius reduces the amount of noise and makes sure that unaffected households are not accidentally shown as affected. Nonetheless, a radius too small might highly understate the scale of locust bands and swarms. As pointed out in Chapter 2.1, an average locust swarm can easily cover an area of 50 square kilometres. However, there is a considerable heterogeneity in swarm sizes, which can vary between one and several hundred square kilometres. This uncertainty poses a major challenge to the methodology and the matching of observations. For example, let us take the example of a swarm with a size of 100 square kilometres, where locusts are circularly distributed. This would imply a radius of roughly 16 kilometres as shown in Figure 3. Assuming that locust observations, on average, represent the centroid of the swarm, it can easily be that big parts of a cluster are affected by a locust infestation, which would not necessarily be shown when using a radius of ten kilometres.

[9] The values are standardized over time and location.

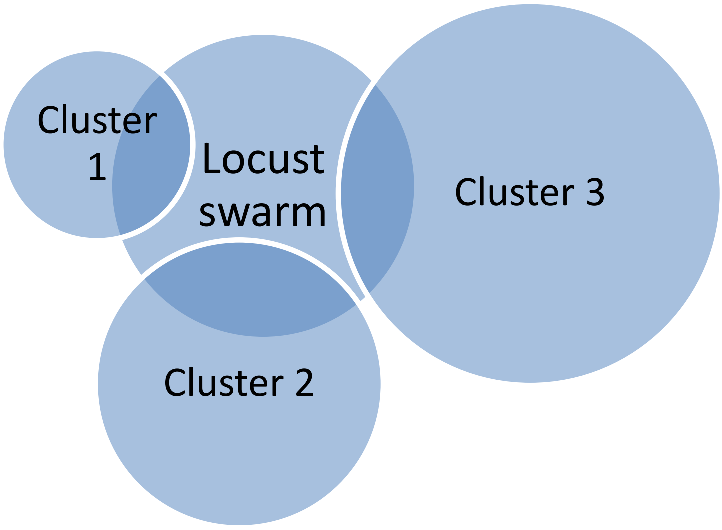


Figure 3: Exemplary illustration of the impact of the use of different radii

Radius sizes: Cluster 1 = 10km, Cluster 2 = 15km, Cluster 3 = 20km, Locust swarm = 16km

On top of that, locust swarms can be expected to have a rising destructive impact with an increase in size. Indeed, it might be particularly the vast swarms that have long-term impacts. Not considering households affected by these swarms would lead to a considerable underestimation of my estimates. For these reasons, I start applying a ten kilometre radius which potentially is a good "middle path" of the biases that could be created. However, in the robustness section I include additional buffer zones of 15 kilometres and 20 kilometres.

3.5 Limitations

There are several limitations to my data which have to be considered and discussed. Particularly the data on desert locusts has a number of limiting features. First, we can expect a clear reporting bias. The reporting of locust observations by phone calls and scouts dependent on good infrastructure inherits four principal problems. One is that more densely populated regions that are closer to urban areas are more likely to report a higher number of observations given the sheer number of people. In addition to that, taking into account the time frame analysed, phones, and particularly mobile phones, can be expected to be not widely spread in developing countries in the 1980s. They should be seen more likely in populated areas with wider network coverage and more people who own a phone. Furthermore, the access to a phone implies a certain level of well-being, so that it might be that a comparatively big amount of locust infestations was reported in areas where more wealthy people live. Lastly, the reporting of observations implies that people knew about the possibility to contact the authorities in case they spotted locusts. These people might have been more informed than the average, which on the other hand could be linked to further characteristics that are hard to control for.

Second, there is a general problem independent of the reporting mechanism. As pointed out

earlier, desert locust infestations predominantly affect remote areas that are hard to access. Thus, given the limited capacity of ground teams to scan areas, isolated areas might be less likely to be checked, especially during a plague when an inadequate number of ground teams has to set preferences for the scanning of areas, where remote areas might not be as efficiently studied.
Third, although a few reported infestations have information on the size and density of locust swarms and bands, this is only a minor proportion of all observations and the quality of the assessment can be doubted. Missing this information puts a clear limit to the assessment of the scale and intensity of locust exposures.

Another limitation comes from the DHS surveys. Using adult outcomes in general poses certain restrictions to my analysis. First and foremost, people are surveyed in their place of residence and no information on place of birth is provided. Only in a few cases a variable measuring the time an individual has been living in the current place of residence is provided. Besides the considerable reduction in sample size created by limiting the analysis to these individuals, it might also not entirely eliminate the selection bias created.

However, the use of adult data has the main advantage to be able to derive the persistent impacts of the desert plague. The DHS surveys allow me to study a broad band of people and countries using a similar standardized procedure. Particularly in the developing countries in the Sahel, having such precise geo-coded information is rare. The large cross-country sample size generates a high level of external validity.

3.6 Descriptive Statistics

Figure 4 displays all rural clusters included in my analysis categorized by whether they were likely affected by the locust plague or not. As explained above, cluster locations are matched to locust observations when they are within a radius of ten kilometres. The map shows several first indicative patterns: A majority of the affected clusters lies within the Sahel, a region that is characterized by considerable variations of climate and highly irregular rainfall patterns. Thus, although the exact location of locust swarms and bands cannot be forecasted, it can be seen that they cluster in that area. On top of that, a higher number of Senegalese individuals in the sample was affected by the locust plague compared to Malians or Chadians.

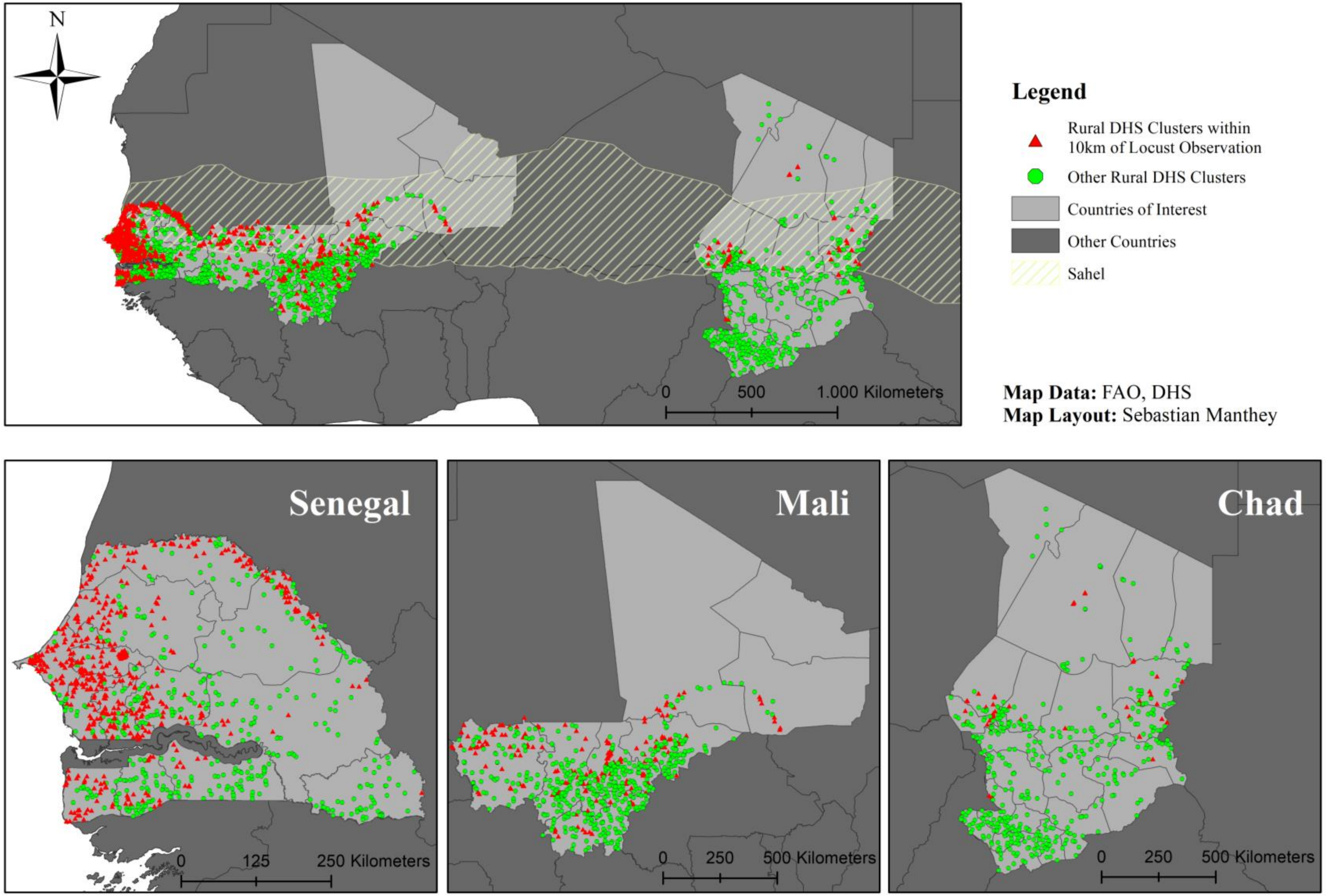
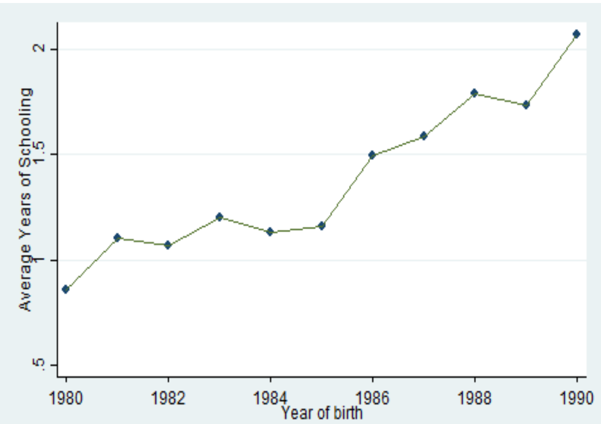


Figure 4: DHS Clusters in Senegal, Mali and Chad

Figure 5 shows that, on average, education levels in terms of years of education rose considerably during the analysed period from well below one year for individuals born in 1980 to more than two years for those born in 1990.[10] Furthermore, there are considerable differences between men and women. Whereas a woman born in 1990 only has approximately two years of education, for a man this is nearly twice as high. We see a considerable drop in average years of education for men born in 1989. This drop is not seen in the women sample. When comparing education levels across the countries of interest, similar education levels in all countries are seen. Chad, however, has markedly more variance in its levels with an extraordinary drop of education levels in 1989 (see Figure A. 2). A similar trend is seen when looking at the share of people per cohort that ever attended school (see Figure A. 3). Over the ten cohorts included the share in the overall sample doubled from around 16 percent for the 1980-born to more than 32 for those born in 1990. Once again, there is a substantial gap between men and women: whereas around half of the men born in 1990 attended at least primary school, it was less than 30 percent of women (see Figure A. 4).



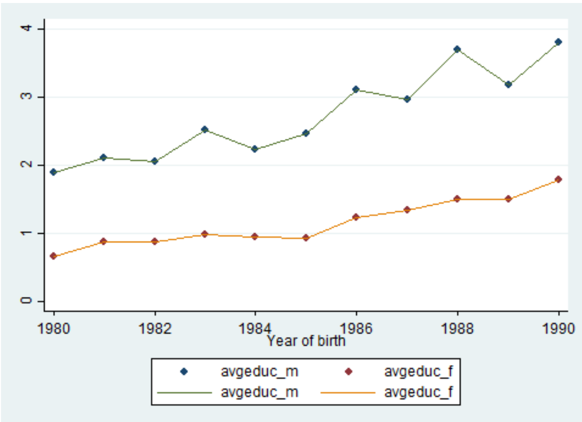


Figure 5: Years of education, cohort averages (Birth cohorts 1980-1990)

3.6.1 Affected and non-affected clusters

In a second step, I compare all the outcomes for males and females by clusters and whether they were affected by the locust plague or not. Regardless of age groups, I consider those clusters as affected, where at least one confirmed locust band or swarm observation was made between 1986 and 1989. Table A. 1 indicates that individuals in affected areas are significantly better educated than those in unaffected ones. This counts particularly for women and is a first indication that indeed we can find a reporting bias of locust infestations with a higher likelihood of reportings being made in areas with more educated people. A similar pattern can be seen for individuals who never migrated and women with height data.

[10] Note that my sample has a high proportion of women which dominates the average numbers.

4 Empirical Strategy

4.1 Empirical Model

I use a fixed-effects model for continuous outcomes and a linear probability model for binary outcomes. Further controls minimize the potential impact of biases caused by geographical and meteorological factors. Unobservable factors related to the location of the individuals are controlled for by using fixed effects on the level of the second administrative unit for men and third administrative for women.[11] Moreover, I control for birth years to rule out any effect related to different birth cohorts. Survey fixed effects are included because DHS surveys from different years are used.

One crucial assumption which has to be made is that the timing and location of locust infestations must be exogenous and not driven by further unobservable factors. Thomson & Miers (2002) argue that locust infestations might be driven by political factors or the occurrence of war. It is often argued that preventive desert locust control is particularly hindered by the lack of access to potential breeding grounds due to safety issues (Zhang, Lecoq, Latchininsky & Hunter, 2019). However, in general the monitoring of locust movements is centralized and done by the FAO, which increases the reliability and effectiveness of measures taken on broader scales to combat locust infestations. Also, the advantage of using the desert locust plague is that its scale and wide regional distribution minimizes the potential endogeneity. Once desert locusts leave the remote recession areas, they are mobile and any prediction of movements, particularly in the analysed time period, are probably highly difficult (Showler, 2019). Also, desert locust control is mainly implemented by national governments and international organizations, so that regional or local capacities are likely to be of second-order importance.

Furthermore, as pointed out above, climatic and geographical factors are likely to be related to desert locust habitats. Most locust infestations are seen in areas close to the Sahel, which due to climatic and followingly vegetational reasons attracts desert locust populations.

[11] There are considerably less observations for men compared to women. Taking a broader administrative unit for men enables me to have more representative units to control for.

To minimize the potential effect of unobservable variables I control for the third/ second administrative unit.[12]

The outcome variables of interest for the empirical model are adult education levels for both men and women and height indicators for women, and shall be described more in detail in this chapter. The main independent variables describe the presence of locust infestations during early childhood presented earlier. I also include a dummy variable indicating any locust infestation that happened to people who were older than four years when the locust shock occurred. This way I get a clear reference group of people who were not directly affected by locust infestations during the plague. I use the following model:

$$y_{i,c,t,s} = ß_1 * LocustUtero_{ct} + ß_2 * LocustFirstYear_{ct} + ß_3 * LocustSecondYear_{ct} + ß_4 * LocustThirdYear_{ct} + ß_5 * LocustFourthYear_{ct} + ß_6 * LocustRest_{ct} + \alpha_c + \theta_s + W_{ct} + \varepsilon_{i,c,t,s}$$

$$LocustUtero_{ct} = \begin{cases} 1, if -9 \leq \tau - t_i \leq 0 \\ 0, otherwise \end{cases}$$

$$LocustFirstYear_{ct} = \begin{cases} 1, if\ 0 < \tau - t_i < 12 \\ 0, otherwise \end{cases}$$

$$LocustSecondYear_{ct} = \begin{cases} 1, if\ 12 < \tau - t_i < 24 \\ 0, otherwise. \end{cases}$$

$$LocustThirdYear_{ct} = \begin{cases} 1, if\ 24 < \tau - t_i < 36 \\ 0, otherwise. \end{cases}$$

$$LocustFourthYear_{ct} = \begin{cases} 1, if\ 36 < \tau - t_i < 48 \\ 0, otherwise. \end{cases}$$

$$LocustRest_{ct} = \begin{cases} 1, if\ \tau - t_i > 48 \\ 0, otherwise. \end{cases}$$

$y_{i,c,t,s}$ is education/health of individual i, living in cluster c, born at the date t (month and year), from survey s (described by survey year and country). $LocustUtero_{ct}$ is a binary variable indicating if a locust infestation occurred in cluster c when the person i was in utero. τ is the date (month and year) of a locust infestation that was reported between the 1st of January, 1986 and the 31st of December, 1989. $LocustUtero_{ct}$ takes the value 1 if it occurred while the child was between -9 and 0 months old. Similarly, $LocustFirstYear_{ct}$ indicates whether locust infestations were observed when the child was between 0 and 12 months old. In the same

[12] The general term is used because the administrative units have different names depending on the country. For example, in Chad the third administrative units are referred to as sub-prefectures and in Mali and Senegal arrondissements.

manner, variables are coded when the child was between 12 and 24, 24 and 36 and 36 and 48 months old. The last locust treatment variable $LocustRest_{ct}$ includes all individuals who were affected by the locust plague when older than four years. The dates are displayed as months since January 1960. Accordingly, bigger values imply later dates. α_c is a fixed effect for the second/third administrative unit within which cluster c is located. θ_s displays survey year dummies. W_{ct} is a set of five weather dummies indicating the average climatic conditions for each individual whilst in utero, during the first, second, third and fourth year of life.[13] $\varepsilon_{i,c,t,s}$ is the error term.

4.1.1 Outcome Variables

The focus of this thesis lays on the long-run level of health and education. Heights are a valid proxy for the accumulated health status of a person and to a certain degree they represent health and nutrition during early life growth (Currie & Vogl, 2013). Thus, adult heights may be a highly reliable indicator of nutrition shocks experienced in early childhood. In addition to absolute height numbers, I also include indicators on height for age percentiles in an international normative distribution.[14] To quantify the level of schooling I employ two different variables: education in single years and a binary variable indicating if the person has ever attended school.

4.1.2 Control Variables

4.1.2.1. Administrative Areas

One factor besides e.g. survey and birth years I control for is the second/ third administrative area. Although the socioeconomic data used in this analysis is provided at cluster level, the use of geo-referenced data allows me to cluster observations on further geographic units. The problem that arises with cluster fixed-effects is that they are relatively small (for my reduced sample on average 17 individuals per cluster), so that any within cluster variation is very unlikely to have external validity. In addition to that, given that observations for locust infestations were derived cluster-wise, I run in risk of washing out any likely effect the locust plague might have had by limiting our analysis to within-cluster differences. GADM (2018) provides data on the boundaries of the first three administrative units for the three analysed countries. In Figure A. 5 the different levels of administrative areas are illustrated by country. Given that the first unit is very broad (e.g. 14 regions in Senegal), I instead use the third administrative unit to "cluster the clusters" for the women sample. For the men's sample I limit the analysis to the second unit due to a lack of observations. Given that cluster units change with each DHS survey, this method is particularly useful for the repeated surveys in Senegal,

[13] Further description can be found in Appendix D.

[14] See https://dhsprogram.com/pubs/pdf/MR6/MR6.pdf for more information.

where several clusters of one survey are physically close to those of other surveys. By grouping them in broader areas I can account for the geographic proximity. For example, there are 123 arrondissements (third administrative unit) and 45 departments (second administrative unit) in Senegal, compared to a total of 950 clusters.

4.1.2.2. Meteorological Circumstances

According to WMO & FAO (2016), an average level of 25 millimetres of rainfall in two consecutive months can be enough rain to expect notable increases in desert locust reproduction. Thus, above-average precipitation levels are likely to be related to the presence of desert locusts. Similarly, temperatures and soil moisture are crucial indicators for the reproduction of desert locusts (WMO & FAO, 2016). Although we expect a high correlation between rainfall levels, evapotranspiration and increased locust activity, this does not imply a causation effect. It can be anticipated that there is a positive relationship between SPEI values above zero and crop yields, particularly in rural areas. Controlling for the yearly values for weather conditions in the critical ages we can thus separate the effect of these from locust infestations.

4.2 Further Issues

4.2.1 Methodological Issues with Locust Infestations

There are two issues that complicate the methodological approach of analysing the impact of locust infestations during the locust plague of 1986 and 1989.

First, the plague lasted several years. Thus, people could be affected by locust infestations at several points in their life. For example, 198 individuals experienced a shock while in utero and also during their first year of life.[15] Second, the dummy variables of locust infestations can only provide information on whether the individuals were affected, not on the intensity of the shock. While there is information on the number of locust infestations that can be linked to clusters, this has to be analysed with caution. On the one hand, a higher number of locust infestations might imply that individuals were indeed affected several times or that the locust swarm had a size that made it being reported several times in a given radius. On the other hand, however, an increase in reports can also be a sign of the reporting bias mentioned in Chapter 3.5.

[15] Accordingly, 181 were affected in the first and second year of life, 175 in the second and third, and 201 in the third and fourth.

4.2.2 Treatment of Locust-Affected Areas

When locust-affected areas are spotted, they are often treated with chemicals to eliminate the locusts. These treatments are expected to have two effects. First, in treated areas the effect of locust infestations might be reasonably small if the reactive measures are taken before the locusts could produce major damage to grazing land and crops. Second, the treatment itself could have a negative impact on the health of individuals living in those areas. Abou-Ali & Belhaj (2008) show the negative health effects of pesticides in relation to desert locust treatments. Due to inconsistency in the data, these treatments cannot be accounted for in the analysis. However, the lack of preparation and reactive measures during the locust plague from 1986 to 1989 is pointed out by Showler (2019). Showler & Potter (1991) underline that the plague was the first in a time period of roughly 30 years, which led to a lack of funding and preparedness for the locust infestations. However, I cannot completely rule out an unobserved effect of the use of pesticides.

4.2.3 Mortality and Attrition

One problem that tends to arise when dealing with disastrous food crises is that of a survivor selection bias. In the case of a considerable nutrition shock and food insecurity for entire regions infant mortality can be high. I cannot entirely preclude that the weakest and most affected individuals already died in early ages. This would arguably create a bias and underestimate the expected effect. In the case of larger famines this might indeed be a serious shortcoming. Given their rather localized nature, locust plagues in recent years are not reported to have led to spikes in deaths though. Thus, a bias created by this is unlikely.

On the other hand, as pointed out earlier, malnutrition in early ages makes individuals considerably more vulnerable to diseases in adulthood. Thus, we might run into the problem of selective attrition. If long-term health is considerably worsened by the locust plague, the mortality risk of affected individuals can be expected to be higher at any age. Arguably, this bias can be expected to be low given that all individuals included in the analysis are in the range of 17 to 38 years old when surveyed.

4.2.4 Migration

One of the principal concerns is related to migration. Possibly the most serious assumption that has to be made in my analysis is that, at least for the major part of the surveyed people, the current place of residence also is their place of birth. This might at first sight be a grave shortcoming of my analysis, particularly because of the use of adult data, where with the course of time it is more likely that people migrate. We would expect such migration to be mostly common after the occurrence of a shock. This includes the desert locust plague from 1986 to 1989 but also subsequent disasters such as the locust upsurge in Western Africa from 2003 to 2005 or the 2010 Sahel famine.

The kind of bias caused by not being able to account for migration movements *a priori* is not entirely clear. Clearly evident, one crucial factor to migrate would be related to the intensity of the shock experienced through the occurrence of disasters. More affected people can be expected to be more likely to migrate. Thus, if the people who were most affected by the locust plague decided to migrate this would lead to an underestimation of the negative effect in my results. Another issue is the question who could or would afford to migrate to other regions. On the one hand, wealthier (and probably more educated) people have the financial means to migrate to a different place. On the other hand, and related to the first point, wealthier people might have better-working insurance mechanisms to cope with the damage caused by adverse shocks. Similarly, they might have more location-bound capital invested in their farm and thus less incentives to move to another place. In other words, it might be hard to tell what effect unobserved selective migration might have on my results.

There are two papers that analyse migration patterns in the context of countries in the Sahel. Findley (1994) analyses migration patterns during and after a major drought in Mali from 1983 and 1985 and argues that there are two types of migration: short-cycle and long-cycle/ permanent migration. The author's argumentation is that long-cycle migrants emigrate to larger cities or other countries as far as France. On the other hand, short-cycle migrants tend to stay in the region and return to their home region in regular periods. Whereas permanent migration is mainly limited to wealthier households, short-term migration is also practiced by poorer households. Belayneh (2005) points out that the locust upsurge in 2003-2005 led to a mass migration of people from rural to urban areas in the Sahel.

This leaves me with two indications: First, given the "universal" nature of short-cycle migration including wealthier and poorer individuals, the bias created by it can arguably be comparatively low. Second, focusing on rural areas I can likely avoid major biases created by migrants in my data. This possibly leaves me with less observations of critically affected people, who might have emigrated to urban areas. However, chances are relatively low that I capture migrants in completely unrelated rural areas. Rural migrants tend to live in areas close to their birth areas with a similar environment and higher likelihood to have been affected by locusts, too.

The only way to directly deal with the problem using the available data is limiting the sample to those individuals who indicate that they never changed their place of residence. This would largely reduce my sample and also have its shortcomings. There may be substantial unobserved differences between people who never migrated and those who did. Nonetheless, this option is included as a robustness check.

5 Analysis and Discussion

5.1 Basic Results

Table 2 illustrates the results of the baseline regression on education. Columns (1) to (4) show regression results for men with a step-wise addition of fixed effects. Columns (5) to (8) show the same for females. The obtained results do not show clear effects of locust infestations on the years of education of neither men nor women. If the results show anything, it is a possible positive impact of locust infestations on women's level of education. However, it can be observed that there are indications that there is a positive correlation between infestations in critical ages and education, for both men and women even after controlling for the approximate geographic locations. Table B. 1 shows a similar pattern when taking the indicator whether people ever attended school.[16] As illustrated in the descriptive section, it seems like there is a reporting bias which is positively related to education levels. This is shown by the coefficient on Shock > 4 years, which for both the men and women sample is positive when all controls are included and close to significance. Thus, in a next step I try to at least partly correct for that bias. Also, it can be observed that results do not change considerably when adding the weather controls in the last step. This is of importance because regression results for the variable indicating if the person ever attended school does not include the weather control variables.[17]

5.2 Stratification

5.2.1 Education – Stratified Model

In order to do this, the sample is stratified into two parts of grossly equal size for men and women separately. The stratification is based on average levels of education by

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[16] Country-wise regressions results for both education outcomes can be seen in Table B. 2 (Senegal), Table B. 3 (Mali) and Table B. 4 (Chad).

[17] The weather control variables are the only non-dummy variables in the regression. Limiting the regression to binary explanatory variables guarantees that we can with more reliability have a direct interpretation of the coefficients.

Table 2: Basic regressions results for education in years by men and women

	MEN				WOMEN			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
In utero shock	0.705*	0.704*	0.410	0.428	0.728***	0.380***	0.213*	0.214*
	(0.375)	(0.393)	(0.422)	(0.430)	(0.162)	(0.108)	(0.111)	(0.114)
First year shock	0.985**	0.703*	0.454	0.457	0.445***	0.170**	0.121	0.120
	(0.477)	(0.386)	(0.385)	(0.389)	(0.124)	(0.0844)	(0.0936)	(0.0947)
Second year shock	0.763*	0.809**	0.854**	0.850**	0.693***	0.280**	0.410***	0.408***
	(0.438)	(0.388)	(0.385)	(0.388)	(0.129)	(0.121)	(0.122)	(0.123)
Third year shock	-0.220	-0.228	-0.272	-0.300	0.328***	-0.0389	0.179*	0.190*
	(0.355)	(0.334)	(0.330)	(0.339)	(0.123)	(0.0885)	(0.100)	(0.101)
Fourth year shock	-0.424	-0.365	-0.00970	-0.0401	-0.151**	-0.415***	-0.133	-0.118
	(0.320)	(0.345)	(0.401)	(0.412)	(0.0768)	(0.0882)	(0.0986)	(0.101)
Shock > 4 years	-0.499*	-0.392	0.364	0.332	0.00610	-0.412***	0.0963	0.107
	(0.262)	(0.252)	(0.285)	(0.281)	(0.0861)	(0.0863)	(0.0880)	(0.0902)
Observations	5,217	5,217	5,217	5,217	29,883	29,883	29,883	29,883
R-squared	0.008	0.221	0.236	0.237	0.008	0.189	0.202	0.202
AdmFE	NO	YES	YES	YES	NO	YES	YES	YES
BirthyearFE	NO	NO	YES	YES	NO	NO	YES	YES
Survey FE	NO	NO	YES	YES	NO	NO	YES	YES
Weather FE	NO	NO	NO	YES	NO	NO	NO	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: AdmFE is the second administrative unit for the men sample and third administrative unit for the women sample.

clusters. Actually, for every cluster I calculate the mean level of education of all men (or women) being part of it. Then, all clusters and individuals within them are assigned to either the "low education" or "high education" strata. This is founded on the median of the average cluster-wise education levels. If the cluster's average education level is below (above) it, individuals are assigned to the lower (upper) strata. For the men's sample the cut-off point is 1.75 years of education. In other words, all men from clusters with an average level of education for men of less than 1.75 are located in the first strata. The rest of men is assigned to the second strata. For women the critical value is 0.68 years.

Figure 6 and Figure 7 show the impact of locust infestations on years of education and the probability to have any education at all by strata for men and women, respectively. Table B. 5 and Table B. 6 list all the corresponding regression tables. The results for men show a significant negative relationship between locust infestations and education levels in most age groups and specifications. The strongest negative effect is found on men from the bottom strata that are affected during their first year of life. Results indicate that, on average, the locust infestations might have led to a decrease of education of around five months. Given the low overall education level this is a substantial difference. For the upper strata the results are considerably less clear. However, evidence points towards a strong negative impact of the locusts on education levels of children between two and four years old, with an average reduction of education up to nearly a year. The variable indicating any education at all shows even stronger results. For all age groups we see negative coefficients and once again there seems to be a particularly strong effect on children during the first year in the lower education strata. However, results must be analysed with care due to the comparatively small sample of men that was analysed. This is reflected in the substantial size of coefficients.

The results for women are considerably less clear. The coefficient largely fluctuates around zero for both outcomes in the lower-education strata. In the higher-education strata we see clear indications of a positive effect of locust infestations. For example, the effect generated on women who were affected while in their second year of life might have been an increase of education levels by 0.58 years.

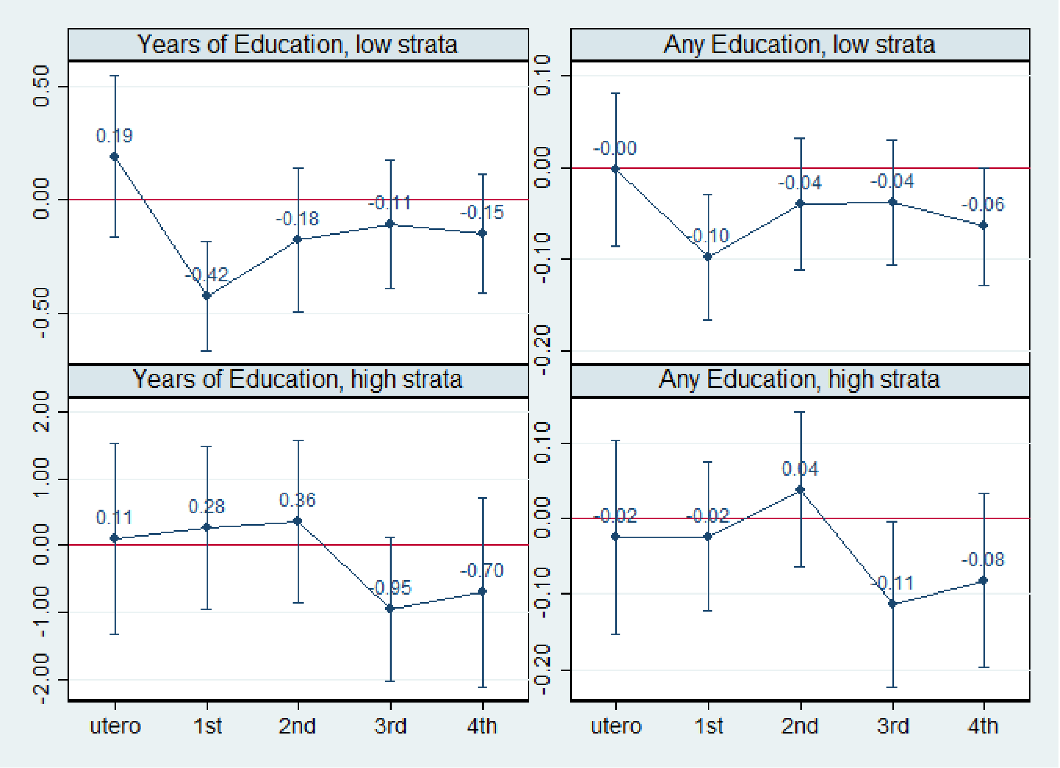

Figure 6: Plotted regressions coefficients for education outcomes by strata, male

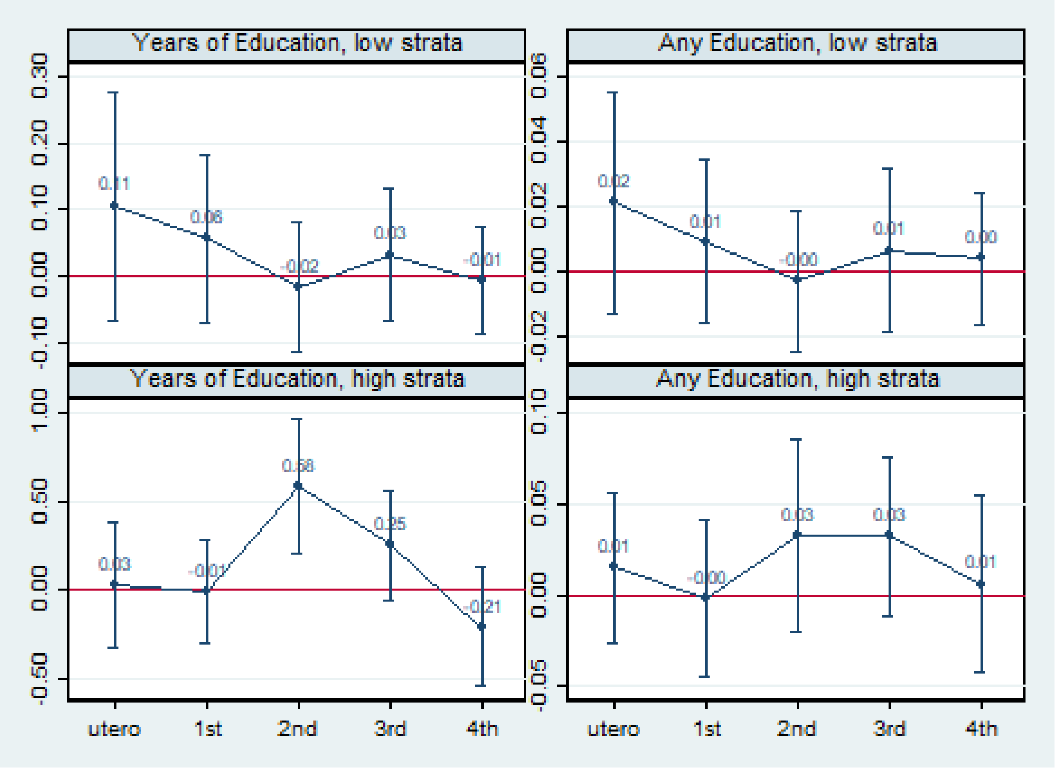

Figure 7: Plotted regressions coefficients for education outcomes by strata, female

5.2.2 Height

Figure 8 displays the results for height levels (in centimetres) of affected women.[18] The results are ambiguous. Evidence on the lower-education strata shows evidence of a negative impact of locust infestations on height levels. The strongest effects are seen for women who were affected while in utero, with a gradually decreasing effect in a higher age. On average, the locust infestations might have led to a decrease of height for women affected in utero by nearly 1.6 centimetres. On the other hand, we see no clear or even a positive relationship in the upper-education strata. Results indicate that the infestations led to an increase in height of more than 2.2 centimetres for women affected when four years old. Similar results can be seen when using height for age percentiles (see Table B. 7).

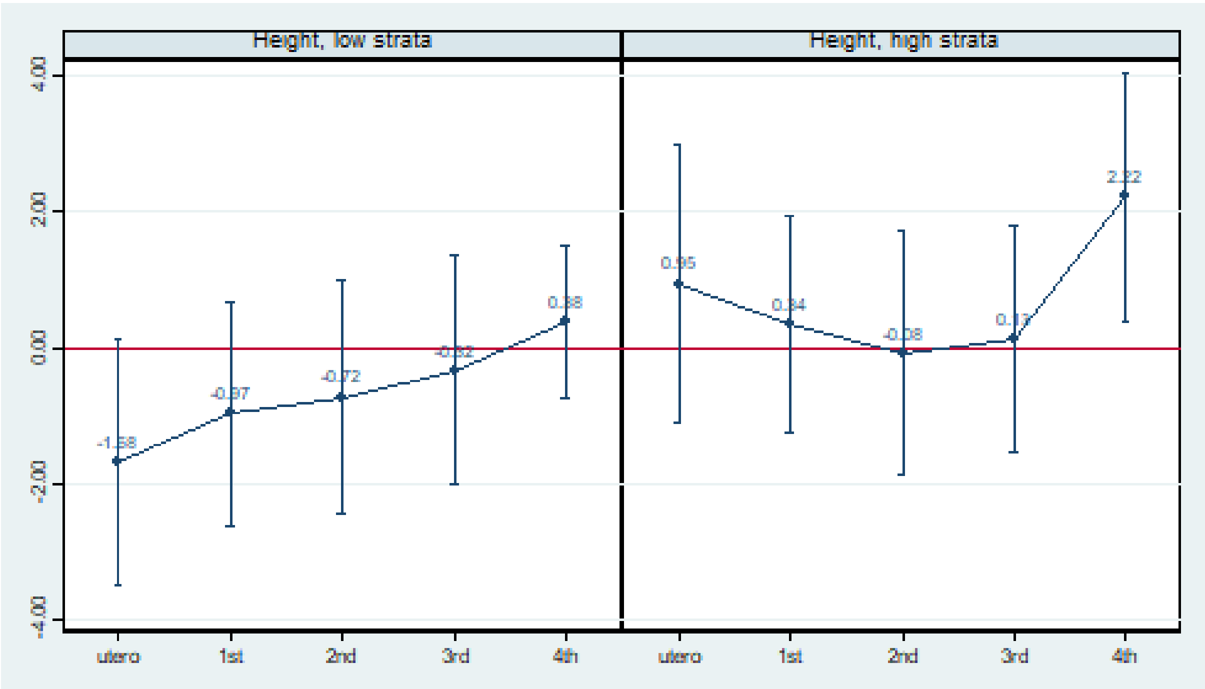

Figure 8: Plotted regression coefficients for height by strata

5.3 Robustness Checks

In order to check for the robustness of my results, I perform several additional regressions.

[18] Regression results are shown in Table B. 7.

5.3.1 Migration

To test for the possible role of selective migration I limit my results to individuals who indicate that they have never migrated. Given the small number of observations (4,766), this part of the analysis does not distinguish between men and women.[19] Also, it has to be restricted to the education outcomes. However, a dummy variable indicating if someone is a man is included to account for overall differences by gender. Results indicate that individuals from the bottom education strata have, on average, been in most parts negatively affected by the locust plague. On the other hand, we observe a clear positive effect on absolute years of education for the upper education strata (see Table C. 1).

5.3.2 Restricted Treatment

As a further robustness check I perform the stratified regressions using only locust bands as indicators of locust infestations. As argued earlier, locust bands are considerably less mobile than swarms and thus it is more likely that areas affected by bands saw a substantial shock which lasted over an extended period. Also, this does not rule out the possibility that areas affected by locust swarms are included in the analysis. Indeed, given that locust bands are composed of young locusts it automatically implies that infestations by adult locusts preceded them, which then started breeding. Locust bands are easier to combat than swarms and can for example be trapped into trenches (Sharma, 2015). Thus, it is more likely that control measures were taken in affected areas. However, this does still imply large prior infestations by locusts. Taking just the bands reduces the number of affected clusters from 757 to 426 out of 2,073 clusters in total. The results for education are presented in Figure 9 and Figure 10.[20] They show a similar pattern as the one seen in the case of including all infestations. Indeed, the average effect on men seems to be even stronger, with the most affected groups (in their first or second year of life) seeing a reduction of nearly six months in education and a decrease of ten percentage points in the likelihood of ever attending school through the locust infestation. Results for women are still mixed. However, the large positive effect seen in previous regressions partly disappears. Similarly, height outcomes change markedly (see Table C. 4). The effect on height outcomes in the lower education strata are not as clear anymore. On the other hand, a clear negative effect on women from the upper education strata can be identified, in particular for those who were affected in their first year of life.

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[19] Accordingly, the stratification is redone for this sample taking average values for years of education by cluster as the base. The critical value for the allocation of clusters to the strata is 0.86 years.

[20] Regression results are shown in Table C. 2 (for men) and Table C. 3 (for women).

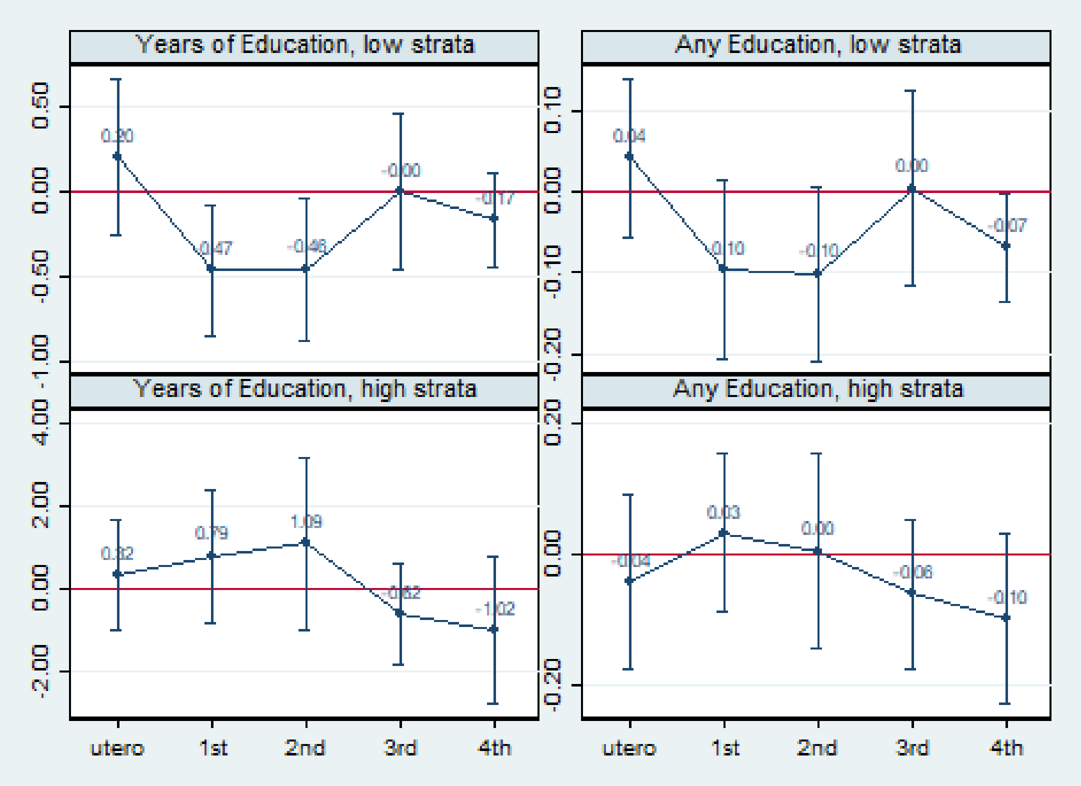

Figure 9: Plotted regression coefficients for education outcomes by strata, only bands, male

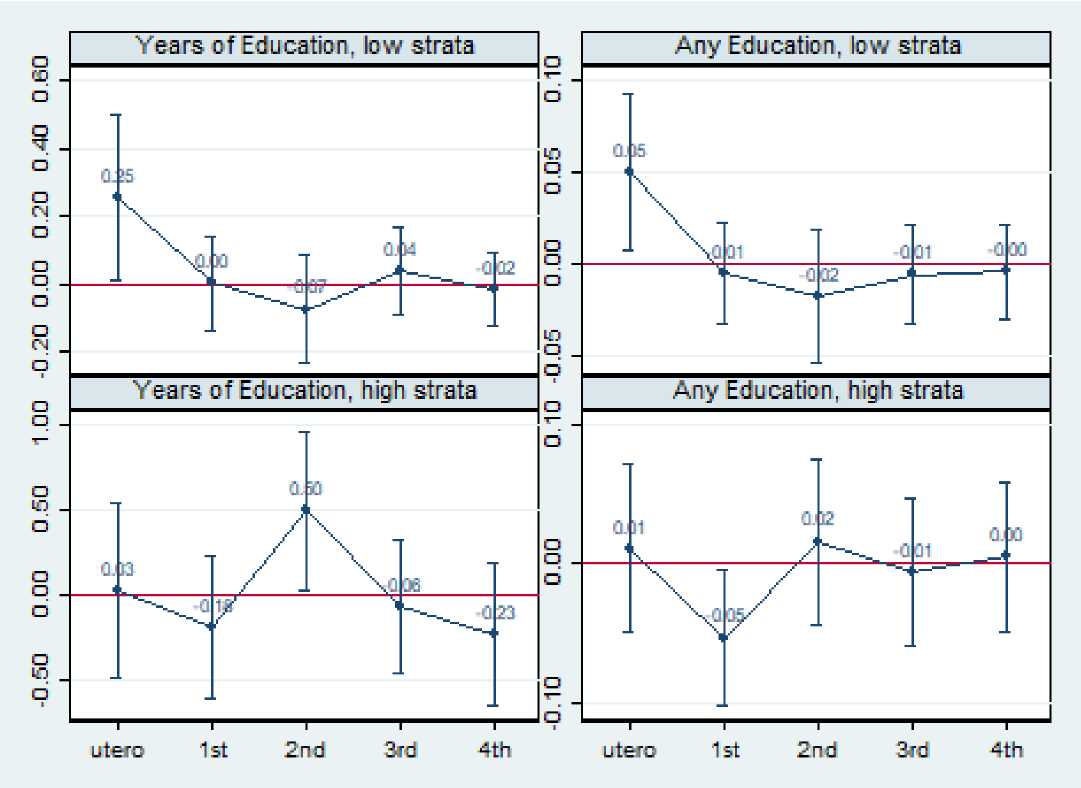

Figure 10: Plotted regression coefficients for education outcomes by strata, only bands, female

5.3.3 Further Tests

As an additional test I add further dummy variables to see if any effect of the locust plague on children that were in their fifth to ninth year of life when they were affected can be found. Figure C. 1 shows the results for education outcomes of the men sample. For the lower education strata one can observe negative values for early year coefficients which then gradually disappear and become positive or close to zero for the older year coefficients. This is in line with theory, which implicates that the long-term effect on older children can be expected to be smaller. The results for women resemble the unclear effect of previous parts (see Figure C. 2). Similarly, when using 15 or 20 kilometres as a radius to indicate if someone was affected by locusts, results largely hold for both education and height outcomes, although many coefficients lose some significance, which would be expected given that more noise is picked up.[21] Lastly, one may argue that the difference in effects is found because of the use of different levels of administrative units for men and women. Table C. 11 shows the basic stratified regression results for men using the third administrative unit. Results are nearly identical to the ones from the original regression.

5.4 Discussions

The findings show several interesting patterns which in parts are in line with previous analyses and in others strongly contradict them. The main results can be put into three broad categories: the role of education strata, gender and age.

5.4.1 Education Strata

A first important point is that before stratification my results show no negative (but rather a positive) impact of the locust plague on any age group affected. This points towards a critical issue that has to be dealt with: reporting bias. The reporting of locust observations is clearly linked to available infrastructure which on the other hand can be connected to education infrastructure. This can be only partially corrected for by using controls for administrative units because within-region differences remain. To the best of my knowledge, none of the three other papers dealing with locust infestations[22] report this bias. This might be for two reasons: First, Vreyer, Guilbert & Mesple-Somps (2015) and Conte, Piemontese & Tapsoba (2020) focus their analysis on a single country, Mali where due to less overall population density reporting biases might be smaller. Second, Linnros (2017) and Conte, Piemontese & Tapsoba (2020) use more

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[21] For education outcomes see Table C. 5 and Table C. 6 for 15km radius and Table C. 7 and Table C. 8 for 20km radius. For height outcomes see Table C. 9 and Table C. 10.

[22] (Vreyer, Guilbert & Mesple-Somps, 2015; Linnros, 2017; Conte, Piemontese & Tapsoba, 2020).

recent data which, as pointed out previously, is likely to present more accurate estimations compared to the data available during the plague from 1986 to 1989.

After a stratification into two parts based on average education levels we see a negative association between locust infestations in critical ages and education outcomes as well as heights. However, this evidence is mostly limited to the bottom strata. This is a clear indication that malnutrition due to the locust infestations was seen for infants in areas with a lower educational level. A similar effect was found by Conte, Piemontese & Tapsoba (2020) who show a considerably more robust negative impact of the locust plague from 2003 to 2005 on children from poor areas compared to richer ones, where no significant results are shown. As argued by the authors, it is common for richer rural individuals to buy up the harvests from previous years from other farmers. Thus, some of these households might have actually taken advantage of the plague due to increases in prices for crops, which then could compensate for losses of the current harvesting season. This would similarly explain some of the positive impact we observe. However, taking exclusively locust band observations, which potentially show a more precise indicator of a notable infestation, we observe that the previously found positive impacts are largely reduced. On top of that, height outcomes for women in above-median education regions are shown to be negatively impacted by locust infestations, particularly in utero and the first year of life. Thus, the effect of locust plagues on the higher educated people might arguably depend on the intensity of locust infestations that was experienced, with locust bands pointing towards more critical infestations.

Another important point is that differences by strata seem to be particularly marked when limiting the analysis to non-migrants. The pronounced positive impact seen on people in better-educated clusters can imply several things: The fact that they did not migrate itself might imply that the shock did not affect the households as much. On the contrary, they might have taken advantage of the situation due to increased local food prices and have possibly been better prepared. As argued before, the less educated people though arguably had less opportunities to migrate and thus the sample might include a higher proportion of severely affected individuals.

5.4.2 Gender Differences

For men from the less-educated strata I find strong evidence for a negative impact of the locust plague on those affected whilst in their infancy. The strongest effect was found for the likelihood of ever going to school instead of the absolute number of years of education. As it seems, a valid result: in the regions where education is less spread the observed difference we see between people might be marginal in terms of absolute years of education compared to the binary variable of ever attending school. On the other hand, we expect a high level of heterogeneity in years of education which can vary between zero and more than 20 years. Given that most individuals have low levels of education, a few highly-educated individuals could cloud the interpretation of results. Using a binary outcome differentiating between those never attending school and those who did we can clarify the interpretation.

Education outcomes show no marked effect of the locust infestations on women's level of education though. On the contrary, it seems like locust infestations are positively associated with it, for both strata classes. However, when looking at height levels in the restricted sample results show a substantial negative effect of the infestations on women in early years of life. The most consistent negative result is found for women who were affected in utero and during their first year of life in both education strata. This is in opposition to Hyland & Russ (2019) who argue that significant effects found on height indicators might point towards a more severe impact of the locust plague, whereas a mere impact on education hints towards a comparatively weaker economic shock. The lack of impact on education could be of statistical nature though. Given the extremely low average education levels for women in the analysed countries, there might be insufficient variation in the variable of interest. On top of that, as mentioned before it is likely that there is a discrimination of women in the education sector. Possibly, being of anthropometric nature, height estimates can be a more reliable estimator for showing long-term effects of malnutrition caused by locust infestations.

5.4.3 The Role of Age

It can be observed that the negative effects can mainly be seen for children who were affected when already born. Although this might at first sight be counterintuitive and contradicts the findings made by Conte, Piemontese & Tapsoba (2020), in the specific context it might make more sense. Unlike famines or droughts, locust plagues do not merely bring destruction with them but the locusts can in the short term be used as food intake. To my knowledge, there is no concrete evidence on this topic. However, a likely channel would be that adult people can easily consume and digest locusts. Indeed, this is done in several countries. However, babies and young children might lack the capacity to digest them or parents be reluctant to feed them to their children.[23] Thus, those children that were in utero when the locust plague happened might have been more likely to have had indirect access to sufficient nutrients. Children that were already born and not breastfed anymore, though, might have been more affected by the shock since they could possibly not consume locusts.

On the other hand, though, these results only hold for the men's sample. The consistent negative impact found on height levels of women who were affected whilst in utero contradict this point and are in line with Conte, Piemontese & Tapsoba (2020)'s findings. There is no apparent reason for why these temporal differences by gender should exist. Indeed, as pointed out before, if anything, we would expect female foetuses to be more resilient than male ones. Without the availability of height data for men this outcome cannot be further investigated. However, it might be of interest for following studies.

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[23] see https://africa.com/grasshoppers-and-locusts-for-protein-rich-baby-food/.

6 Conclusion

This thesis analyses the long-term effects of a desert locust plague on men and women from rural areas that were affected during their early childhood and before. I use a broad variety of surveys from three countries in the Sahel. To my knowledge, this is the first study that uses both education and health outcomes to derive the impact of locust infestations. Similarly, it is the first to assess the persistence of early-life shocks into adulthood in this context. In order to correct biases caused by reporting mechanisms I stratify the sample based on average local education levels. The evidence indicates that the plague might have had long-standing consequences for the development of children.

However, clear impacts on education levels could only be seen for male individuals from areas with comparatively low education levels. Findings demonstrate that using education outcomes for women might suffer from the fact that most women in the region barely have any access to education and thus less variations in outcomes can be discovered. Indeed, height outcomes show a negative impact on health for women. Thus, the gender differences found in other studies cannot be entirely confirmed. Although the adverse impacts seen on males seem to be more consistent, anthropometric indicators show comparable results for women. Consequently, this study helps in understanding the challenges that arise when studying education outcomes in an environment of extremely low schooling levels, which is characterised by clear gender inequalities.

Also, the obtained results underline that people from less educated (and possibly poorer) regions are more vulnerable to income shocks. Highly depending on agricultural outcomes and lacking proper insurance mechanisms, they are significantly more likely to lose their access to food and thus be affected by malnutrition. By limiting my analysis to locust bands, which has not been done in previous studies, I can show that extreme infestations can also affect people from arguably wealthier areas.

Lastly, this analysis underlines the persistence of the damages caused during early childhood into adulthood. In line with the literature presented, my findings suggest that after the experience of shocks as infants, the damages caused could not be reversed. The high frequency of natural disasters in the Sahel region can be expected to make a recuperation from the shocks considerably more difficult.

The evidence generates a clear case in favour of maintaining the effort to prevent locust plagues. The present locust infestations with billions of locusts flying across Eastern Africa once again illustrate the potentially devastating impacts of the failure of locust prevention mechanisms. Besides the direct apparent agricultural losses, the persistent impact on the development of young children adds to the damage caused by desert locusts over time. Similarly, building up resilience against income shocks (for example, designing microinsurances) is key, particularly for those individuals living in areas that are characterised by lower educational levels and more poverty.

Locust infestations are a topic that has been concerning mankind since ancient times. However, only in recent years has research on their economic and social impact started. My analysis is only a first step and there are various interesting topics that can be explored. Surely, the data quality is the biggest hurdle for my analysis. The analysis of more recent locust infestations promises an increase in the precision of locust observations given the improvements in technological equipment and a rising interest of donors as well as affected countries (Cressman, 2016). One crucial topic that can be analysed is the role of the timing of locust infestations for the creation of adverse economic shocks. A different impact can certainly be expected when locust infestations occur before the harvest season compared to, for example, right after it. This has been done by Conte, Piemontese & Tapsoba (2020) and interestingly they show that price shocks even before the infestations actually occur and can have severe consequences. However, like Vreyer, Guilbert & Mesple-Somps (2015) the authors limit their analysis to Mali. A broader analysis including further countries could lead to more representative results on a broader level. The precise location and timing of locust infestations, furthermore, might enable an analysis of the role of subsequent shocks. As I pointed out in Chapter 2.2, it might be valuable to know how shocks could cause long-lasting effects when followed by further shocks. The Sahel region which is frequently plagued by droughts and locust infestations might be a good area for this kind of study combining analyses of different natural and possibly also man-made disasters to study the interaction of shocks at different points in life.

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Appendix A: Supplementary Descriptive Figures and Tables

Figure A. 1: Locust band and swarm observations, by country

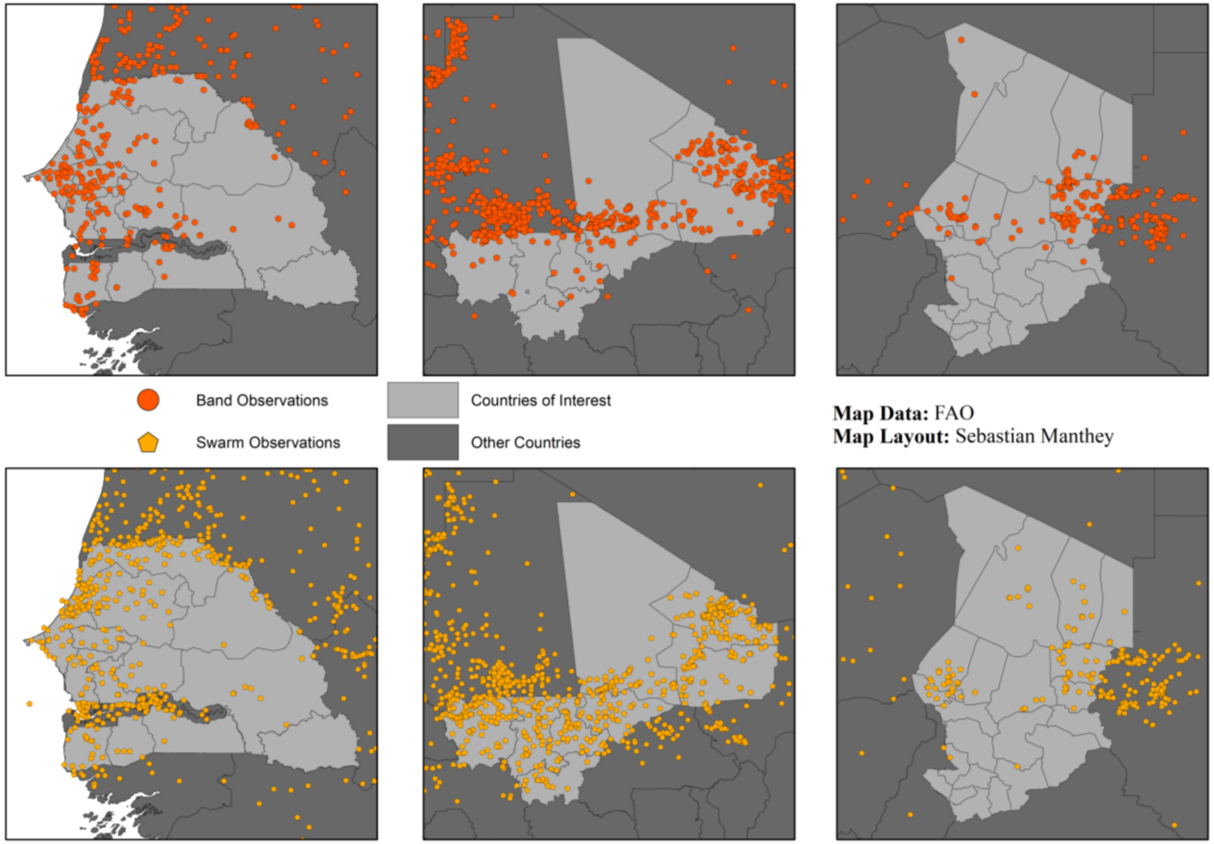


Figure A. 2: Average years of education by country, cohort averages

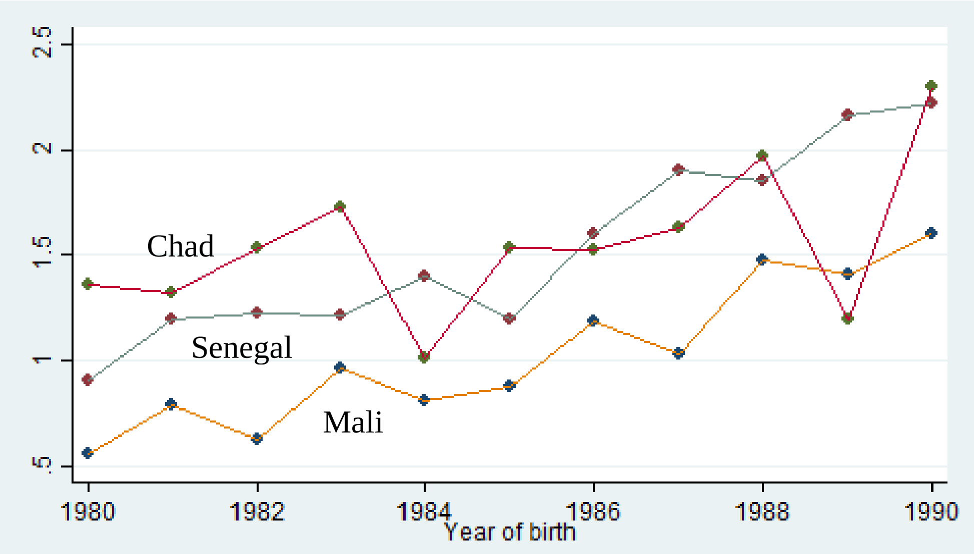


Figure A. 3: Ever attended school, cohort averages

Figure A. 4: Ever attended school, cohort averages, by men and women

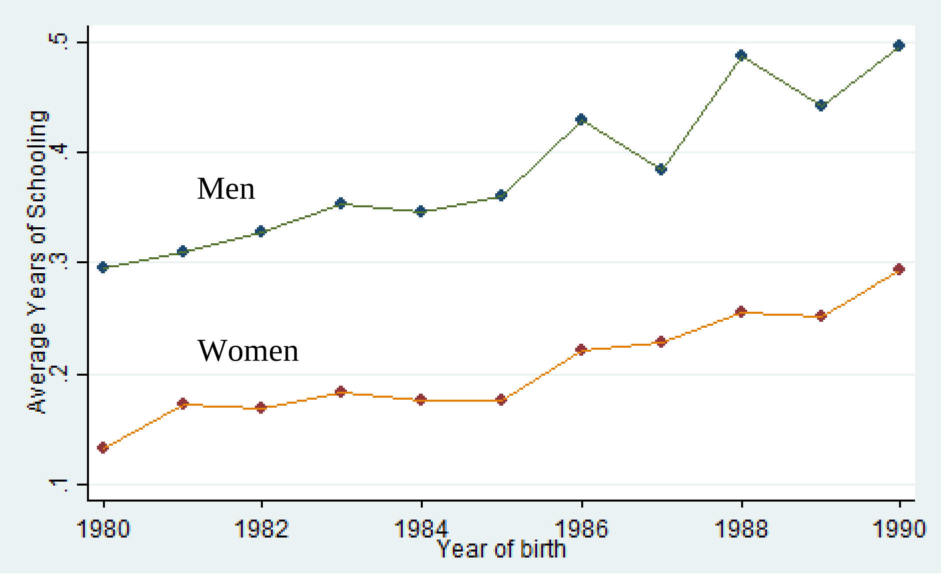


Table A. 1: Standard indicators by area and gender

	MALES			FEMALES		
	Total (N=5,217)	**Unaffected** (N=3,223)	**Affected** (N=1,994)	**Total** (N=29,883)	**Unaffected** (N=17,149)	**Affected** (N=12,734)
Age	28.71	29.00	28.24	27.01	27.52	26.31
Years of education	2.74	2.64	2.91	1.18	0.99	1.44
Ever attended school	0.39	0.38	0.39	0.21	0.19	0.24

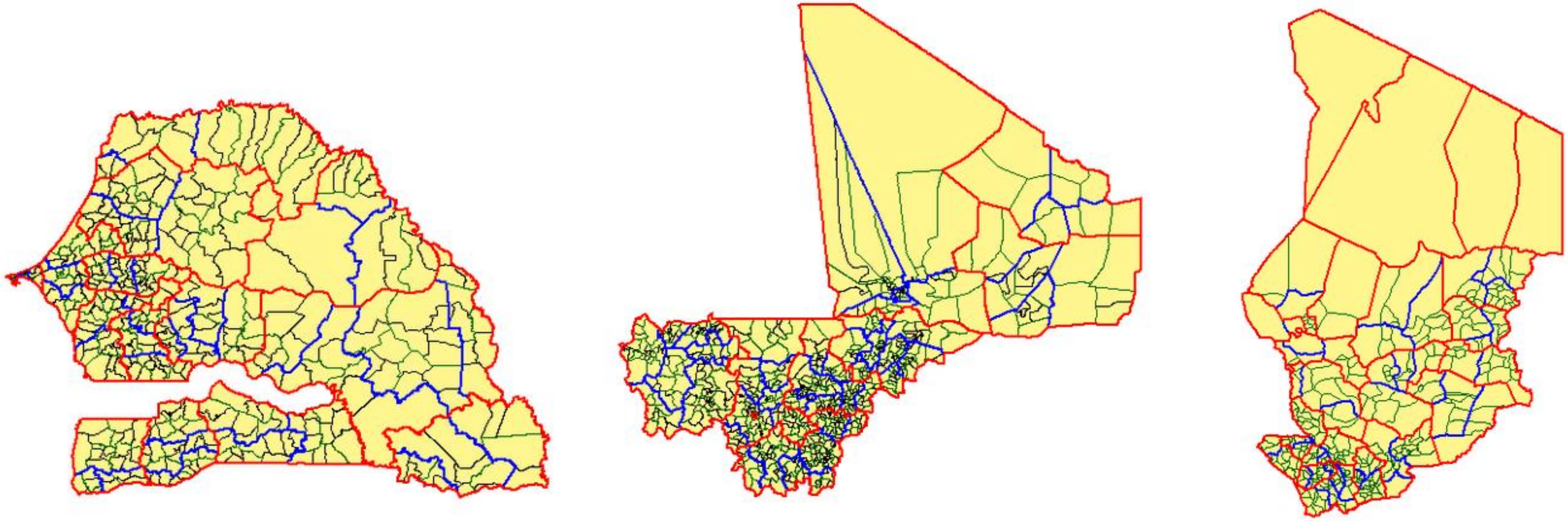
Individuals who never migrated (both men and women)

	Total (N=4,766)	**Unaffected** (N=2,337)	**Affected** (N=2,429)
Age	26.124	27.629	24.676
Years of education	1.499	1.211	1.776
Ever attended school	.25	.211	.289

Women with height information

	Total (N=7,343)	**Unaffected** (N=5,489)	**Affected** (N=1,854)
Age	27.991	28.279	27.137
Years of education	1.021	.975	1.157
Ever attended school	.193	.196	.182
Height (in cm)	1621.721	1619.703	1627.694

Figure A. 5: Administrative areas by country



Notes: Red lines: administrative area 1, blue lines: administrative area 2, green lines: administrative area 3, black lines: administrative area 4

Source: https://gadm.org/index.html

Appendix B: Supplementary Regression Tables and Figures

Table B. 1: Basic regression results for any education

	MEN				WOMEN			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
In utero shock	0.0565	0.0674*	0.0210	0.0217	0.0972***	0.0564***	0.0376***	0.0354**
	(0.0411)	(0.0403)	(0.0427)	(0.0429)	(0.0191)	(0.0128)	(0.0136)	(0.0138)
First year shock	0.0545	0.0312	-0.0113	-0.00189	0.0566***	0.0259**	0.0166	0.0178
	(0.0494)	(0.0337)	(0.0357)	(0.0363)	(0.0162)	(0.0119)	(0.0135)	(0.0138)
Second year shock	0.0535	0.0682*	0.0753*	0.0812**	0.0687***	0.0174	0.0301*	0.0327*
	(0.0498)	(0.0387)	(0.0382)	(0.0381)	(0.0157)	(0.0170)	(0.0180)	(0.0180)
Third year shock	-0.0379	-0.0307	-0.0440	-0.0448	0.0393**	-0.00323	0.0240	0.0264*
	(0.0407)	(0.0347)	(0.0377)	(0.0380)	(0.0194)	(0.0135)	(0.0152)	(0.0154)
Fourth year shock	-0.0573	-0.0500	-0.0252	-0.0215	-0.0136	-0.0424***	0.00311	0.00728
	(0.0417)	(0.0337)	(0.0369)	(0.0384)	(0.0141)	(0.0130)	(0.0151)	(0.0153)
Shock > 4 years	-0.0604*	-0.0338	0.0393	0.0341	-0.00517	-0.0530***	0.0203	0.0232*
	(0.0328)	(0.0284)	(0.0323)	(0.0323)	(0.0141)	(0.0108)	(0.0126)	(0.0130)
Observations	5,217	5,217	5,217	5,217	29,883	29,883	29,883	29,883
R-squared	0.005	0.246	0.261	0.262	0.005	0.183	0.196	0.196
AdmFE	NO	YES	YES	YES	NO	YES	YES	YES
BirthyearFE	NO	NO	YES	YES	NO	NO	YES	YES
SurveyFE	NO	NO	YES	YES	NO	NO	YES	YES
Weather FE	NO	NO	NO	YES	NO	NO	NO	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table B. 2: Basic regression results for Senegal

VARIABLES	(1) Years MEN	(2) Any Education MEN	(3) Years WOMEN	(4) Any Education WOMEN
In utero shock	-0.328	-0.0202	0.118	0.0198
	(0.451)	(0.0507)	(0.143)	(0.0167)
First year shock	0.748	0.00337	0.0749	0.0107
	(0.523)	(0.0471)	(0.114)	(0.0162)
Second year shock	0.848	0.0579	0.299**	0.0191
	(0.560)	(0.0538)	(0.145)	(0.0221)
Third year shock	-0.293	-0.0328	0.166	0.0295
	(0.398)	(0.0477)	(0.127)	(0.0189)
Fourth year shock	-0.432	-0.0666	-0.122	0.0144
	(0.487)	(0.0494)	(0.127)	(0.0206)
Shock > 4 years	0.0973	0.0350	0.213*	0.0416**
	(0.395)	(0.0474)	(0.116)	(0.0177)
Constant	1.467***	0.211***	0.517***	0.146***
	(0.438)	(0.0364)	(0.161)	(0.0161)
Observations	2,583	2,583	17,450	17,450
R-squared	0.200	0.194	0.182	0.156
AdmFE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Note: AdmFE is the second administrative unit for the men sample and third administrative unit for the women sample.

Table B. 3: Basic regression results for Mali

VARIABLES	(1) Years MEN	(2) Any Education MEN	(3) Years WOMEN	(4) Any Education WOMEN
In utero shock	2.274**	0.0858	0.331	0.0388
	(0.977)	(0.0869)	(0.269)	(0.0341)
First year shock	-0.0329	-0.0472	0.429*	0.0726**
	(0.661)	(0.0687)	(0.219)	(0.0323)
Second year shock	0.837*	0.108*	0.569*	0.0571
	(0.484)	(0.0572)	(0.291)	(0.0362)
Third year shock	0.144	-0.00923	0.351	0.0380
	(0.612)	(0.0698)	(0.245)	(0.0291)
Fourth year shock	1.881**	0.158**	-0.00870	0.00303
	(0.916)	(0.0741)	(0.184)	(0.0197)
Shock > 4 years	0.397	0.0185	0.0672	0.0223
	(0.433)	(0.0541)	(0.169)	(0.0198)
Constant	-0.292	0.0497	0.0871	0.0248
	(0.449)	(0.0435)	(0.185)	(0.0180)
Observations	1,636	1,636	7,509	7,509
R-squared	0.139	0.115	0.141	0.117
AdmFE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: AdmFE is the second administrative unit for the men sample and third administrative unit for the women sample.

Table B. 4: Basic regression results for Chad

	(1)	(2)	(3)	(4)
VARIABLES	Years MEN	Any Education MEN	Years WOMEN	Any Education WOMEN
In utero shock	-0.340	-0.0717	-0.0303	-0.0238
	(0.465)	(0.0653)	(0.360)	(0.0485)
First year shock	- 2.288***	-0.183***	-0.145	-0.00619
	(0.680)	(0.0665)	(0.298)	(0.0505)
Second year shock	3.252*	0.488**	0.203	0.0335
	(1.819)	(0.223)	(0.341)	(0.0541)
Third year shock	-1.129**	-0.198***	-0.116	-0.00858
	(0.554)	(0.0550)	(0.219)	(0.0514)
Fourth year shock	-0.372	-0.0542	0.0381	0.000811
	(0.511)	(0.0580)	(0.195)	(0.0353)
Shock > 4 years	1.425	0.130	0.101	-0.00905
	(0.891)	(0.0935)	(0.143)	(0.0211)
Constant	0.947*	0.346***	-0.426***	-0.0644***
	(0.484)	(0.0419)	(0.154)	(0.0234)
Observations	998	998	4,924	4,924
R-squared	0.461	0.516	0.365	0.372
AdmFE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: Survey FE were left out because there was just one survey used for Chad. AdmFE is the second administrative unit for the men sample and third administrative unit for the women sample.

Table B. 5: Years of education and any education by strata, men

VARIABLES	(1) Years MEN	(2) Any Education MEN	(3) Years MEN	(4) Any Education MEN
In utero shock	0.190	0.00837	0.135	-0.0248
	(0.179)	(0.0430)	(0.726)	(0.0651)
First year shock	-0.424***	-0.103***	0.212	-0.0239
	(0.122)	(0.0355)	(0.619)	(0.0497)
Second year shock	-0.176	-0.0467	0.297	0.0384
	(0.159)	(0.0367)	(0.623)	(0.0518)
Third year shock	-0.106	-0.0341	-1.025*	-0.114**
	(0.143)	(0.0339)	(0.555)	(0.0551)
Fourth year shock	-0.151	-0.0679**	-0.768	-0.0820
	(0.131)	(0.0309)	(0.723)	(0.0580)
Shock > 4 years	0.0516	-0.0183	0.0373	0.0333
	(0.0823)	(0.0173)	(0.537)	(0.0553)
Constant	-0.0638	0.271***	2.573***	0.418***
	(0.118)	(0.0209)	(0.602)	(0.0464)
Observations	2,593	2,593	2,624	2,624
R-squared	0.076	0.103	0.136	0.155
Adm2FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table B. 6: Years of education and any education by strata, women

	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	0.105	0.0211	0.0368	0.0149
	(0.0876)	(0.0174)	(0.187)	(0.0207)
First year shock	0.0557	0.00718	-0.0242	-0.00159
	(0.0646)	(0.0128)	(0.149)	(0.0217)
Second year shock	-0.0165	-0.00576	0.564***	0.0328
	(0.0492)	(0.0108)	(0.195)	(0.0269)
Third year shock	0.0318	0.00294	0.259	0.0320
	(0.0510)	(0.0128)	(0.159)	(0.0223)
Fourth year shock	-0.00745	0.000315	-0.215	0.00602
	(0.0408)	(0.0104)	(0.176)	(0.0244)
Shock > 4 years	0.0172	0.00428	0.203	0.0332
	(0.0274)	(0.00635)	(0.151)	(0.0215)
Constant	0.495***	0.0999***	0.222	0.0775***
	(0.0637)	(0.0127)	(0.146)	(0.0132)
Observations	14,931	14,931	14,952	14,952
R-squared	0.031	0.040	0.153	0.135
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table B. 7: Height by strata

VARIABLES	(1) Height_low	(2) Height_perc_low	(3) Height_high	(4) Height_perc_high
In utero shock	-1.682*	-0.499	0.946	0.559
	(0.916)	(0.373)	(1.034)	(0.434)
First year shock	-0.969	-0.542	0.338	0.175
	(0.836)	(0.392)	(0.810)	(0.390)
Second year shock	-0.718	-0.392	-0.0787	-0.0867
	(0.882)	(0.388)	(0.910)	(0.419)
Third year shock	-0.325	-0.276	0.130	0.000322
	(0.851)	(0.384)	(0.843)	(0.384)
Fourth year shock	0.381	0.153	2.223**	0.999**
	(0.573)	(0.288)	(0.928)	(0.405)
Shock > 4 years	-1.031*	-0.452*	-0.254	-0.112
	(0.590)	(0.269)	(0.616)	(0.275)
Constant	165.7***	6.146***	168.1***	5.706***
	(1.010)	(0.465)	(0.639)	(0.283)
Observations	4,179	4,179	3,164	3,164
R-squared	0.178	0.181	0.203	0.207
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Appendix C: Robustness Checks

Table C. 1: Education outcomes for non-migrants

VARIABLES	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	0.000354	0.0262	0.587	0.0482
	(0.180)	(0.0397)	(0.429)	(0.0551)
First year shock	-0.0614	-0.00326	0.336	0.0369
	(0.151)	(0.0327)	(0.351)	(0.0492)
Second year shock	-0.0794	-0.0380	0.127	-0.0283
	(0.204)	(0.0315)	(0.443)	(0.0510)
Third year shock	-0.351**	-0.0375	0.416	0.0413
	(0.142)	(0.0241)	(0.373)	(0.0520)
Fourth year shock	0.206	0.0338	-0.392	-0.0537
	(0.213)	(0.0450)	(0.388)	(0.0693)
Shock > 4 years	-0.00865	-0.00199	0.508	0.0603
	(0.105)	(0.0232)	(0.339)	(0.0430)
Male	0.228***	0.0494***	1.630***	0.186***
	(0.0675)	(0.0140)	(0.321)	(0.0373)
Constant	0.137	0.00756	-1.207***	-0.120**
	(0.102)	(0.0252)	(0.387)	(0.0481)
Observations	2,230	2,230	2,536	2,536
R-squared	0.047	0.049	0.180	0.150
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 2: Years of education and any education by strata, just locust bands, men

VARIABLES	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	0.199	0.0420	0.317	-0.0440
	(0.235)	(0.0494)	(0.673)	(0.0673)
First year shock	-0.467**	-0.0958*	0.788	0.0313
	(0.195)	(0.0556)	(0.817)	(0.0613)
Second year shock	-0.460**	-0.101*	1.094	0.00468
	(0.214)	(0.0542)	(1.052)	(0.0759)
Third year shock	-5.48e-05	0.00422	-0.623	-0.0612
	(0.236)	(0.0607)	(0.625)	(0.0574)
Fourth year shock	-0.167	-0.0682**	-1.018	-0.0996
	(0.139)	(0.0337)	(0.904)	(0.0661)
Shock > 4 years	-0.0135	-0.0179	0.835	0.0735
	(0.0984)	(0.0229)	(0.676)	(0.0739)
Constant	-0.116	0.234***	2.026***	0.377***
	(0.0926)	(0.0145)	(0.620)	(0.0378)
Observations	2,593	2,593	2,624	2,624
R-squared	0.075	0.102	0.138	0.155
Adm2FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 3: Years of education and any education by strata, just locust bands, women

	(1)	(2)	(3)	(4)
	Years	Any Education	Years	Any Education
In utero shock	0.252**	0.0499**	0.0291	0.0106
	(0.124)	(0.0217)	(0.259)	(0.0307)
First year shock	0.00148	-0.00513	-0.185	-0.0535**
	(0.0696)	(0.0140)	(0.212)	(0.0252)
Second year shock	-0.0740	-0.0171	0.495**	0.0158
	(0.0793)	(0.0182)	(0.237)	(0.0303)
Third year shock	0.0355	-0.00546	-0.0607	-0.00641
	(0.0658)	(0.0138)	(0.200)	(0.0271)
Fourth year shock	-0.0157	-0.00385	-0.226	0.00462
	(0.0562)	(0.0131)	(0.215)	(0.0272)
Shock > 4 years	0.0290	-0.000923	-0.0309	0.00171
	(0.0383)	(0.00840)	(0.181)	(0.0246)
Constant	0.510***	0.104***	0.277*	0.0809***
	(0.0566)	(0.0108)	(0.143)	(0.0128)
Observations	14,931	14,931	14,952	14,952
R-squared	0.032	0.040	0.152	0.135
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 4: Height by strata, just locust bands

VARIABLES	(1) Height_low	(2) Height_perc_low	(3) Height_high	(4) Height_perc_high
In utero shock	-1.110	-0.397	-0.788	-0.195
	(1.290)	(0.614)	(1.691)	(0.686)
First year shock	-0.222	-0.134	-2.164*	-1.035*
	(1.245)	(0.625)	(1.155)	(0.543)
Second year shock	0.654	0.268	-0.726	-0.569
	(1.270)	(0.631)	(1.415)	(0.631)
Third year shock	-0.217	-0.261	0.160	-0.0584
	(1.191)	(0.553)	(1.301)	(0.477)
Fourth year shock	0.829	0.414	1.202	0.379
	(0.827)	(0.428)	(1.126)	(0.484)
Shock > 4 years	0.195	0.105	-1.331*	-0.715**
	(0.720)	(0.344)	(0.702)	(0.286)
Constant	164.6***	5.661***	168.1***	5.707***
	(0.725)	(0.339)	(0.622)	(0.280)
Observations	4,179	4,179	3,164	3,164
R-squared	0.176	0.180	0.203	0.206
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Figure C. 1: Plotted regression coefficients, dummies utero-9th year of life, by strata, men

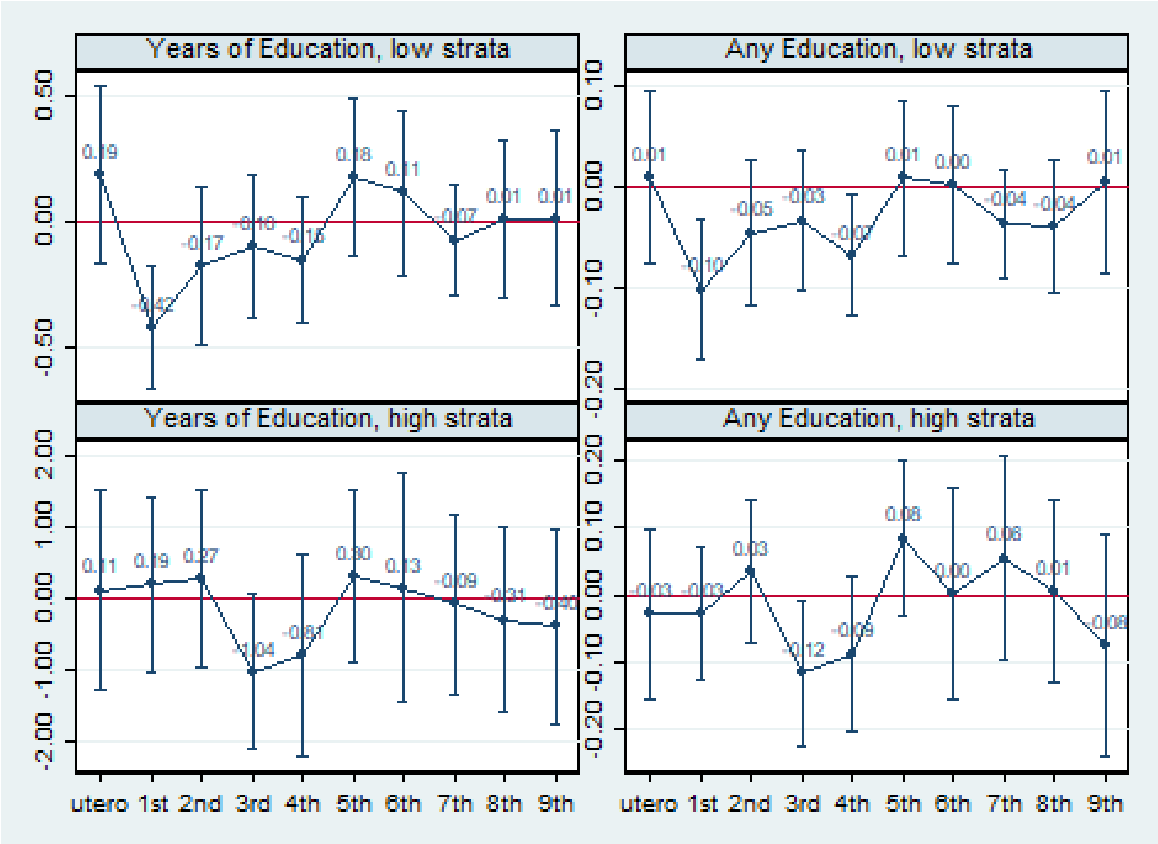


Figure C. 2: Plotted regression coefficients, dummies utero-9th year of life, by strata, women

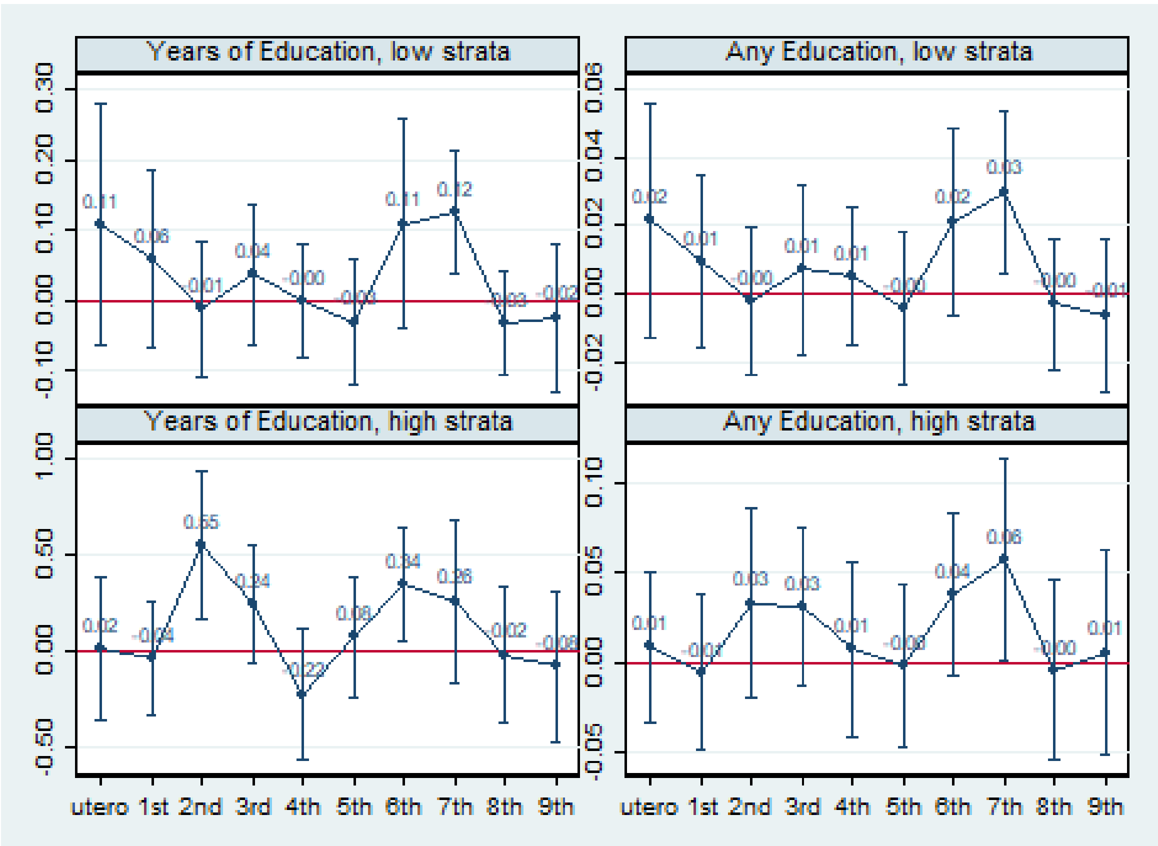


Table C. 5: Years of education and any education by strata, 15km radius, men

VARIABLES	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	0.117	0.00716	0.425	-0.00245
	(0.163)	(0.0367)	(0.667)	(0.0590)
First year shock	-0.430***	-0.0960***	0.318	0.0339
	(0.107)	(0.0260)	(0.618)	(0.0463)
Second year shock	-0.0678	0.000448	0.418	0.0264
	(0.150)	(0.0349)	(0.535)	(0.0462)
Third year shock	-0.0380	-0.0257	-0.0911	-0.0550
	(0.129)	(0.0307)	(0.584)	(0.0479)
Fourth year shock	-0.167	-0.0301	-0.135	-0.0307
	(0.102)	(0.0265)	(0.544)	(0.0476)
Shock > 4 years	0.00776	-0.0148	0.193	0.0462
	(0.0756)	(0.0188)	(0.478)	(0.0482)
Constant	-0.0655	0.263***	2.105***	0.377***
	(0.131)	(0.0246)	(0.603)	(0.0438)
Observations	2,593	2,593	2,624	2,624
R-squared	0.077	0.102	0.135	0.154
Adm2FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 6: Years of education and any education by strata, 15km radius, women

VARIABLES	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	0.0931	0.0252*	-0.142	-0.00244
	(0.0691)	(0.0143)	(0.160)	(0.0195)
First year shock	0.0642	-0.000662	-0.0870	0.000480
	(0.0491)	(0.0114)	(0.158)	(0.0213)
Second year shock	0.00839	0.00298	0.405***	0.0354*
	(0.0430)	(0.00947)	(0.139)	(0.0209)
Third year shock	-0.0208	-0.0111	0.414***	0.0509**
	(0.0397)	(0.0103)	(0.144)	(0.0200)
Fourth year shock	-0.0178	-0.00472	-0.112	0.0109
	(0.0328)	(0.00836)	(0.154)	(0.0220)
Shock > 4 years	-0.00491	0.000110	0.268*	0.0516**
	(0.0295)	(0.00738)	(0.142)	(0.0202)
Constant	0.529***	0.104***	0.159	0.0733***
	(0.0625)	(0.0131)	(0.146)	(0.0138)
Observations	14,931	14,931	14,952	14,952
R-squared	0.031	0.040	0.153	0.136
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 7: Years of education and any education by strata, 20km radius, men

VARIABLES	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	-0.00261	-0.00769	0.398	-0.0198
	(0.148)	(0.0323)	(0.594)	(0.0496)
First year shock	-0.438***	-0.0863***	0.460	0.0396
	(0.118)	(0.0291)	(0.570)	(0.0442)
Second year shock	-0.180	-0.0135	0.203	-0.0165
	(0.153)	(0.0325)	(0.445)	(0.0429)
Third year shock	-0.0190	-0.0229	0.100	-0.0659
	(0.104)	(0.0247)	(0.533)	(0.0427)
Fourth year shock	-0.124	-0.0210	-0.121	-0.0249
	(0.110)	(0.0276)	(0.563)	(0.0474)
Shock > 4 years	-0.0313	-0.0161	0.515	0.0337
	(0.0808)	(0.0190)	(0.454)	(0.0476)
Constant	-0.0290	0.263***	1.826***	0.386***
	(0.134)	(0.0246)	(0.584)	(0.0418)
Observations	2,593	2,593	2,624	2,624
R-squared	0.077	0.102	0.135	0.154
Adm2FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 8: Years of education and any education by strata, 20km radius, women

VARIABLES	(1) Years	(2) Any Education	(3) Years	(4) Any Education
In utero shock	0.0999	0.0249*	-0.0589	0.0118
	(0.0619)	(0.0129)	(0.163)	(0.0177)
First year shock	0.0718	0.00185	-0.175	-0.0124
	(0.0456)	(0.0102)	(0.159)	(0.0204)
Second year shock	0.0414	0.0120	0.311**	0.0313
	(0.0439)	(0.00964)	(0.140)	(0.0202)
Third year shock	-0.0187	-0.0135	0.340**	0.0535***
	(0.0378)	(0.00954)	(0.142)	(0.0193)
Fourth year shock	-0.0124	-0.00371	-0.0767	0.0109
	(0.0312)	(0.00780)	(0.141)	(0.0211)
Shock > 4 years	0.0142	0.00487	0.0954	0.0338*
	(0.0311)	(0.00796)	(0.148)	(0.0202)
Constant	0.510***	0.0991***	0.140	0.0516**
	(0.0606)	(0.0125)	(0.208)	(0.0227)
Observations	14,931	14,931	14,952	14,952
R-squared	0.032	0.040	0.152	0.135
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 9: Height by strata, 15km radius

VARIABLES	(1) Height_low	(2) Height_perc_low	(3) Height_high	(4) Height_perc_high
In utero shock	-1.779**	-0.649**	-0.270	-0.0181
	(0.726)	(0.306)	(0.852)	(0.375)
First year shock	-0.451	-0.260	-0.662	-0.237
	(0.629)	(0.292)	(0.767)	(0.366)
Second year shock	-0.791	-0.326	-0.371	-0.234
	(0.654)	(0.282)	(0.825)	(0.373)
Third year shock	-0.744	-0.302	0.585	0.209
	(0.743)	(0.324)	(0.774)	(0.360)
Fourth year shock	-0.200	-0.108	1.129	0.432
	(0.489)	(0.237)	(0.794)	(0.355)
Shock > 4 years	-0.766	-0.302	-0.0530	-0.0351
	(0.507)	(0.229)	(0.600)	(0.259)
Constant	165.5***	5.994***	167.8***	5.583***
	(0.949)	(0.445)	(0.644)	(0.286)
Observations	4,179	4,179	3,164	3,164
R-squared	0.178	0.181	0.202	0.205
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	YES	YES	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 10: Height by strata, 20km radius

VARIABLES	(1) Height_low	(2) Height_perc_low	(3) Height_high	(4) Height_perc_high
In utero shock	-0.890	-0.303	-0.565	-0.138
	(0.641)	(0.284)	(0.765)	(0.346)
First year shock	0.0356	-0.0738	-0.781	-0.305
	(0.546)	(0.261)	(0.716)	(0.304)
Second year shock	-0.0929	-0.0170	-0.670	-0.331
	(0.579)	(0.250)	(0.681)	(0.309)
Third year shock	-0.0465	-0.0718	-0.144	0.00676
	(0.585)	(0.262)	(0.667)	(0.304)
Fourth year shock	0.235	0.0987	0.670	0.284
	(0.479)	(0.225)	(0.756)	(0.347)
Shock > 4 years	0.0541	0.0378	-0.629	-0.250
	(0.452)	(0.205)	(0.529)	(0.234)
Constant	164.6***	5.635***	168.6***	5.875***
	(0.902)	(0.417)	(0.856)	(0.373)
Observations	4,179	4,179	3,164	3,164
R-squared	0.177	0.180	0.202	0.205
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Table C. 11: Years of education and any education by strata, men, third administrative unit control

VARIABLES	(1) Years MEN	(2) Any Education MEN	(3) Years MEN	(4) Any Education MEN
In utero shock	0.220	0.00727	0.221	-0.0102
	(0.210)	(0.0487)	(0.754)	(0.0670)
First year shock	-0.418**	-0.0945**	0.0168	-0.00699
	(0.169)	(0.0474)	(0.701)	(0.0621)
Second year shock	-0.226	-0.0566	0.196	0.0441
	(0.159)	(0.0418)	(0.663)	(0.0668)
Third year shock	-0.143	-0.0608	-1.195*	-0.107*
	(0.183)	(0.0431)	(0.680)	(0.0643)
Fourth year shock	-0.191	-0.0833**	-1.089	-0.0868
	(0.152)	(0.0340)	(0.752)	(0.0736)
Shock > 4 years	0.0566	-0.0236	-0.00410	0.0470
	(0.119)	(0.0293)	(0.504)	(0.0506)
Constant	0.630***	0.240***	3.644***	0.611***
	(0.140)	(0.0214)	(0.995)	(0.0872)
Observations	2,593	2,593	2,624	2,624
R-squared	0.136	0.188	0.215	0.221
Adm3FE	YES	YES	YES	YES
BirthyearFE	YES	YES	YES	YES
Survey FE	YES	YES	YES	YES
Weather FE	YES	NO	YES	NO

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: (1) and (2) show values for the lower education strata, (3) and (4) for the upper education strata.

Appendix D: Technical Appendix

W_{ct} includes five dummies showing early-life deviations in precipitation and evapotranspiration from the long-run mean. Each of these dummies was derived by averaging monthly weather data around the date of birth for each individuals:

$$WUtero_{ct} = \frac{1}{9} * \sum_{x=t_i-9}^{t_i-1} W_{xc}$$

$$WFirstYear_{ct} = \frac{1}{12} * \sum_{x=t_i}^{t_{i+11}} W_{xc}$$

$$WSecondYear_{ct} = \frac{1}{12} * \sum_{x=t_i+12}^{t_{i+23}} W_{xc}$$

$$WThirdYear_{ct} = \frac{1}{12} * \sum_{x=t_i+24}^{t_{i+35}} W_{xc}$$

$$WFourthYear_{ct} = \frac{1}{12} * \sum_{x=t_i+36}^{t_{i+47}} W_{xc}$$