Economic development and sustainable resource use in Africa

Mandy Malan

Propositions

1. Economic incentives are crucial for the design of environmental policies.
   (this thesis)
2. We can learn more from a meta-perspective than from micro-level analysis.
   (this thesis)
3. The choice of research method should not drive the research question.
4. There should be a Journal of Null Results.
5. Measuring output is not the same as evaluating impact.
6. Collaborating with partners from other sectors is like speaking to each other in different languages.

Propositions belonging to the thesis entitled:

"Economic development and sustainable resource use in Africa"

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Chapter 1

Introduction

1.1 Problem statement

At the beginning of the 21st century, humanity is facing the complex challenge of simultaneously protecting the environment and combatting climate change, whilst also improving the lives of poverty-stricken people. These processes influence each other in a number of ways and, for that reason, cannot be seen separately. Economic forces are driving unsustainable use of resources such as agricultural land and forests, thereby contributing to climate change. Climate change is, in turn, posing a threat for the economic development of especially low-income countries, with extreme weather expected to reduce crop yields in the world's most food-insecure regions. Climate change is also developing into a major hazard for global health, as an additional 250.000 deaths per year caused by climate change-induced illnesses are expected from 2030-2050 (World Health Organization, 2018).

The international community has taken efforts to combat these challenges. In 1983, the United Nations' World Commission on Environment and Development first popularised the term 'sustainable development' in their report entitled 'Our Common Future'. By 2015, a new course was set in the global strategy by replacing the United Nation's eight Millennium Development Goals (MDGs), which concentrated mostly on economic development, with the 17 Sustainable Development Goals (SDGs). Set to be reached by 2030, the SDGs have a much stronger focus on attaining prosperity for the planet as well as for its people.

Despite these efforts, there is much progress to be made in order to achieve the targets defined under the SDGs (United Nations, 2021). The ongoing COVID-19 pandemic has turned recent downward trends in poverty reduction, undoing all progress made since 2015. Advances made to protect key biodiversity areas have stalled over the last five years. The world's forest area is still decreasing, albeit at a slower rate in the recent decade, despite efforts to improve sustainable forest management. The adoption of sustainable technologies, such as land restoration practices and clean energy technologies, is viewed as a major pathway for sustainable change, yet is also falling behind on desired trends.

Underneath the lack of progress in reaching the SDGs lurks a pressing knowledge gap on how economic development and environmental degradation interact. We still know very little about how poverty-alleviation interventions affect environmental outcomes and vice versa, despite decades of debate and actions (Alpízar and Ferraro, 2020). Research on the interface of the environment and economics has long focused on the North, and it is only recently that environmental and development economists have entered into each other's line of sight (Jack, 2017).

Another important question underlying these challenges concerns which actors and policies can effectively drive sustainable development. Government policy and development aid have traditionally been the go-to approach to reach vulnerable regions and communities, and to achieve environmental protection. But the issues at hand demand a global response and require contributions from sectors of society other than governments. As such, Northern governments and civil society are holding firms accountable for their environmental impact, gradually expanding the role of the private sector in achieving sustainable development. One way in which the role of private actors is becoming more dominant, is through the procurement of carbon credits in carbon offset markets, a market whose value has skyrocketed from $473 million to over $1 billion over the past two years. The private sector also increasingly plays a role in Northern government's development aid strategy (Kindornay and Reilly-King, 2013). As official development assistance's relative importance is decreasing, non-aid flows like trade and Foreign Direct Investment (FDI) are becoming relatively more important for low-income countries. The Aid for Trade Initiative by the World Trade Organization (WTO) stimulates high and low-income countries to leverage trade to reach SDGs. Since 2006, Aid for Trade disbursements have more than doubled from around 20 billion United States Dollars (USD) to 45.7 billion USD in 2019 (OECD, 2021). Despite these trends, the effectiveness of private sector involvement in development aid has not been researched widely (Kindornay and Reilly-King, 2013).

As illustrated above, there is still a lot to learn about whether and under what circumstances the SDGs can be reached. With this thesis, I aim to contribute to filling this knowledge gap by examining how development aid and private sector interventions can achieve economic and environmental improvement simultaneously. In doing so, I provide insights on the apparent trade-off between economic development and the environment, and on the role of the private sector in sustainable development policy. Furthermore, I dive into some of the pathways through which change is attained: behaviour, institutions, and geography.

What follows is a discussion of the relevant literature this thesis speaks to. Thereafter, I present the research questions that this thesis attempts to answer. I then turn to a concise description of the methods and data used in the chapters.

1.2 Literature

1.2.1 The trade-off between economic development and the environment

The relationship between economic development and environmental degradation has long been widely debated. A notable hypothesis on this relationship is the environmental Kuznets curve (EKC). Originally applied to the relationship between income and income inequality, the EKC-hypothesis suggests that the relationship between per capita income and environmental degradation can be characterised by an inverted U-curve (Grossman and Krueger, 1995). As a country's per capita income rises, environmental conditions worsen, until a turning point is reached after which environmental conditions steadily improve. Theoretically, the EKC-hypothesis is explained by structural changes in the type of output produced and inputs used, advances in technology, and increased environmental awareness that occur at higher levels of development (Stern, 2017). Grossman and Krueger (1991) were the first to provide empirical evidence of this inverted-U relationship for a range of environmental pollutants. The 1992 World Development Report popularised the idea that economic growth and poverty reduction can improve environmental conditions, as long as effective policies and institutions are in place (World Bank, 1992). Since then, however, there have been numerous macro-level attempts to prove the existence of the EKC, with most research encountering methodological issues and, more importantly, finding limited empirical support (Stern, 2017).

Today, the academic consensus on the nature of the relationship between economic development and environmental degradation is that it is in many cases monotonic and positive, but that there are many other factors that mediate the relationship that cannot be accounted for in a macro-level framework (Jayachandran, 2022). The question of how economic development and the environment influence each other is therefore best answered empirically at the micro-level.

One side of this empirical question is studying how interventions to combat poverty and spur economic growth influence the environment. Jayachandran (2022) provides a recent review of the micro-level research attempting to answer this question. This review shows that this question can be answered in many ways depending on the particular domain. One could study how increases in income and access to capital affect the environment, what the environmental impact of investment in technology and infrastructure is, or how institutional changes associated with economic growth interact with the environment. Each of these questions will have a different answer, but a cross-cutting conclusion from such studies is that processes underlying or caused by economic growth produce negative externalities, which ultimately can harm the environment. Only through environmental regulation can these externalities be tempered, and can economic growth, in potential, be directed to be pro-environment. How this environmental regulation should take place, however, remains a key knowledge gap.

The other side of the relationship, how environmental interventions impact economic development, is equally important for advancing sustainable economic goals. The puzzling adoption decisions by smallholder farmers, who forgo sustainable and high-yielding agricultural practices, or alternatively, adopt practices that do not result in significant yield-gains or environmental protection, illustrate this. Recent evidence of technology adoption points out that much of the existing research focuses, narrowly, on agricultural yield impacts, not accounting for other factors that determine the profitability of a technology (e.g. the marketability of the production output) (Takahashi et al., 2020; Michler et al., 2019). Similarly, one aspect of technology adoption often overlooked is the induced reallocation of productive inputs, such as labour, within the household, which could make the adoption of a sustainable technology economically unfeasible (Takahashi and Barrett, 2013). What these studies commonly emphasise, is that economic benefits do matter. A recent review of 18.000 studies on the drivers of the adoption of sustainable agricultural practices confirms this, showing that direct economic benefits, increased productivity or profitability is an essential condition for adoption in the short run (Piñeiro et al., 2020). Hence, understanding if and how environmental interventions can be economically beneficial at the household-level is crucial for improving the adoption of sustainable practices.

In this thesis, I study popular environmental policies that aim to improve economic and environmental outcomes in a low-income context. In Chapter 2, I conduct a systematic literature review on the socioeconomic impacts of widely promoted strategies to combat land degradation. In Chapter 3, I study the impact of a voluntary REDD+ (Reducing Emissions from Deforestation and Degradation) programme on environmental and livelihood outcomes. In Chapter 5, I study the role of monetary incentives and economic information in improving the uptake of sustainable cooking practices.

1.2.2 Aid (f)or trade?

The traditional approach to spur (sustainable) development is through development aid. In this approach, donors, often governments from high-income countries or international organisations such as the United Nations or the World Bank, finance development programmes through low-income countries' governments or non-governmental organisations (NGOs).

In the past decades, the private sector is increasingly involved in reaching the SDGs, thereby playing a role historically fulfilled only by governments, international organisations, and NGOs. One conventional way in which the private sector can contribute to economic development is through FDI. FDI in low-income countries is mostly welcomed because of the potential to create employment opportunities, increase human capital, and trigger technology spillovers, all contributing to economic growth (OECD, 2002). In addition, FDI can potentially lead to trade opportunities for the investor's country. For this reason, many high-income countries direct their development aid policy towards private sector involvement, rather than traditional forms of development aid (Kindornay and Reilly-King, 2013).

But FDI may come at a cost. Specifically, in the case of agricultural and mining investments, an important form of FDI in low-income countries, concerns over the impact on local communities and the environment are widespread. Theoretical contributions by Dessy et al. (2012); Kleemann and Thiele (2015) show that agricultural FDI can cause economic development under certain conditions. Yet, there is ample anecdotal evidence of the detrimental effects of mining and agricultural investments, ranging from land appropriation and conflicts with local communities to increased inequality and corruption. Rigorous quantitative studies that back this up are rare because of limited data availability and a lack of transparency that surrounds the investments in question.

Another rapidly expanding way in which the private sector can potentially foster sustainable development is through purchasing carbon offsets. Carbon offsets are sold in voluntary carbon credit markets to actors that wish to reduce their carbon footprint beyond legally mandated levels. These markets are increasingly deemed crucial for meeting climate change goals set by the Paris Agreement. Carbon offsets can be sourced from a number of different sectors, but mostly stem from the forestry sector (Forest Trends' Ecosystem Marketplace, 2021). These so-called voluntary REDD+ programmes (reducing emissions from deforestation and degradation) are set up to incentivise the owners of a specific forested area to reduce the baseline rate of deforestation and degradation, thereby increasing carbon storage. Carbon credits based on these programmes are sold under the condition that any avoided deforestation should be caused by the programme (i.e. carbon sequestration should be additional to the business-as-usual case). Because they typically contain a livelihood component,[1] they can also, in theory, improve local economic outcomes. Though the projects are evaluated and accredited by accrediting agencies, there is substantial criticism surrounding the objectivity, transparency, and robustness of these assessments (West et al., 2020). Yet despite multiple calls from the scientific community for more independent evaluations, there is very little rigorous evidence of the effectiveness of voluntary carbon credit programmes.

There is still a lot to learn about the effectiveness of private sector involvement, both in the case of foreign direct investment, and recently popularised carbon offset markets. Impeding this learning process is a lack of transparency surrounding many private sector projects. Academic research, as presented in this thesis, can contribute to this knowledge gap by supporting data collection and evaluations of

[1] In fact, these programmes explicitly carry the condition of having no adverse impact on local communities (Herr et al., 2019)

such projects.

In this thesis, I study different approaches to achieving the SDGs. The REDD+ programme I focus on in Chapter 3 is financed and accredited through the voluntary carbon market, but implemented by a local NGO. In Chapter 4, I describe a census of large-scale mining and agricultural investments in Sierra Leone that focuses on the interaction of private companies with host communities and local institutions. In contrast, I focus on a traditional form of development aid in Chapter 5, evaluating a programme implemented by a donor-financed NGO aimed at incentivising rural Ethiopian households to adopt a sustainable cooking technology. Though these chapters are stand-alone studies on varying topics in varying contexts, they do offer some general lessons on what we can learn from different approaches to sustainable development.

1.2.3 Pathways to development

In order to design effective policies to attain economic development and environmental protection, understanding the causes of development is crucial. Underlying the chapters in this thesis are three pathways to development: behaviour, institutions, and geography. In the following section, I briefly discuss important theories and literature on these pathways and link them to the relevant chapters.

Behaviour

Many questions in development economics ultimately boil down to studying human behaviour. In fact, in order to reach the SDGs touched upon in this thesis, some form of behavioural change is often required (World Bank, 2015). Studying behaviour in economics first started with the foundational work of Adam Smith in the 18th century. For a long time, economists treated individuals as rational economic actors who maximise utility by basing their decisions on self-interest. Even though the limits of human rationality were acknowledged much earlier (Herbert Simon introduced the term 'bounded rationality' in the 1950s), it was not until the end of the 20th century that economists slowly departed from some of the assumptions underlying rational choice theory (Thaler and Sunstein, 2008; Thaler, 2015). Since then, insights from psychology have been introduced into economic models allowing for more realistic predictions about human behaviour in an economic setting.

Studying behaviour and interventions to induce behavioural change is particularly relevant for the technology adoption literature. Duflo et al. (2011) find that sub-optimal levels of fertiliser used by farmers in Kenya can be explained by the present-biasedness of farmers and show how this can be overcome with a simple time-limited subsidy. Studies on the adoption of improved cooking technologies have come to similar conclusions, finding that price incentives can stimulate adoption in a number of contexts (Pattanayak et al., 2019; Bensch et al., 2015; Mobarak et al., 2012).

In the context of stimulating pro-environmental behaviour, policies can broadly be placed on a scale from indirect approaches, where individuals or communities are encouraged to change behaviour by providing education or alternative income possibilities, to direct approaches, where individuals or communities receive payments conditional on their observed behaviour (Ferraro and Kiss, 2002). Which of these is most effective and least costly is ultimately an empirical question (Jayachandran et al., 2017).

Two of the chapters in this thesis study the impact of an intervention on behaviour of rural households. In Chapter 3, the intervention studied is aimed at directing behaviour of farmer households towards more sustainable land-use by promoting forest-friendly agricultural practices and crops. In Chapter 5, Ethiopian households receive varying levels of subsidies and types of information about the benefits of a sustainable cooking technology. The study aims to detect the effective level of subsidisation and test how households respond to different types of information when making an adoption decision.

Institutions

The role of institutions in economic development has been widely discussed in the economic literature. Institutions are, simply put, the formal and informal rules that underpin economic activity (Jayachandran, 2022). Institutions can influence development in a variety of ways. Famous work by Acemoglu et al. (2001) and later Michalopoulos and Papaioannou (2013) document the pervasiveness of colonial and pre-colonial institutions in Africa by showing how they may influence development, even today. Corruption in low-income countries, another channel through which institutions can affect development, has been found to potentially have a detrimental impact on efficiency and equity (Olken and Pande, 2012). Moreover, countries with democratic institutions generally receive more FDI. A recent meta-analysis shows that one of the most robust mechanisms underlying this observation are the formalised property rights that characterise democratic countries (Li et al., 2018). Similarly, whether property rights are legally defined or not, influences investment levels of smallholder farmers, which in turn affects agricultural productivity (Lawry et al., 2016).

In the context of large-scale land investments, institutions constitute the framework in which investors operate. This framework can determine how investors interact with host communities, with local authorities, and vice versa (Schoneveld, 2017). For example, the type of property rights system has been found to determine whether investors acquire land in an area (Christensen et al., 2021). Furthermore, local institutions play a large role in how lease agreements are negotiated and land rents are distributed. Who benefits from such investments, therefore, at least in part, depends on the local institutions in place (Schoneveld, 2017).

Institutions can thus potentially be a pathway to development, but studying this relationship often results in methodological challenges. Most notably, institutions are endogenous to economic development, that is, they determine economic development but are also shaped by economic development. Economists in this field are thus always on the lookout for exogenous variation in institutions, or if possible, an instrument for institutions. The difficulty of finding valid instruments is illustrated by the heavy debate sparked after the publication of Acemoglu et al. (2001) on the validity of the author's instrumental variable approach.

In Chapter 4, I study the relationship between the chieftaincy, an important institution in many African countries, and large-scale land investments. More specifically, I study whether the political power of the paramount chief in Sierra Leone influences an investor's decision to acquire land. To deal with the issue of endogeneity discussed above, I use a plausibly exogenous proxy for chief political power developed by Acemoglu et al. (2014) and relate this to data from a census of land investments in Sierra Leone.

Geography

Besides behaviour and institutions, some economists have put forward the importance of the geographic environment in determining economic development. In Gallup et al. (1999), the authors show how geographic location and climate have large effects on income. Important mechanisms identified for this pathway are, for example, transportation costs (Redding and Venables, 2004), disease burden (Sachs and Malaney, 2002), climate shocks (Dell et al., 2012), and agricultural productivity.

The latter of these, agricultural productivity, is considered a major constraint to economic development in Sub-Saharan Africa. The main limiting factor for agricultural productivity growth put forward is low soil fertility (Jayne and Sanchez, 2021; Tittonell and Giller, 2013). Low soil fertility has also recently gained attention in the context of malnutrition - the suboptimal consumption of essential nutrients with severe health effects as a result. Malnutrition is thought to be the result of low agricultural productivity (Kihara et al., 2017) and the ensuing impacts on poverty (Barrett and Bevis, 2015), or because of low nutrient availability in consumed food (Kim and Bevis, 2019), both of which are rooted in low nutrient availability in the soil. Though widely recognised as a potential pathway to development, research establishing the link between soils and health is at a very early stage.

In Chapter 6, I contribute to this research gap. In particular, I explore whether soil nutrient content in Sub-Saharan Africa influences health outcomes. By exploring the cost-effectiveness of different policy options to reduce malnutrition, this research also contributes to a growing policy agenda.

1.3 Objectives

The overarching objective of this thesis is to understand how development aid and private sector investments can contribute to improving both environmental and economic outcomes. I aim to reach this objective in five chapters which all answer a specific research question:

- Chapter 2: What is the socioeconomic impact of common strategies for land restoration?
- Chapter 3: How do voluntary REDD+ programmes affect development and conservation?
- Chapter 4: To what extent is there a relationship between local institutions and private sector investment?
- Chapter 5: How can we incentivise households to use sustainable cooking technologies?
- Chapter 6: To what extent is there a relationship between soils and health outcomes?

In Chapter 2, I contribute to the lack of knowledge on the socioeconomic impacts of widely promoted land restoration strategies by systematically reviewing and synthesising existing literature. This chapter can help direct researchers and policymakers to focus on the areas where knowledge gaps are largest and to inform the design of much-needed land restoration programmes. Chapter 3 is one of the few studies that looks at long-term impacts of a voluntary REDD+ project, using a rigorous causal methodology and studying both conservation and livelihood outcomes. Chapter 4 provides a unique insight into how large-scale land investments operate and interact with communities in a low-income country. It is also one of the few studies to look at the relationship between institutional quality and land investments at a meso-level. Chapter 5 contributes to the growing body of literature that aims to determine how to motivate households to adopt sustainable cooking technologies. The study is one of the largest randomised controlled trials on cook stoves investigating the effect of monetary and information incentives. Chapter 6 is a preliminary inquiry into the relationship between soil nutrient content and health outcomes. The insights from this study form a basis for future research on agronomic fortification as a strategy to combat malnutrition.

1.4 Methodology

Most of the research questions of this thesis, and many of the questions answered in economics, are of a causal nature. To answer these, I use both experimental and quasi-experimental methods. In addition, I employ non-experimental methods to answer descriptive questions. In this section, I will briefly discuss each of these methods, their strengths, and their limitations. Each chapter has its respective methodology section in which I dive deeper into the details.

1.4.1 Metascience

Metascience or meta-research is, broadly speaking, the use of scientific methods to study science itself. The discipline first appeared within the medical sciences, but has become popular in economics in recent years. Metascience is considered an important aspect of research transparency (see Christensen and Miguel 2018 for a recent overview of research transparency in economics). There are different forms of metascience, ranging from reproducing results and revisiting conclusions, to synthesising the results of a large number of studies on a particular topic. The latter, often done through a systematic review of the relevant literature and sometimes coupled with a meta-analysis using authors' original data, can be used to estimate the average impact of an intervention across different contexts. Not only is a systematic review arguably more appropriate to approach the truth, as opposed to a single study, it also allows for exposing biases in the types of questions studied and results published, and helps identify key knowledge gaps. In Chapter 2, I conduct a systematic review of the literature on the socioeconomic impact of common interventions to combat land degradation. In this review, I focus solely on rigorous experimental and quasi-experimental methods, as discussed below.

1.4.2 Field experiments

In order to test causal claims in economics, field experiments (or randomised controlled trials (RCTs), the terms are often used interchangeably) have rapidly gained popularity in the past two decades (Levitt and List, 2009). The 2019 Nobel Memorial Prize in Economics Sciences, awarded to Esther Duflo, Abhijit Banerjee, and Michael Kremer for their use of field experiments in development economics, demonstrates the huge impact randomised inference has had on the economic discipline. Originating from the medical sciences, field experiments differ from laboratory experiments in that they are (at least partially) conducted in the natural habitat of study subjects.

Field experiments are widely used in programme impact evaluation to measure the causal impact of an intervention by randomly assigning the intervention to some (the treatment group) and not to others (the control group). The identifying assumption underlying field experiments is that the only difference between the treatment and the control group is the assigned treatment (also called the Stable Unit Treatment Value Assumption or SUTVA). If this assumption is met, the average effect of the treatment can simply be measured by taking the difference in means between the two groups. It is this simplicity that makes field experiments an attractive method to apply in impact evaluations.

Field experiments are considered the golden standard within causal inference, but they do come with their set of limitations. First, field experiments usually have low external validity (Peters et al., 2018). Because of their high costs and their need for a controlled environment, they are often conducted in specific study samples, resulting in low applicability of the results to other contexts. Second, the focus on RCTs may very well be a source of bias in itself. By choosing only to work on problems that can be solved by simple randomisation, researchers set themselves up for a blind spot in the research agenda. Other issues widely discussed in the literature are ethical dimensions and insufficient attention for the mechanisms underlying causal relationships (Deaton and Cartwright, 2018; Barrett and Carter, 2010)

In Chapter 5, I describe the results of a field experiment to test the impact of subsidisation and information on the adoption of improved cooking stove technologies. This field experiment has a 2x4 factorial design, meaning that there are two treatments, with two treatment arms in the first treatment (different types of information), and four treatment arms in the second treatment (different subsidy levels). This design also allows for testing interaction effects between the two treatments.

1.4.3 Quasi-experimental methods

Randomisation may not be possible for various reasons. In some cases, it is deemed unethical to treat some and not others (for example in the case of humanitarian aid). A programme or event may also be bound to a specific location, automatically treating everyone. In such cases, quasi-experimental methods can sometimes offer a solution. There are different quasi-experimental methods with identifying assumptions that vary in their stringency (Abadie and Cattaneo, 2018).

One of the more rigorous quasi-experimental approaches is the differences-in-differences (DiD) method (Abadie, 2005). In this method, the outcome variable of interest is measured before and after an intervention for both the control group and the treatment group. To estimate the treatment effect of the intervention, the difference between the control group before and after the intervention is compared to the difference between the treatment group before and after the intervention. This approach allows for 'differencing out' any time-invariant differences between the treatment and control group. The groups thus do not need to be statistically the same (as is the case for a field experiment). What is necessary for the treatment effect to be unbiased, is that there are no time-variant differences between the two groups, that is to say, the groups should have trended similarly in the outcome of interest, had the intervention not taken place. If this identifying assumption, called parallel trends, holds, the control group offers a valid counterfactual for the treated group. Though the parallel trends assumption is fundamentally untestable, careful inspection of pre-treatment trends can strengthen the method significantly.

In Chapter 3, I use a differences-in-differences method to study the impact of a REDD+ programme on communities surrounding a national park. Since the programme was set up to target all communities residing around the park, randomisation was not possible. A control group was sought in neighbouring communities and pre-treatment parallel trends were established with the help of data collected for another study prior to the baseline.

1.4.4 Cross-sectional observational and descriptive approaches

Though recent advances in causal inference set a high standard for economic research, there are cases where neither experimental nor quasi-experimental methods are possible or even useful. In such cases, a cross-sectional observational approach, in which a relationship between two variables is studied controlling for a range of other variables, can be a useful method. Although establishing causality with this approach requires more assumptions than for (quasi)-experimental methods, a cross-sectional observational approach can be useful to uncover patterns and relationships, and provide avenues for future research. Likewise, descriptive approaches, where data is described using simple descriptive statistics can offer important insights and form the basis for further research.

I use these approaches in two chapters of this thesis. In Chapter 4, I describe the data from a census of land investments in Sierra Leone and use a cross-sectional analysis to study the relationship between chief political power and land investments. I use a similar approach in Chapter 6, where I study the relationship between soil nutrients and health outcomes.

1.5 Data

The challenges that form the background of this thesis are complex and intertwined and crosscut the economic, environmental, and social domains. To understand these problems and find potential solutions, I aimed to use a wide variety of data, collected at different scales, through primary as well as secondary sources. This section briefly describes the different types of data used and their respective advantages and disadvantages. In addition, each chapter has its own data section in which I discuss the used data in greater detail.

1.5.1 Survey data

In this thesis, I make extensive use of survey data, either obtained from secondary sources, or collected by a team of researchers including myself. In Chapter 3, I obtained survey data through structured face-to-face interviews with the heads of randomly selected households from the study population. The questionnaire was administered digitally using tablets and survey software, and questions are formulated in such a way that answers are in a quantifiable form (asking for example about amounts, quantities, or attitudes using Likert scales). Such digitally administered questionnaires allow for quantitative analysis and reduce the possibility of human error. Of course, household survey data comes with its own set of problems (such as social desirability/researcher effects and recall bias). In Chapter 4, I use survey data collected from representatives of agricultural and mining investors. In order to reduce potential social desirability bias for sensitive questions, data was also collected for affected communities. This allows for describing the investor activities from the perspective of the firms as well as the communities. In Chapter 6, I use data from the well-known Demographic and Health Surveys (DHS). DHS is a standardised regularly administered survey on health and demographics conducted in a range of low- and middle-income countries, making them a popular secondary data source.

1.5.2 Geospatial data

The second type of data I use extensively in this thesis is geospatial data. Geospatial data is data that describes information about a specific location on the earth's surface. This could be a variety of information types, such as the location of country borders or administrative features like provinces, cities, and villages or data describing road networks, elevation maps, or forest cover. Such data can be obtained in various ways. They can be the output of the surface pictures taken by satellites (as is the case for forest cover). They can also be generated via collaborative open-source networks (for example, for much of the road network data in low-income countries). Another way that data is obtained is through machine learning models that predict certain characteristics for areas where data is unavailable based on data from other areas and on related characteristics.

An important advantage of geospatial data is that it is often freely accessible. Especially compared to household surveys, geospatial data has the potential to save resources. Furthermore, geospatial data allows for analysis at different units of analysis than that of a village or region. For example, in Chapter 6, the unit of analysis is a 5x5km grid cell. This allows for generating a large number of observations across a geographical area, with each pixel having its own geographic and economic characteristics. Last, geospatial variables can serve as important (and often exogenous) control variables in regression analyses. By taking into account geographic, environmental, and economic variables, a lot of variation in the outcome variable can potentially be explained.

In Chapter 3, I measure actual conservation behaviour by looking at changes in forest loss in treated and control communities. In Chapter 4, I use various geospatial variables as controls in my analysis on whether local institutions have an impact on land investments. In Chapter 6, I use detailed soil maps, that were generated using machine learning algorithms, and link these to health outcomes.

Chapter 2

Socioeconomic impacts of land restoration in agriculture: a systematic review

At the onset of the United Nations' decade of ecosystem restoration, lessons from well-designed impact evaluations on land restoration programs are crucial for improving policy-making. This study presents findings from a systematic review of research on the socioeconomic impact of such interventions, namely within agroforestry, conservation agriculture, integrated soil fertility management, and soil and water conservation. We focus on identifying rigorous impact assessments, and after careful methodological assessment select only 29 relevant publications. We identify three key knowledge gaps. First, we retained no studies on agroforestry, suggesting a need for impact evaluations in this domain. Second, most studies look solely at farm-level outcomes instead of socioeconomic outcomes. Third, two-thirds of studies report positive on farm- or socioeconomic outcomes, but the impact does not appear ubiquitous and may emerge under certain circumstances only. Overall, we conclude that there is a lack of well-designed impact assessments in this field. Promises of land restoration leading to improvements in the socioeconomic situation of households cannot yet be backed up by existing studies and it remains unclear which interventions work under which conditions.

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2.1 Introduction

Land degradation is a significant obstacle to agricultural productivity and can lead to local declines in agricultural production if unaddressed (UNCCD, 2017; FAO, 2020; Van der Esch et al., 2022). Reversing land degradation and restoring land and soils is essential for a long-term sustainable food system and feeding growing populations while conserving biodiversity and limiting agriculture's impact on climate change (Tilman et al., 2011; Alexandratos and Bruinsma, 2012). Land degradation – the loss of soils, nutrients and water holding capacity – is typically caused by soil nutrient mining, erosion, loss of vegetative cover, or a combination of these, and affects between 15% and 75% of the global landmass.[1] The economic loss resulting from land degradation is estimated to amount to at least US$ 15 billion, or 0.07% of annual global GDP (Nkonya et al., 2016). Land restoration encompasses the improvement of natural ecosystems through rehabilitation and sustainable management of lands under human use. Applying land restoration measures in agriculture is therefore synonymous with reversing or preventing, wholly or partially, land degradation. Restoration measures are thus often similar to sustainable land management measures.

The need to combat land degradation and invest in land restoration is quickly rising on policy agendas. The United Nations' (UN) 'Decade on Ecosystem Restoration' aims to mainstream land restoration in policies and investments. Existing commitments to restore or rehabilitate land by countries under the Rio Conventions and the Bonn Challenge add up to between 0.8 to 1 billion hectares, with almost half of these commitments made by Sub-Saharan African countries (Sewell et al., 2020). Several initiatives aim to upscale land restoration, such as the Bonn Challenge, AFR100, and Initiative 20x20. In the EU, a proposal is expected by the European Commission with legally binding targets on nature restoration. The investment that would be required to implement the current restoration commitments by countries is estimated between US$ 300 and 1,700 billion (Verhoeven et al., 2022).

Clearly, there is no shortage of ambitious plans, but the potentially high investments required for land restoration warrant a closer inspection of their expected benefits.

[1] Depending on assumptions made and on the method of estimation, see Van der Esch et al. (2022) for an overview

Many of these will be public goods related to water management, biodiversity conservation, and carbon sequestration (Roe et al., 2019; Pretty et al., 2018; Pretty, 2018; Barbier and Hochard, 2018; IPBES, 2018; Navarro et al., 2017), but the projected private benefits to local stakeholders – enhanced resilience and productivity of agriculture, livestock, and forestry – are often the selling point. Whether, when and where these benefits will materialise unfortunately remains an open question. At the onset of the Decade of Restoration (UNEP and FAO, 2020; FAO, 2020), such knowledge is imperative. This systematic review aims to fill this void.

We assess the impact of land restoration practices in the agricultural domain on farm households, with a focus on four of the most common interventions (Pandit et al., 2018): 1) soil and water conservation (SWC), 2) integrated soil fertility management (ISFM), 3) conservation agriculture (CA), and 4) agroforestry (AF).

There is substantial evidence from agronomic (often researcher-managed) trials, that land restoration interventions improve crop yields and reduce soil degradation (Droppelmann et al., 2017; Brouder and Gomez-Macpherson, 2014; Corbeels et al., 2014). However, there is less evidence available on whether these interventions also improve farming outcomes under farmer-managed conditions. Even more so, whether they also improve aspects of economic well-being such as household income and food security is poorly understood (Barbier and Hochard, 2018; Prince et al., 2018). An aggregate positive impact is by no means guaranteed. First, the impact of some of the interventions on crop yields is strongly heterogeneous, as documented, for instance, in the case of conservation agriculture (Brouder and Gomez-Macpherson, 2014). Second, many studies take only a partial view of income derived from a specific crop or land restoration method. Studies rarely control for possible reallocations of productive inputs, such as labour, across household activities. Farmers typically earn income from diverse sources, including farm and off-farm activities. When labour-intensive land restoration technologies are adopted, this may cause a shift of labour away from other productive farm or off-farm activities. Such reallocations may explain why some promising sustainable agricultural technologies (e.g. Takahashi and Barrett 2013) do not alter aggregate income, despite increases in crop yields.

Because of this potential discrepancy between agronomic trials and the on-farm reality, we purposely move away from agronomic trials and focus solely on studies that investigate interventions under farmer-managed conditions. We further make a distinction between farming outcomes, such as crop yield and crop income, and aggregate socioeconomic outcomes such as household income and food security.

We seek to identify those rigorous studies that make the strongest case that observed changes in outcome indicators are *caused* by land restoration methods, and not simply correlated with them (when, for instance, wealthier households are more likely to adopt conservation and restoration methods). To that end, we follow the methodologies put forward by the International Initiative to Impact Evaluation (3ie) and Campbell Collaboration (e.g. Waddington et al. 2012) in this review.

Despite long-term promotion of land restoration methods, we identify just 29 relevant studies that meet the quality criteria. Together these studies assess the impact of 35 combinations of intervention and outcome indicators, although only six document the impact on socioeconomic indicators such as income, poverty, and food security. We find positive impacts for two-thirds of the interventions. For the remaining studies, the impact is negative or not significantly different from zero. These findings resonate with similar systematic reviews in the agricultural domain which suggest that private benefits from land restoration cannot be assumed as given and that considerable variation exists across the type of restoration method and localities.[2]

In Section 2.2, we discuss the methods underlying this systematic review. Section 2.3 presents a quantitative descriptive analysis of the characteristics of the studies followed by an in-depth qualitative assessment. Section 2.4 concludes.

2.2 Methods

Below we describe the strategy used to identify, evaluate, and analyse relevant studies on land restoration. First, we describe the database search, the screening

[2] See recent reviews on improvements in land tenure (Lawry et al., 2016; Higgins et al., 2018), promoting farmer field schools (Waddington et al., 2014), and agricultural input subsidies (Hemming et al., 2018).

process and how we assessed the risk of bias for each of the selected papers. Figure 2.1 provides an overview of the steps and papers retained at each step. Our final list contains 29 low and medium-risk studies, of which we analyse the results below (see the Appendix Table A.2.4 for the full list of papers reviewed).

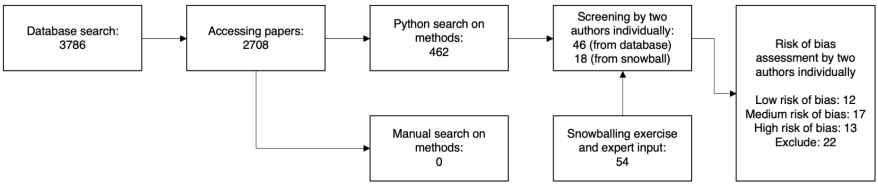

Figure 2.1: Flow diagram of systematic review process

2.2.1 Database search

The database search is based on a list of four sets of keywords associated with land restoration: 1) the processes that underlie land degradation, 2) the general aspects of sustainable land management, 3) specific land restoration approaches, and 4) modes of technological transfer and dissemination. We include several keywords (see Table 2.1) capturing distinct elements of each land restoration approach relating to soil and water conservation structures (SWC), integrated soil fertility management practices (ISFM), conservation agriculture practices (CA), and agroforestry practices (AF).[3] For detailed insights on the agronomic principles underpinning these practices, and how these improve productivity, see e.g. Vanlauwe et al. (2010); Farooq and Siddique (2014); Nair et al. (2021) and references therein.

The keywords included in Table 2.1 form the basis for our search strategy. Using several databases, we search through all titles and abstracts for studies containing at least one keyword associated with the first three categories on land degradation and sustainable land management practices, and at least one keyword associated with the

[3] As part of the process, we asked several experts to review these terms for correctness and completeness.

Table 2.1: Keywords used in the structured literature searches

<table>
<tr><th colspan="2">Topic</th><th>Keywords</th></tr>
<tr><td colspan="2">Underlying processes on degradation</td><td>Land clearing; Erosion; Soil crusting; Soil compaction; Soil sealing; Nutrient depletion; Soil contamination; Soil organic matter loss</td></tr>
<tr><td colspan="2">General aspects of sustainable land management</td><td>Soil improvement; Sustainable Land Management; Agro-ecological farming practices; Soil management; Soil and water conservation; Agricultural soil; Sustainable intensification</td></tr>
<tr><td rowspan="4">Specific land restoration approaches</td><td>Construction of soil and water conservation structures (SWC)</td><td>Terracing; Contour bunds; Zaï; Water use efficiency; Water harvesting</td></tr>
<tr><td>Integrated soil fertility management practices (ISFM)</td><td>Nutrient management; Crop rotation; Manure; Manuring/composting; Fertilizer/fertilization; Organic fertilizer; Organic amendment; biochar</td></tr>
<tr><td>Conservation agriculture practices (CA)</td><td>Reduced tillage; Zero tillage; Mulching; Residue retention; Residue management; Soil cover; Vegetative cover; Cover crops</td></tr>
<tr><td>Agroforestry practices (AF)</td><td>Parkland; Home gardens; Vegetative barriers; Improved fallow; (tree) intercropping</td></tr>
<tr><td colspan="2">Mode of technological transfer</td><td>Technology transfer; Agricultural extension; Innovation platform; Agricultural service delivery; Public service delivery; Farmer field school; Public-private partnership; Farmer cooperative</td></tr>
</table>

mode of technological transfer. This setup ensures that we primarily identify studies that focus on farmer-managed adoption (instead of researcher-managed trials). Moreover, it keeps the search strategy manageable as only searching on categories 1-3 would yield hundreds of thousands of publications. The full search strings used for each database are provided in the Appendix (Subsection 2.5.1).

The choice of which databases to include was motivated by several pragmatic considerations: the database must be open access or available to one of the co-authors via an existing institutional subscription, it allows for advanced Boolean search using sufficiently long strings, and can export citation lists in bulk. Of the 26 databases originally considered, 12 met these criteria: AgEcon, AGRICOLA, Agris, ArticleFirst, CAB Abstracts, ECO, EconLit, GreenFile, OpenGrey, Scopus, SocIndex, and Web of Science.[4] Given the large number of databases included in the search, it is unlikely that we systematically missed out on key studies. In addition, we asked key experts to screen the final list of retained studies. The search yielded a total of 3,786 publications after the removal of duplicates.

2.2.2 Screening and quality assurance

Screening on methods

Moving from the long list of potentially relevant publications, we further refine our search to select studies that use rigorous impact evaluation methods, including: Randomised Controlled Trials (RCTs) (or experiments), Regression Discontinuity, Difference-in-Differences (DiD), Instrumental Variable (IV), and Propensity Score Matching (PSM).

We use an automated screening script in Python (see the Appendix Subsection 2.5.2 for the full script) to select studies that mention one of these methods. We first download all full-text PDFs of the studies. This step reduced the number of publications to 2,708, as the remainder could either not be accessed or found digitally, or were not written in English. We then use the resulting PDFs as input for the automated screening process, involving four steps:

[4] A list of consulted databases is included in the Appendix (Table A.2.1)

1. Extract text from PDF files and set aside PDFs that can not be extracted.[5]
2. Write text (.txt) files and set aside the studies for which text files are empty or too small (due to failed extraction).[6]
3. Parse through text files and evaluate whether any of the methods are mentioned, using regular expressions.[7]
4. Select papers that mention any of the methods.

This automated process leaves us with 462 papers that mention any of these methods. In addition, 259 studies that are not extracted are manually screened on mentioning of the methods. Of those manually screened, none of the studies is relevant for this review.

Screening on the relevance of intervention, outcomes, and methodology

We then conduct a manual screening on the relevance of the 462 papers in terms of the interventions and outcomes studied. In addition, we confirm whether the papers actually apply any of the impact evaluation methods. For each paper, this screening is carried out by two authors independently, using four criteria:

1. The study should focus on a relevant intervention (soil and water conservation structures, integrated soil fertility management, conservation agriculture, or agroforestry).
2. The study should have a relevant outcome (farm production, farm productivity, farm income, household income, food security, or poverty).

[5] In order to parse through text files and search for mentions of one of the relevant methods, we had to convert PDFs to text files. For some of the PDF files, the text extraction function in Python failed because of how these files are rendered. The Python script is written in such a way that the studies that are not extracted are set aside for manual screening.

[6] The text extraction process is not always perfect. Some PDFs cannot be converted to .txt successfully due to how they are rendered (e.g. when papers are scanned files). To automatically flag papers that are not extracted successfully, we devise a rule that sets aside extracted text files of a size below 10.000 bytes. We manually screen these files.

[7] The regular expressions used to select papers methodologically relevant are: 'randomized', 'randomised', 'RCT', 'difference in difference', 'difference-in-difference', 'dif-in-dif', 'dif in dif', 'double difference', 'regression discontinuity', 'RDD', 'propensity score', 'PSM', 'instrumental variable'.

3. The study should use one of the pre-specified evaluation methods (RCT, RD, DiD, IV, PSM).
4. The study should not be an agronomic field trial.

We also exclude studies that assess the impact of input subsidies, which was reviewed in Hemming et al. (2018). We do, however, retain studies that consider packaged interventions, possibly including input subsidies, that also include any of the four land degradation measures. After this step, we have a list of 46 studies.

Expert opinion and snowballing exercise

To be certain that we do not miss any important studies, the final list of papers is sent to several experts in the field, yielding two additional studies. We then conduct a final snowballing exercise for all high-quality studies, in which we scan through the reference list and select 52 studies that might be relevant. These are subsequently screened, as described in the previous section. Those selected for further review are assessed in terms of their risk of bias, as described below. The snowball exercise yields 18 additional studies, bringing the total to 64 studies.

Risk of bias

As a final step, we assess the internal validity of the evidence presented in each study by determining its risk of bias. We follow the tool proposed by Waddington et al. (2014), in which each paper is assessed on four aspects: 1) selection bias, 2) spillovers, 3) reporting bias, and 4) other sources of bias. For each of these, we follow a list of criteria to evaluate whether the paper has a low, medium, or high risk of bias. We then establish the overall risk of bias (low, medium, or high risk) (see Subsection 2.5.3 in the Appendix for the criteria).

Each study is evaluated by one of the authors and checked by a second author. The study is evaluated by a third author if any disagreement occurs. Detailed outcomes of this evaluation are presented in the Appendix Table A.2.3 and summarised in Figure 2.2. We exclude 22 publications because they are not relevant in terms of interventions/outcomes/methods. Of the remaining 42 publications, 12 publications are assessed as having a low risk of bias, 17 publications as having a medium risk of bias, and 13 publications as having a high risk of bias. For the subsequent review (Section 2.3) only the 29 studies with a low or medium risk of bias are considered. Studies with a high risk of bias often lack sufficient information on methodological choices and report incomplete result tables. All excluded studies use an IV or matching method. For IV studies, the strength of the instrument is often not discussed, nor is a first-stage regression always reported. In the matching studies, matching is often carried out on endline characteristics that could have been affected by participation in the program. None of the selected studies used RD methods.

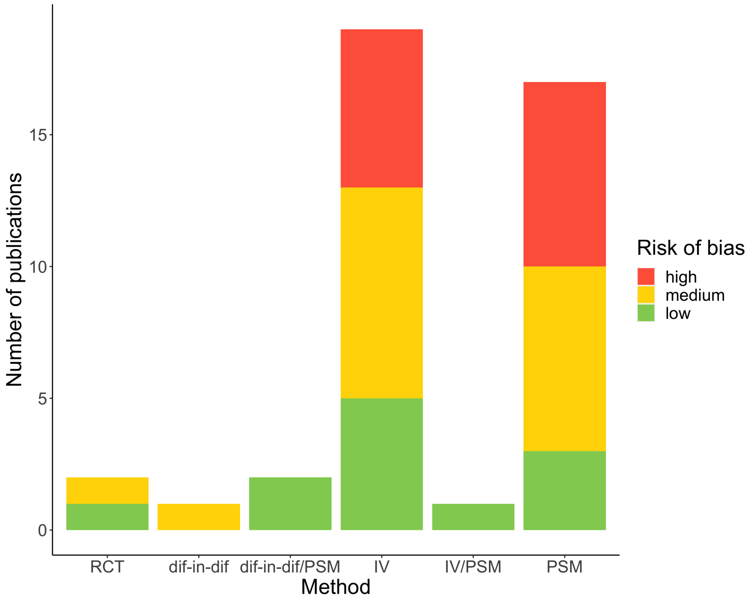

Figure 2.2: Methods and risk of bias

This figure shows the number of studies found per method. Methods are randomized controlled trials (RCT), difference-in-differences (dif-in-dif), instrumental variable (IV), and propensity score matching (PSM). In some studies, methods are combined.

Based on our experiences of applying the risk of bias tool (Waddington et al., 2014) several issues are worth mentioning. Firstly, one of the criteria relates to the way studies deal with spillovers. This is irrelevant for most studies assessed (especially IV studies), we therefore sometimes score a study as having a low risk of bias, even though spillovers are not explicitly discussed. Secondly, the risk of bias assessment tool does not penalise multiple hypothesis testing. However, many studies do present a large number of regressions and models. Related to this, we suspect that there is a large chance of a publication bias, as many of the papers that we do find, show significant results. It is plausible, similar to other systematic reviews, that studies showing significant results are more likely to be published than studies that find null effects (Franco et al., 2014). Since we are unable to conduct a statistical meta-analysis (see Subsection 2.2.3), we also do not formally test for publication bias.

2.2.3 Analysis

We analyse the selected papers by summarising some key characteristics of the studies (region, intervention type, and outcomes), and then provide an in-depth qualitative discussion of the results for each land restoration approach (following the approach of Higgins et al. 2018). The initial goal of this review was to synthesise the results by conducting a quantitative meta-analysis computing aggregate estimates of impact. But this turned out to be infeasible as either the data provided, or the research methods followed, in many studies are not apt for a formalised meta-analysis. Very few studies follow an experimental approach. Calculating aggregate effects requires a comparison group, which is not readily available. The latter (13 out of the total 29) studies are regression-based and include several variables and interactions with the treatment variable, which makes it challenging to compare treatment effects across studies. Secondly, the quality of reporting for many studies is insufficient to extract the necessary data for doing a meta-analysis. Descriptive statistics are often missing, as are necessary p-values or t-statistics, and in some studies, the sample size remains unclear. Lastly, as we will show later, the types of interventions and outcomes studied varied greatly, and we argue that computing standardised impact scores across such a diversity of land restoration practices obscures more information than it would yield.

2.3 Impact of land restoration

2.3.1 Quantitative descriptive assessment

Figure 2.3 summarises the number of publications for each land restoration approach for each studied country. Close to all studies are conducted in Africa, with a regional focus on East Africa (Ethiopia, Kenya, Malawi, Tanzania, and Zambia), and West Africa (Ghana and Nigeria). Research from other contexts is limited to three studies: a study on conservation agriculture (CA) done in Syria, a study of a package intervention in Honduras, and a study on integrated soil fertility management (ISFM) in India. There are no studies conducted in Latin America.

There are also no studies with low and medium bias on agroforestry (AF).[8] This is surprising given the widespread expectation that agroforestry is crucial for attaining some of the UN Sustainable Development Goals (van Noordwijk et al., 2018; Waldron et al., 2017). A recent systematic review on agroforestry interventions by Castle et al. (2021), paints a similar picture. In this review, 11 studies on the impact of agroforestry systems using quasi-experimental methods were identified. All of these were evaluated to have a high or critical risk of bias. The authors do review each of these studies and carefully conclude that agroforestry has the potential to improve agricultural yields, but evidence of socioeconomic outcomes is extremely limited. The most important takeaway from this review is that there is an obvious lack of evidence of the impact of agroforestry interventions, despite significant investment by donors, governments, and NGOs in the promotion of agroforestry (Castle et al., 2021).

Next, we take the intervention-outcome combinations of the included studies and organise them in an evidence gap map to highlight where evidence is concentrated and missing (Figure 2.4). We also include information on the evaluated risk of bias. Close to all studies consider changes in farming outcomes due to SWC, ISFM, and to some extent CA. As mentioned, there are no studies among the 29 that consider

[8]After the search, screening, and risk of bias assessment we were left with only one study that considers a package intervention that includes an agroforestry component (Bravo-Ureta et al., 2011). Unfortunately, the study assesses an extensive program (MARENA program in Honduras) in which agroforestry is one of the multiple activities promoted, and the analysis does not allow for disentangling the effects of specific components of the program.

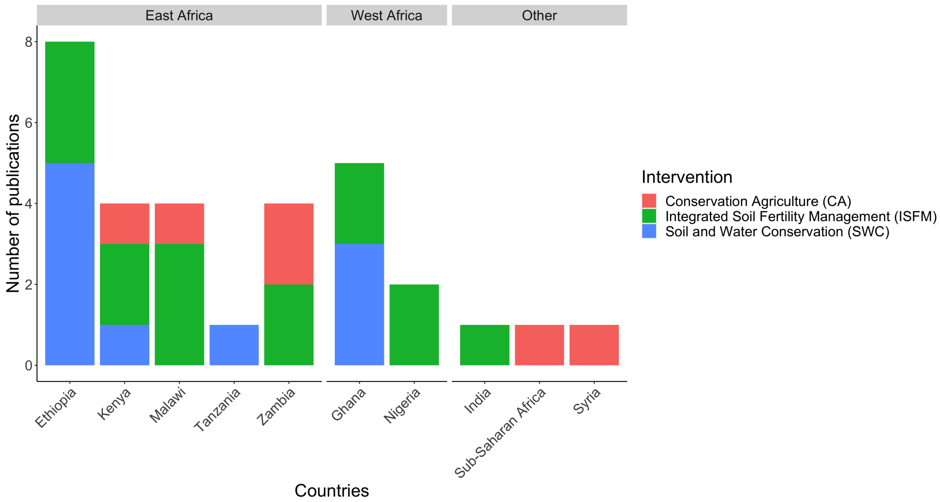

Figure 2.3: Number and types of studies by country

This graph shows the number of publications identified by country and region and coloured by type of land degradation or restoration intervention. There were no publications found on Agroforestry.

the impacts of agroforestry. ISFM is the most studied land restoration intervention, followed by SWC. As for the outcomes, we classify the outcomes into two different types: 1) farming outcomes (all outcomes that measure only partial output of a household, e.g. crop yields or value of production) and 2) socioeconomic outcomes (e.g. household income, food security or poverty). The majority of studies are limited to farming outcomes, and just six studies also report on socioeconomic indicators.

2.3.2 Qualitative assessment

In this section, we present the results of a qualitative review of the included studies. Figure 2.5 synthesises the results by type of intervention and impact (positive, negative or no effect). Three of the six publications that study the impact of land restoration interventions on a socioeconomic outcome (e.g. household income or poverty) find a positive effect and two-thirds of the studies find a positive effect on farming outcomes (e.g. crop yields or value of production). Below, we describe the

Figure 2.4: Evidence gap map

This figure shows all intervention-outcome combinations we found in the different publications. The colour coding indicates whether a publication is considered to have a low or medium risk of bias.

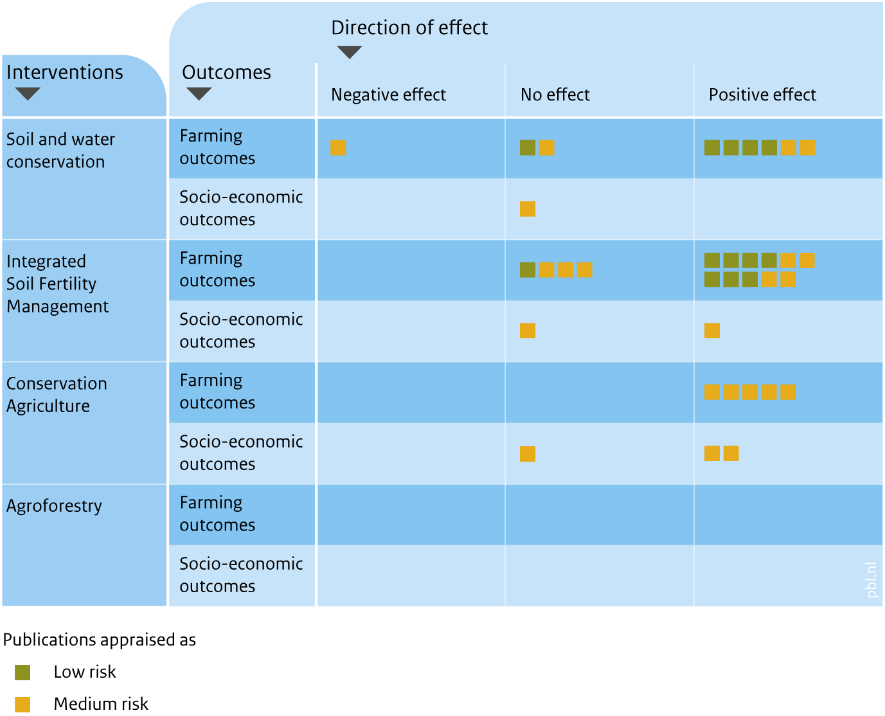

Figure 2.5: Results synthesis

This figure shows all intervention-outcome-effect combinations we found in the different publications. The colour coding indicates whether a publication is considered to have a low or medium risk of bias.

main insights for the three types of interventions (Soil and Water Conservation, Integrated Soil Fertility Management, and Conservation Agriculture).

Soil and water conservation

Ten studies explore the impact of Soil and Water Conservation (SWC) on farming and, to a limited degree, socioeconomic outcomes. Geographically, the studies provide a very narrow snapshot, with three studies done in Ghana, one in Kenya, one in Tanzania, and the remaining five in Ethiopia. The types of interventions vary across studies. Usually, a combination of technologies is studied, often including bund and terrace construction. Most of the studies look at ex-post adoption of a technology rather than the impact of a specific implemented SWC intervention.

Considering changing farming outcomes, most studies find positive effects of SWC, with effect sizes ranging from 20% - 24% on crop yield or value of production (Kassie et al., 2008; Abdulai and Huffman, 2014; Arslan et al., 2017; Schmidt and Tadesse, 2017). Abdulai and Huffman (2014) also report the impact on net rice profit and find a significant increase of 16%. Two studies report positive effects but do not report baseline values or effect sizes (DeGraft-Johnson et al., 2014; Kato et al., 2011). Two studies report null effects (Faltermeier and Abdulai, 2009; Schmidt and Tadesse, 2017). Whereas, Kassie et al. (2008) find that for households adopting terraces, the net value of crop income is reduced by 15%. Three studies also look at the heterogeneity of impact as a function of climatic variation and find that SWC methods are particularly useful in regions with low rainfall or high climatic variability (Kassie et al., 2008; Kato et al., 2011; Arslan et al., 2017). Schmidt and Tadesse (2017) estimate the marginal effect of each additional year of SWC adoption in Ethiopia, shedding some light on the long-term impact of SWC technologies. They estimate that SWC structures should be in place for at least seven years for the technologies to have a significant impact on the value of production. Wainaina et al. (2018) is the only study that looks at impacts beyond the farm and find no significant effect of several technologies (including but not limited to SWC technologies) on per capita household income in Kenya.

In sum, while most studies report a positive impact of SWC on farming outcomes, the impact varies across contexts. SWC seems to hold the most promise in areas with low rainfall and high climatic variability. There is a lack of evidence of socioeconomic impacts due to missing data. This makes it hard to draw firm conclusions, as increased farm outcomes may come with higher input costs, making the net benefits for households uncertain.

Integrated Soil Fertility Management

Seventeen studies investigate the impact of Integrated Soil Fertility Management (ISFM). The study sites are largely in Eastern Africa (Malawi, Ethiopia, Kenya, Zambia, and Tanzania), and some in Western Africa (Ghana and Nigeria) with only one non-African study, implemented in India. Fourteen studies explore the impacts of fertiliser application, in some cases accompanied by a training intervention. Other types of interventions include intercropping and crop rotations. Nearly all studies explore a package intervention, including, besides ISFM technologies, other technologies such as improved seeds, pesticides or fungicides, SWC technologies and CA technologies.

In terms of outcomes, the studies present a narrow snapshot, with only two studies using a socioeconomic outcome whereas all others study a farming outcome. In these studies, the impact of ISFM on socioeconomic outcomes is negative or insignificant, whereas farming outcomes are usually affected positively. Ragasa and Mazunda (2018), one of the two studies looking at a socioeconomic outcome, study the impact of fertiliser use and access to extension services on the value of production and three different food security indicators. They do so for maize and legume farmers in the context of a subsidised input system in Malawi. The authors look at any type of extension services ranging from advice on fertiliser use, crop-specific training, to credit. They do not find significant effects of having access to extension services on production or any food security indicators. For the quantity of (subsidised) fertiliser used, they find no effect on production, and inconsistent, sometimes negative results on food security indicators. Wainaina et al. (2018) (also discussed in the previous section) study the impact of fertiliser, crop residue, and manure application on household (per capita) income. Manure is the only ISFM technology that has a significant positive effect (of 20%) on per capita income. For farming outcomes, 11 studies show positive effects with large differences in effect sizes (ranging from approximately 10% to 100% increase in production or productivity) (Deininger and Olinto, 2000; Chakravarty, 2009; Teal et al., 2010; Bardhan and Mookherjee, 2011; Asfaw et al., 2015; DeGraft-Johnson et al., 2014; Liverpool-Tasie et al., 2014; Kassie et al., 2015; Burke et al., 2017; Liverpool-Tasie, 2017; Biggeri et al., 2018). Four of the studies find no effect on farming outcomes (Pender and Gebremedhin, 2007; Arslan et al., 2017; Abate et al., 2018; Ragasa and Mazunda, 2018). In addition, three studies look at profitability of fertiliser use. Burke et al. (2017) find that depending on the specific fertiliser technology, fertiliser use may not be profitable for up to 92% of farmers. Liverpool-Tasie (2017) concludes that fertiliser use is not profitable for 65% of farmers. Both studies note that this lack of profitability can explain low adoption rates. The last of these studies does find profitability (Deininger and Olinto, 2000).

The only two experimental studies in this review are on ISFM technologies. Chakravarty (2009) studies the impact of a randomised fertiliser intervention on maize productivity for vulnerable farmers (HIV patients) in Kenya. Treated farmers increased yields by 9% on average compared to the control group. In addition, treated farmers increased maize sales by 70% (though this large effect can be explained by a low baseline level of sales, as most farmers were net consumers). Abate et al. (2018), with an RCT on a package of training, inputs (improved seed on credit, fertiliser, gypsum), and marketing support on wheat yield in Ethiopia, find no significant impact on wheat yields.

In sum, even though ISFM is supposed to entail a variety of technologies aimed at improving soil fertility, nearly all studies focused on fertiliser alone. Most studies find predominantly positive effects on yields or other farm outcomes. We find no robust evidence that ISFM adoption also increases household incomes, and studies that try to explain low fertiliser adoption rates find that for many farmers, fertiliser use is not profitable at the farm level.

Conservation Agriculture

Seven studies look at the impact of conservation agriculture (CA). Five studies were conducted in Eastern Africa (Zambia, Malawi, Kenya, and Ethiopia), one in multiple countries across Sub-Saharan Africa, and one in Syria. Again, the evidence provides a geographically narrow view. Four studies look at CA in combination with other technologies. The CA practice mostly studied is minimum or zero tillage. Just three studies also consider socioeconomic outcomes.

Most studies find positive effects of CA on farming and socioeconomic outcomes. Abdulai (2016) reports positive effects on socioeconomic outcomes measured by a reduction in poverty of 27% - 69% in Zambia. Tambo and Mockshell (2018) look at the impact of three main CA techniques (minimum soil disturbance, residue retention, and crop rotation) and combinations thereof for a range of Sub-Saharan African countries, also using observational data. They find no impact of the three practices separately but do find significant impacts when they are combined. Per capita household income increases by about 30%. Wainaina et al. (2018) (also discussed in the previous section) evaluate, amongst other technologies, zero tillage. Though they do find a significant positive impact on household income, this effect disappears when looking at per capita income. The remaining studies all find positive effects of CA on farming outcomes of 30 - 80% (Pender and Gebremedhin, 2007; Kassie et al., 2015; Abdulai, 2016; El-Shater et al., 2016; Abdulai and Abdulai, 2017).

Taken together, similar to the other two types of interventions, there is little rigorous evidence out there on how CA affects farm households. Most studies are conducted in African countries and focus on zero/minimum tillage, often in combination with other technologies. In all but one of the found studies, CA is associated with improvements in farming and socioeconomic outcomes.

2.4 Discussion

Widespread land degradation poses a threat to long-term agricultural productivity and well-being. For this reason, projects which aim to promote or reverse land degradation are receiving more attention from policymakers. However, evidence of the effects of such measures on farmer and landowner welfare remains limited. This systematic review synthesises the available evidence, focusing on the impact of land restoration on socioeconomic household-level indicators such as income, consumption, and poverty. We purposely move beyond farm-level indicators (such as crop yields or production) to better understand aggregate income and poverty effects on households. We focus on four key restoration methods (conservation agriculture (CA), agroforestry (AF), integrated soil fertility management (ISFM) and soil and water conservation (SWC)), together constituting the most commonly promoted restoration interventions in the agricultural domain. The review is centred around studies applying a rigorous identification strategy, making it most likely that changes in outcome indicators reflect the causal effects of the land restoration intervention.

Using database searches, a snowball exercise, and input from experts, we identified 64 relevant studies, which we evaluated on methodological quality using a risk of bias assessment tool. We retain 29 studies for our final review.

For many of the included studies, the risk of bias remains moderate. Only two experimental studies are identified. Most (23) studies use an instrumental variable regression (IV) or propensity score matching (PSM). In the first group, many studies report insufficiently on necessary statistics (e.g. first-stage regressions, or a motivation on the strength of instruments). In the latter group, many studies match on endline data using variables that could logically have been affected by the intervention. For these reasons a quantitative meta-analysis was deemed impractical and motivated a qualitative review instead.

The 29 included studies report on 35 intervention-outcome relations, of which 23 suggest a positive relation and the remainder non-significant or negative effects. Non-significant effects are particularly observed in 5 studies that investigate the impact on household level indicators. Somewhat more studies report positive impacts when considering the on-farm impact. This suggests that while restoration practices may increase on-farm productivity in sub-practices, the overall effects on households are negligible. A possible hypothesis is that adoption of labour-intensive restoration practices induces shifts in labour from productive off-farm or other farm activities causing any partial yield gains to be outweighed (as previously found for other profitable agricultural practices e.g. Takahashi and Barrett 2013). To design effective policies that promote restoration practices, this hypothesis should be investigated in more detail.

Taking account of these observations, this review concludes that no firm evidence emerges, at present, to support the claim that agricultural restoration interventions have a ubiquitous positive impact on households. The evidence base revealed in this review is small, with considerable diversity in findings including many null results. No clear tendencies emerge across the types of restoration practices as impact (changes in indicators) range from relatively large to very small (or no impact). The diversity in impact observed strongly suggests practices do not raise incomes universally, but in some specific instances only.

Considering the specific land restoration interventions, the impact of promoting AF practices remains particularly under-reported. We retained only one study that investigates the impact of a package intervention with AF as a component. Seven and ten studies were identified on CA and SWC respectively. Fifteen studies on ISFM are included, in absolute terms the greatest number among the four practices. However, the impact of components within ISFM (like composting, manuring, and specific crop rotations) remains unclear, as most of these assess packages also including inorganic fertiliser, improved seeds, and pesticides.

Two issues warrant further investigation. First, some interventions may mitigate downside risks. This has been documented particularly for SWC. Three studies (Kassie et al., 2008; Kato et al., 2011; Arslan et al., 2017) show that the impact of SWC is especially significant in areas with temperature shocks or lower rainfall. In fact, mitigating downside risk could sometimes be more important than increases in mean income. Second, synergies between the restoration techniques require further investigation. Two studies find synergistic effects when minimum tillage and ISFM practices are used simultaneously, but other intervention combinations are possible (Kassie et al., 2015; Wainaina et al., 2018).

In conclusion, this review does not imply that interventions in agricultural land restoration have no impact at the household level. There is simply too little evidence at present to make a judgement on their effectiveness. Much greater effort should be placed on rigorous impact assessments of land restoration programs – shifting focus from estimating their impact on technology adoption, to the impact on households as a result thereof. The focus should also be placed on disentangling the different impact pathways and discerning what works under which conditions. Addressing these knowledge gaps at the onset of the decade of ecosystem restoration is a prerequisite in developing effective and efficient policies.

2.5 Appendix

2.5.1 Search criteria and results

Table A.2.1: Selection criteria used for scientific databases

Database	Accessibility	Advanced search	Max search string length	Bulk export	Used in review
AgEcon	Yes (open access)	Yes	No	Yes	Yes
AGRICOLA	Yes (WUR)	Yes	No	Yes	Yes
Agris	Yes	Yes	No	Yes (max 1000 records)	Yes
ArticleFirst	Yes (IFPRI)	Yes	No	Yes	Yes
ASSIA	No				No
British Library for Development Studies	Offline				No
CAB Abstracts	Yes (IFPRI)	Yes	No	Yes (max 1000 records)	Yes
ECO	Yes (IFPRI)	Yes	No	Yes	Yes
EconLit	Yes (IFPRI)	Yes	No	Yes (max 50 records)	Yes
ELDIS	Yes (open access)	Yes	100		No
FAO Gender & Land Rights Database	Yes (open access)	No			No
Google Scholar	Yes (open access)	Yes	256	No	No
Greenfile	Yes (WUR)	Yes	No	Yes	Yes
HeinOnline	No				No
International Bibliography of Social Science	No				No
JSTOR	Yes (IFPRI)	Yes	250	No	No
NBER	Yes (open access)	No		No	No
Networked Digital Library of Theses and Dissertations	Yes (open access)	Yes		No	No
OpenGrey	Yes (open access)	Yes	No	Yes	Yes
PAIS	No				No
Repec/Ideas (EconPapers)	Yes (open access)	Yes		No	No
Scopus	Yes (WUR)	Yes	No	Yes	Yes
SocIndex	Yes (WUR)	Yes	No	Yes	Yes
SSRN	Yes (open access)	No		No	No
WB and IMF Library search (JOLIS)	Yes (open access)	Yes	512	No (only IMF/WB employees)	No
Web of Science	Yes (WUR)	Yes	No	Yes, only EndNote users	Yes

Database:

- Scopus on 03/12/2018, 254 results

Search string:

```
TITLE-ABS-KEY ( ( ( land W/3 clearing ) OR erosion OR ( soil W/3 crusting ) OR ( soil W/3 compaction ) OR ( soil W/3 sealing ) OR ( soil W/3 contamination ) OR ( soil W/3 organic W/3 matter W/3 loss ) OR ( nutrient W/3 depletion ) OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR ( water W/3 efficiency ) OR ( water W/3 harvesting ) OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping ) AND ( technology W/3 transfer ) OR "agricultural extension" OR "innovation platform*" OR ( agricultural W/3 service* W/3 delivery ) OR ( public W/3 service* W/3 delivery ) OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*" ) AND ( LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "ECON" ) )
```

Database:

- AGRIS on 24/10/2018, 382 results

Search string:

```
("land clearing" 3 OR erosion OR "soil crusting" 3 OR "soil compaction" 3 OR "soil sealing" 3 OR "soil contamination" 3 OR "soil organic matter loss" 3 OR "nutrient depletion" 3 OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR "water efficiency" 3 OR "water harvesting" 3 OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ("technology transfer" 3 OR "agricultural extension" OR "innovation platform*" OR "agricultural service delivery" 3 OR "public service delivery" 3 OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*")
```

Database:

- Agricola on 03/12/2018, 166 results

Search string:

```
(("land clearing" or "clearing of land" or erosion or "soil crusting" or "crusting of soil" or "soil compaction" or "compaction of soil" or "soil sealing" or "sealing of soil" or "soil contamination" or "contamination of soil" or "soil organic matter loss" or "loss of organic soil matter" or "loss of organic matter in soil" or "nutrient depletion" or "depletion of nutrients" or "soil improvement" or "sustainable land management" or "agro-ecological farming practice*" or "soil management" or "soil and water conservation" or "soil conservation" or "water conservation" or "agricultural soil*" or "sustainable intensification" or "conservation agriculture" or "reduced till*" or "no till*" or "zero till*" or mulch* or "residue retention" or "residue management" or "soil cover" or "vegetative cover" or "cover crop*" or "integrated soil fertility management" or "nutrient management" or "crop rotation" or manur* or compost* or fertiliz* or "organic amendment" or biochar or terracing or "contour bund*" or zai or tassa or "water efficiency" or "water use efficiency" or "efficiency of water use" or "water harvesting" or "harvesting of water" or agroforestry or parkland or "home garden*" or "vegetative barrier*" or "improved fallow" or intercropping) and ("technology transfer" or "transfer of technology" or "agricultural extension" or "innovation platform*" or "agricultural service delivery" or "delivery of agricultural service*" or "public service delivery" or "delivery of public service*" or "farmer field school*" or "public*private partnership*" or "farmer cooperative*")).ab,ti.
```

Database:

- EconLit on 01/11/2018, 1037 results
- GreenFILE on 14/11/2018, 133 results
- SocIndex on 14/11/2018, 26 results

Search string:

```
((land N3 clearing) OR erosion OR (soil N3 crusting) OR (soil N3 compaction) OR (soil N3 sealing) OR (soil N3 contamination) OR (soil N3 organic N3 matter N3 loss) OR (nutrient N3 depletion) OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR (water N3 efficiency) OR (water N3 harvesting) OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ((technology N3 transfer) OR "agricultural extension" OR "innovation platform*" OR (agricultural N3 service* N3 delivery) OR (public N3 service* N3 delivery) OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*")
```

Databases:

- Web of Science on 03/12/2018, 331 results

Search string:

TS=(("land clearing" OR "clearing of land" OR erosion OR "soil crusting" OR "crusting of soil" OR "soil compaction" OR "compaction of soil" OR "soil sealing" OR "sealing of soil" OR "soil contamination" OR "contamination of soil" OR "soil organic matter loss" OR "loss of organic soil matter" OR "loss of organic matter in soil" OR "nutrient depletion" OR "depletion of nutrients" OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR "water efficiency" OR "water use efficiency" OR "efficiency of water use" OR "water harvesting" OR "harvesting of water" OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ("technology transfer" OR "transfer of technology" OR "agricultural extension" OR "innovation platform*" OR "agricultural service delivery" OR "delivery of agricultural service*" OR "public service delivery" OR "delivery of public service*" OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*"))

Database:

- AgEcon on 30/11/2018, 151 results
- CAB Abstracts on 01/11/2018, 1655 results
- OpenGrey on 03/12/2018, 6 results

Search string:

("land clearing" OR "clearing of land" OR erosion OR "soil crusting" OR "crusting of soil" OR "soil compaction" OR "compaction of soil" OR "soil sealing" OR "sealing of soil" OR "soil contamination" OR "contamination of soil" OR "soil organic matter loss" OR "loss of organic soil matter" OR "loss of organic matter in soil" OR "nutrient depletion" OR "depletion of nutrients" OR "soil improvement" OR "sustainable land management" OR "agro-ecological farming practice*" OR "soil management" OR "soil and water conservation" OR "soil conservation" OR "water conservation" OR "agricultural soil*" OR "sustainable intensification" OR "conservation agriculture" OR "reduced till*" OR "no till*" OR "zero till*" OR mulch* OR "residue retention" OR "residue management" OR "soil cover" OR "vegetative cover" OR "cover crop*" OR "integrated soil fertility management" OR "nutrient management" OR "crop rotation" OR manur* OR compost* OR fertiliz* OR "organic amendment" OR biochar OR terracing OR "contour bund*" OR zaï OR tassa OR "water efficiency" OR "water use efficiency" OR "efficiency of water use" OR "water harvesting" OR "harvesting of water" OR agroforestry OR parkland OR "home garden*" OR "vegetative barrier*" OR "improved fallow" OR intercropping) AND ("technology transfer" OR "transfer of technology" OR "agricultural extension" OR "innovation platform*" OR "agricultural service delivery" OR "delivery of agricultural service*" OR "public service delivery" OR "delivery of public service*" OR "farmer field school*" OR "public*private partnership*" OR "farmer cooperative*")

Database:

- ArticleFirst on 30/11/2018, 4 results
- ECO on 30/11/2018, 22 results

Search string:

((kw: land w "n3" w clearing) or (ti: land w "n3" w clearing) OR kw: erosion or ti: erosion OR (kw: soil w "n3" w crusting) or (ti: soil w "n3" w crusting) OR (kw: soil w "n3" w compaction) or (ti: soil w "n3" w compaction) OR (kw: soil w "n3" w sealing) or (ti: soil w "n3" w sealing) OR (kw: soil w "n3" w contamination) or (ti: soil w "n3" w contamination) OR (kw: soil w "n3" w organic w "n3" w matter w "n3" w loss) or (ti: soil w "n3" w organic w "n3" w matter w "n3" w loss) OR (kw: nutrient w "n3" w depletion) or (ti: nutrient w "n3" w depletion) or (kw: soil w improvement) or (ti: soil w improvement) OR (kw: sustainable w land w management) or (ti: sustainable w land w management) OR (kw: agro-ecological w farming w practice+) or (ti: agro-ecological w farming w practice+) OR (kw: soil w management) or (ti: soil w management) OR "soil and water conservation" OR (kw: soil w conservation) or (ti: soil w conservation) OR (kw: water w conservation) or (ti: water w conservation) OR (kw: agricultural w soil+) or (ti: agricultural w soil+) OR (kw: sustainable w intensification) or (ti: sustainable w intensification) OR (kw: conservation w agriculture) or (ti: conservation w agriculture) OR (kw: reduced w till*) or (ti: reduced w till*) OR (kw: no w till*) or (ti: no w till*) OR (kw: zero w till*) or (ti: zero w till*) OR kw: mulch* or ti: mulch* OR (kw: residue w retention) or (ti: residue w retention) OR (kw: residue w management) or (ti: residue w management) OR (kw: soil w cover) or (ti: soil w cover) OR (kw: vegetative w cover) or (ti: vegetative w cover) OR (kw: cover w crop+) or (ti: cover w crop+) OR (kw: integrated w soil w fertility w management) or (ti: integrated w soil w fertility w management) OR (kw: nutrient w management) or (ti: nutrient w management) OR (kw: crop w rotation) or (ti: crop w rotation) OR kw: manur* or ti: manur* OR kw: compost* or ti: compost* OR kw: fertiliz* or ti: fertiliz* OR (kw: organic w amendment) or (ti: organic w amendment) OR kw: biochar or ti: biochar OR kw: terracing or ti: terracing OR (kw: contour w bund+) or (ti: contour w bund+) OR kw: zaï or ti: zaï OR kw: tassa or ti: tassa OR (kw: water w "n3" w efficiency) or (ti: water w "n3" w efficiency) OR (kw: water w "n3" w harvesting) or (ti: water w "n3" w harvesting) OR kw: agroforestry or ti: agroforestry OR kw: parkland or ti: parkland OR (kw: home w garden*) or (ti: home w garden*) OR (kw: vegetative w barrier+) or (ti: vegetative w barrier+) OR (kw: improved w fallow) or (ti: improved w fallow) OR kw: intercropping or ti: intercropping) AND ((kw: technology w "n3" w transfer) or (ti: technology w "n3" w transfer) OR (kw: agricultural w extension) or (ti: agricultural w extension) OR (kw: innovation w platform+) or (ti: innovation w platform+) OR (kw: agricultural w "n3" w service+ w "n3" w delivery) or (ti: agricultural w "n3" w service+ w "n3" w delivery) OR (kw: public w "n3" w service+ w "n3" w delivery) or (ti: public w "n3" w service+ w "n3" w delivery) OR (kw: farmer w field w school+) or (ti: farmer w field w school+) OR (kw: public#private w partnership+) or (ti: public#private w partnership+) OR (kw: farmer w cooperative+) or (ti: farmer w cooperative+))

2.5.2 Screening and paper selection

Listing 2.1: Python example

```
##############  PDF conversion and parsing  ##############

##      Mandy Malan
##      January 2019
##      Socioeconomic impacts of land restoration measures in agriculture: a
    systematic review

##########################################################

##      This script does the following:
##      1. extract text from PDF files sets aside PDFs that cannot be extracted
##      2. write text files
##      3. parse through text files and evaluate on several regular expressions
##      4. move selected papers to new folder

##########################################################

## Load packages
import re
import os
import sys, getopt
import PyPDF2
import csv
from shutil import copy2
from io import StringIO
from pdfminer.pdfinterp import PDFResourceManager, PDFPageInterpreter
from pdfminer.converter import TextConverter
from pdfminer.layout import LAParams
from pdfminer.pdfpage import PDFPage

## Functions
# Converts pdf, returns its text content as a string
def convert(fname, pages=None):
    if not pages:
        pagenums = set()
    else:
        pagenums = set(pages)

    output = StringIO()
    manager = PDFResourceManager()
    converter = TextConverter(manager, output, laparams=LAParams())
    interpreter = PDFPageInterpreter(manager, converter)
    infile = open(fname, 'rb')
    for page in PDFPage.get_pages(infile, pagenums):
        interpreter.process_page(page)
```

```
    infile.close()
    converter.close()
    text = output.getvalue()
    output.close
    return text

# Converts all pdfs in directory pdfDir, saves all resulting txt files to
    txtdir and filters non-convertible PDFs
def convertMultiple(pdfDir, pdfDirNA, pdfDirConvert, txtDir, txtDirNA):
    if pdfDir == "": pdfDir = os.getcwd() + "\\" #if no pdfDir passed in
    for pdf in os.listdir(pdfDir): #iterate through pdfs in pdf directory
        fileExtension = pdf.split(".")[-1]
        fileExt = pdf.split(".")
        try:
            print(fileExt)
        except UnicodeEncodeError:
            print('error')
        if fileExtension == "pdf":
            pdfFilename = pdfDir + pdf
            try:
                if PyPDF2.PdfFileReader(open(pdfFilename, 'rb')).isEncrypted:
                    print('encr')
                    oldPath = os.path.join(pdfDir, pdf)
                    newPath = os.path.join(pdfDirNA, pdf)
                    os.rename(oldPath, newPath)
                else:
                    text = convert(pdfFilename) #get string of text content of
                         pdf
                    if str.isspace(text): #evaluate whether text was extracted
                         succesfully, if no: move pdf to other folder
                        print('space')
                        oldPath = os.path.join(pdfDir, pdf)
                        newPath = os.path.join(pdfDirNA, pdf)
                        os.rename(oldPath, newPath)
                    else: #if yes: write text file
                        pdfName = pdf[:-4] #remove .pdf from name
                        txtName = pdfName + ".txt"
                        textFilename = txtDir + txtName
                        textFile = open(textFilename, "w", encoding='utf-8') #
                             make text file
                        textFile.write(text) #write text to text file
                        oldPathPDF = os.path.join(pdfDir, pdf)
                        newPathPDF = os.path.join(pdfDirConvert, pdf)
                        os.rename(oldPathPDF, newPathPDF)
                        if os.path.getsize(textFilename)<10000: # if .txt file
                             is smaller than 10000 bytes we assume the pdf
                             conversion was unsuccesfull and move the file
                            print('size')
                            oldPath = os.path.join(pdfDirConvert, pdf)
                            newPath = os.path.join(pdfDirNA, pdf)
```

```
                            os.rename(oldPath, newPath)
                            newPathT = os.path.join(txtDirNA, txtName)
                            os.rename(textFilename, newPathT)
            except Exception:
                print('exceptev')
                oldPath = os.path.join(pdfDir, pdf)
                newPath = os.path.join(pdfDirNA, pdf)
                os.rename(oldPath, newPath)


#Search for keyword in text files and move file to other folder if keyword is
     found
def screenMultiple(txtDir, pdfDirS, searchString):
    with open("/Users/mandymalan/Documents/WUR/sys_review/screening/
         AGRICOLA_20181203.01_select/0_screen_results.csv",'w', encoding='utf-8'
         ) as f:
        writer = csv.writer(f, dialect='excel')
        filesDir = [i for i in os.listdir(txtDir) if not os.path.isdir(i)] #
             ignore subdirectories in list of files
        for text in filesDir:
            fileExtension = text.split(".")[-1]
            if fileExtension == "txt":
                name = open(txtDir + text, 'r', encoding='utf-8', errors='
                     ignore')
                x = re.findall(searchString, name.read(), re.IGNORECASE)
                if x:
                #print(text)
                    print(x)
                    pdfName = text[:-4] +'.pdf'
                    oldPath = os.path.join(pdfDirConvert, pdfName)
                    newPath = os.path.join(pdfDirS, pdfName)
                    copy2(oldPath, newPath)
                    writer.writerow([text, x])

## Script
# Define directory with pdfs that need to be converted to text:
pdfDir = "/Users/mandymalan/Documents/WUR/sys_review/screening/
     AGRICOLA_20181203.01/"
# Define directory where pdfs that could not be converted are moved and
     directory where converted papers are moved
pdfDirNA = "/Users/mandymalan/Documents/WUR/sys_review/screening/
     AGRICOLA_20181203.01_noConvert/"
pdfDirConvert = "/Users/mandymalan/Documents/WUR/sys_review/screening/
     AGRICOLA_20181203.01_convert/"
# Define directory where converted text files are saved
txtDir = "/Users/mandymalan/Documents/WUR/sys_review/screening/
     AGRICOLA_20181203.01_text/"
# Define directory where unsuccesful conversions are moved
txtDirNA = "/Users/mandymalan/Documents/WUR/sys_review/screening/
     AGRICOLA_20181203.01_textNA/"
```

```
# Define search string to select papers
searchString  = "|".join(['randomized', 'randomised', 'RCT', 'difference␣in␣
     difference', 'difference-in-difference', 'dif-in-dif', 'dif␣in␣dif', '
     double␣difference',
   'regression␣discontinuity', 'RDD', 'propensity␣score', 'PSM', 'instrumental␣
        variable'])
# Define directory where selected files are saved
pdfDirS = "/Users/mandymalan/Documents/WUR/sys_review/screening/
     AGRICOLA_20181203.01_select/"

# Run functions
convertMultiple(pdfDir, pdfDirNA, pdfDirConvert, txtDir, txtDirNA)
screenMultiple(txtDir, pdfDirS, searchString)
```

2.5.3 Risk of bias assessment

SELECTION BIAS	
Randomized controlled trial	
Yes if:	
1	a random component in the sequence generation process is described (e.g. referring to a random number table)
2	and if the unit of allocation was at group level (geographical/social/ institutional unit) and allocation was performed on all units at the start of the study; or if the unit of allocation was by beneficiary or group and there was some form of centralised allocation mechanism such as an on-site computer system
3	and if the unit of allocation is based on a sufficiently large sample size to equate groups on average
4	and if baseline characteristics of the study and control/comparisons are reported and overall similar based on t-test or ANOVA for equality of means across groups or covariate differences are controlled using multivariate analysis
5	and the attrition rates (losses to follow-up) are sufficiently low and similar in treatment and control; or the study assesses that loss to follow-up units are random draws from thesample (e.g. by examining correlation with determinants of outcomes, in both treatment and comparison groups);
6	and problems with cross-overs and drop-outs are dealt with using intention- to-treat analysis or in the case of drop-outs, by assessing whether the drop- outs are random draws from the population;
7	and, for cluster assignment, authors control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate analysis.

Unclear if:	
1	the paper does not provide details on the randomisation process, or uses a quasi-randomisation process for which it is not clear whether it has generated allocations equivalent to true randomisation; or insufficient details are provided on covariate differences or methods of adjustment; or insufficient details are provided on cluster controls.
No if:	
1	the sample size is not sufficient; or any failure in the allocation mechanism or execution of the method could affect the randomisation process.
Instrumental variable	
Yes if:	
1	an appropriate instrumental variable is used which is exogenously generated: e.g. due to a “natural” experiment or random allocation.
2	the instrumenting equation is significant at the level of F≥10 (or if an F test is not reported, the authors report and assess whether the R-squared (goodness of fit) of the participation equation is sufficient for appropriate identification);
3	the identifying instruments are individually significant ($p \leq 0.01$); for Heckman models, the identifiers are reported and significant ($p \leq 0.05$);
4	where at least two instruments are used, the authors report on an over-identifying test ($p \leq 0.05$ is required to reject the null hypothesis);
5	and none of the covariate controls can be affected by participation and the study convincingly assesses qualitatively why the instrument only affects the outcome via participation

6	and, for cluster assignment, authors particularly control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate analysis.
Unclear if:	
1	the exogeneity of the instrument is unclear (both externally as well as why the variable should not enter by itself in the outcome equation).
2	relevant confounders are controlled but appropriate statistical tests are not reported or exogeneity of the instrument is not convincing; or if insufficient details are provided on cluster controls (see category f) below).
No if:	
	otherwise
Non-randomised programme placement and self-selection (excl. IV)	
Yes if:	
1	participants and non-participants are either matched based on all relevant characteristics explaining participation and outcomes; or all relevant characteristics are accounted for.
Unclear if:	
	it is not clear whether all relevant characteristics (only relevant time varying characteristics in the case of panel data regressions) are controlled.
No if:	
	relevant characteristics are omitted from the analysis.
Non-randomised trials using panel data (including DID) models	
1	the authors use a difference-in-differences (or fixed effects) multivariate estimation method
2	and the authors control for a comprehensive set of time-varying characteristics

3	and the attrition rate is sufficiently low and similar in treatment and control, or the study assesses that drop-outs are random draws from the sample (e.g. by examining correlation with determinants of outcomes, in both treatment and comparison groups);
4	and, for cluster assignment, authors control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate analysis.
Unclear if:	
1	insufficient details are provided or if insufficient details are provided on cluster controls.
No if:	
	otherwise, including if the treatment effect is estimated using raw comparison of means in statistically un-matched groups.
Statistical matching studies including propensity scores (PSM) and covariate matching	
Yes if:	
1	matching is either on baseline characteristics or time-invariant characteristics which cannot be affected by participation in the programme;
2	and the variables used to match are relevant (e.g. demographic and socioeconomic factors) to explain both participation and the outcome (so that there can be no evident differences across groups in variables that might explain outcomes);
3	and for PSM Rosenbaum's test suggests the results are not sensitive to the existence of hidden bias;
4	and, with the exception of Kernel matching, the means of the individual covariates are equated for treatment and comparison groups after matching;

5	and, for cluster assignment, authors control for external cluster-level factors that might confound the impact of the programme (e.g. weather, infrastructure, community fixed effects etc.) through multivariate or any appropriate analysis.
Unclear if:	
1	relevant variables are not included in the matching equation, or if matching is based on characteristics collected at endline; or if insufficient details are provided on cluster controls.
No if:	
	otherwise
SPILLOVERS	
Was the study adequately protected against performance bias?	
Yes if:	
	the intervention is unlikely to spill over to comparisons (e.g. participants and non-participants are geographically and/or socially separated from one another and general equilibrium effects are unlikely).
Unclear if:	
	spillovers are not addressed clearly
No if:	
1	allocation was at individual or household level and there are likely spillovers within households and communities which are not controlled for in the analysis; or if allocation at cluster level and there are likely spillovers to comparison clusters.
SELECTIVE REPORTING	
Was the study free from outcome and analysis reporting biases?	
Yes if:	
1	there is no evidence that outcomes were selectively reported (e.g. all relevant outcomes in the methods section are reported in the results section);

2	and authors use "common' methods" of estimation and the study does not suggest the existence of biased exploratory research methods.
No if:	
1	some important outcomes are subsequently omitted from the results or the significance and magnitude of important outcomes was not assessed; or authors use uncommon or less rigorous estimation methods such as failure to conduct multivariate analysis for outcomes equations where it is has not been established that covariates are balanced.
Unclear if:	
	otherwise
OTHER **Was the study free from other sources of bias? Important additional sources of bias may include concerns about: blinding of outcome assessors or data analysts; courtesy bias from outcomes collected through self-reporting; coherence of results, for example between descriptive statistics and outcome questions; data on the baseline collected retrospectively; information is collected using an inappropriate instrument (or a different instrument/at different time/after different follow-up period in the comparison and treatment groups).**	
Yes if:	
	the reported results do not suggest any other sources of bias
Unclear if:	
	other important threats to validity may be present
No if:	
	it is clear that these threats to validity are present and not controlled for.
FINAL EVALUATION: RISK OF BIAS	

Low	Clear measurement of and control for confounding was made, including selection bias, where intervention and comparison groups were described adequately (in respect of the nature of the interventions being received) and risks of spillovers or contamination were small, and where reporting biases and other sources of bias were unlikely.
Medium	Threats to the validity of the attribution methodology, or likely risks of spillovers or contamination, arising from inadequate description of intervention or comparison groups or possibilities for interaction between groups such as when they are from the same community, or possible reporting biases.
High	All the others, including those where comparison groups are not matched or differences in covariates are not accounted for in multivariate analysis, or where there is evidence for spillovers or contamination to comparison groups from the same communities, and reporting biases are evident.

Table A.2.3: Risk of bias assessment results

Database	First author	Year	Method	Selection bias	Spill-overs	Reporting bias	Other	Risk of bias	Comments	Final evaluation
Econlit2	Abate	2018	RCT	yes	unclear	unclear	unclear	medium		medium
Econlit2	Abdulai	2014	IV	unclear	unclear	yes	yes	medium		medium
Econlit2	Abdulai	2016	IV	unclear	unclear	yes	yes	medium		medium
Econlit2	Abdulai	2017	PSM	unclear	unclear	unclear	unclear	medium		medium
Econlit2	Adégbidi	2004	OLS/IV	unclear	yes	unclear	yes	medium	Method NA	exclude
Econlit2	Akinola	2012	PSM	no	unclear	yes	no	high		high
snowball	Amare	2012	PSM/IV	unclear	unclear	yes	yes	medium	Intervention NA	exclude
Econlit1	Ariga	2013	panel	no	unclear	no	unclear	high	Method NA	exclude
Econlit2	Arslan	2017	OLS/IV	yes	yes	yes	yes	low		low
snowball	Asfaw	2014	IV	unclear	unclear	unclear	yes	medium		medium
Econlit2	Bardhan	2011	OLS/IV	yes	yes	yes	yes	low		low
CAB	Benin	2006	NA	NA	NA	NA	NA	NA	Method NA	exclude
CAB	Biggeri	2018	IV/PSM	unclear	yes	yes	yes	low		low
Econlit2	Brainerd	2014	NA	NA	NA	NA	NA	NA	Method NA	exclude
snowball	Bravo-Ureta	2011	PSM/DiD	yes	yes	yes	yes	low		low
Econlit2	Burke	2017	OLS/IV	yes	yes	unclear	yes	low		low
Econlit1	Chakravarty	2009	RCT	yes	unclear	yes	yes	low		low
snowball	Cocchi	2007	IV	unclear	unclear	high	yes	high		high
Econlit1	Darko	2016	panel	unclear	unclear	yes	yes	medium	Method NA	exclude
Econlit2	De Graft-Johnson	2014	IV	unclear	yes	yes	yes	low		low
Econlit1	Deininger	2000	IV	unclear	yes	unclear	yes	medium		medium
Econlit1	Diiro	2013	N/A	NA	NA	NA	NA	NA	Method NA	exclude
Econlit2	Duflo	2008	RCT	unclear	unclear	yes	unclear	medium	Intervention NA	exclude
CAB	Ekbom	2008	Heckman	no	unclear	unclear	unclear	NA	Method NA	exclude
Econlit2	El-Shater	2016	PSM	unclear	unclear	yes	yes	medium		medium
Agricola	Emmanuel	2016	PSM	no	unclear	yes	unclear	high		high
Econlit2	Faltermeier	2009	PSM	unclear	unclear	yes	yes	medium		medium
Econlit1	Foltz	2012	panel-IV	unclear	yes	yes	no	high		high
snowball	Kassie	2007	PSM	yes	unclear	yes	yes	low	Duplicate	exclude
snowball	Kassie	2008	PSM	unclear	unclear	yes	yes	medium	Matching done on time invariant variables, selection bias should be yes.	low
Econlit1	Kassie	2011	PSM	no	unclear	yes	no	high		high
snowball	Kassie	2011	PSM	no	unclear	yes	yes	high	They do take measures to deal with bias, selection bias should be unclear	medium
Econlit2	Kassie	2015	IV	unclear	yes	unclear	yes	medium		medium
Econlit2	Kato	2011	IV	unclear	unclear	yes	yes	low/ medium	Method may be valid but confusing reporting style makes it difficult to assess	medium
snowball	Kijima	2012	PSM	no	unclear	yes	yes	high	Intervention NA	exclude

snowball	Kuntashula	2014	PSM	no	yes	yes	yes	high		high
Econlit2	Kuntashula	2015	PSM	unclear	unclear	yes	yes	medium	Intervention NA	exclude
AgEcon	Laurence Jumbe	2016	OLS	no	unclear	no	unclear	high	Method NA	exclude
snowball	Liverpool-Tasie	2015	PSM/IV	yes	yes	yes	yes	low		low
Econlit2	Liverpool-Tasie	2017	panel-IV	unclear	yes	yes	yes	low		low
snowball	Mango	2017	PSM	no	unclear	yes	yes	high		high
CAB	Mapila	2012	PSM	unclear	unclear	no	unclear	high		high
Econlit1	Mason	2011	IV	unclear	unclear	unclear	yes	medium	Intervention NA	exclude
Econlit2	Matchaya	2013	PSM	unclear	yes	yes	unclear	medium		medium
Econlit1	Matsumoto	2011	DiD	no	unclear	yes	unclear	high	Intervention NA	exclude
snowball	Nkala	2011	PSM	no	unclear	yes	unclear	high		high
AgEcon	Nkonya	2005	IV	unclear	unclear	yes	yes	medium	Too many reporting and methodological issues to assess as medium risk	high
CAB	Ogunniyi	2017	PSM	no	unclear	no	unclear	high	Intervention NA	exclude
CAB	Olarinde	2012	IV	no	unclear	no	unclear	high		high
CAB	Pender	2004	IV	yes	unclear	yes	yes	low	Intervention NA	exclude
snowball	Pender	2006	IV	unclear	unclear	yes	yes	medium	Duplicate	exclude
CAB	Pender	2008	IV	unclear	unclear	yes	yes	medium		medium
CAB	Ragasa	2018	panel/IV PSM	unclear	unclear	unclear	yes	medium		medium
snowball	Schmidt	2012	PSM	unclear	unclear	yes	yes	medium	Duplicate	exclude
snowball	Schmidt	2013	PSM	yes	unclear	yes/ unclear	yes	low		low
snowball	Schmidt	2017	PSM/DiD	unclear	unclear	yes	yes	medium	PSM and DiD instead of PSM only, selection bias should be yes	low
CAB	Solis	2009	IV	unclear	no	no	yes	high		high
Econlit2	Tambo	2018	PSM	unclear	unclear	yes	unclear	medium		medium
Econlit2	Teklewold	2012	NA	NA	NA	NA	NA	NA	Method NA	exclude
snowball	Tsegaye	2017	IV	no	unclear	yes	yes	high		high
Econlit2	Wainaina	2018	PSM	unclear	unclear	yes	yes	medium		medium
Econlit1	Xu	2008	panel	no	unclear	NA	NA	high	Method NA	exclude
snowball	Yigezu	2015	model	no	unclear	yes	yes	high	Method NA	exclude
Econlit1	Zeitlin-Teal	2010	DiD	unclear	unclear	yes	yes	medium		medium

2.5.4 Final selection

Table A.2.4: Final selection and characterisation of papers

Study	Method	Country	Intervention	Intervention type	Outcome	Outcome type	Risk of bias
Abate, G. T., Bernard, T., de Brauw, A., & Minot, N. (2018). The impact of the use of new technologies on farmers' wheat yield in Ethiopia: evidence from a randomized control trial. Agricultural Economics, 49(4), 409-421.	RCT	Ethiopia	Package of training, inputs (improved seed on credit, fertilizer, gypsum) and marketing support. Groups are full-package farmers and farmers who only received marketing support	ISFM	Wheat yield in kg/ha (measured in three ways: crop cut, output prediction, farmer recall)	Farm level	Medium
Abdulai, A. N. (2016). Impact of conservation agriculture technology on household welfare in Zambia. Agricultural economics, 47(6), 729-741.	IV	Zambia	Adoption of conservation agriculture	CA	Maize yield, throughput accounting ratio, poverty headcount, poverty gap, severity of poverty	Farm level Poverty	Medium
Abdulai, A., & Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. Land economics, 90(1), 26-43.	IV	Ghana	Adoption of bunds	SWC	Rice yield (bags/ha) and net returns (GHS/ha)	Farm level	Medium
Abdulai, A. N., & Abdulai, A. (2017). Examining the impact of conservation agriculture on environmental efficiency among maize farmers in Zambia. Environment and Development Economics, 22(2), 177-201.	PSM	Zambia	Adoption of conservation agriculture	CA	Technical and environmental efficiency	Farm level	Medium
Arslan, A., Belotti, F., & Lipper, L. (2017). Smallholder productivity and weather shocks: Adoption and impact of widely promoted agricultural practices in Tanzania. Food policy, 69, 68-81.	IV	Tanzania	SWC, organic fertilizer, inorganic fertilizer, intercropping	SWC	Maize yield (kg/ha)	Farm level	Low

Bardhan, P., & Mookherjee, D. (2011). Subsidized farm input programs and agricultural performance: A farm-level analysis of West Bengal's green revolution, 1982-1995. American Economic Journal: Applied Economics, 3(4), 186-214.	IV	India	Intensity of subsidized inputs program on village level (inputs are seeds and fertilizer, they can only test impact of entire kit provided: seeds, fertilizer, insecticides), measured as cumulative number of kits per household	ISFM	Log value added per acre of all crops	Farm level	Low
Biggeri, M., Burchi, F., Ciani, F., & Herrmann, R. (2018). Linking small-scale farmers to the durum wheat value chain in Ethiopia: Assessing the effects on production and wellbeing. Food Policy, 79, 77-91.	PSM	Ethiopia	Package intervention: 1) technical aspects of production, includingproliferation of appropriate agronomic practices,introduction of adapted durum wheat varieties and the provision of key assets at the cooperative level. 2) overall institutional architecture of value chain, capacity-building among cooperatives, establishing links between cooperatives and public agricultural research centres and using cooperatives to establish contract farming arrangements	ISFM	Growth of cereal production value	Farm level	Low
Burke, W. J., Jayne, T. S., & Black, J. R. (2017). Factors explaining the low and variable profitability of fertilizer application to maize in Zambia. Agricultural economics, 48(1), 115-126.	IV	Zambia	Fertilzer application rate	ISFM	Maize yield (kg/ha)	Farm level	Low
Chakravarty, S. (2009). Harvesting health: Fertilizer, nutrition and AIDS treatment in Kenya. Columbia University.	RCT	Kenya	Randomized training and free fertilizer	ISFM	Maize yield (90 kg bags per acre), income from maize (ksh)	Farm level	Low

deGraft-Johnson, M., Suzuki, A., Sakurai, T., & Otsuka, K. (2014). On the transferability of the Asian rice green revolution to rainfed areas in sub-Saharan Africa: an assessment of technology intervention in Northern Ghana. Agricultural Economics, 45(5), 555-570.	IV	Ghana	Modern inputs + bunding + leveling. Package adoption	SWC ISFM	Paddy yield (tons/ha), Profit (USD/ha)	Farm level	Low
Deininger, K., & Olinto, P. (2000). Why liberalization alone has not improved agricultural productivity in Zambia: The role of asset ownership and working capital constraints. The World Bank.	IV	Zambia	Fertilizer application	ISFM	Profitability	Farm level	Medium
El-Shater, T., Yigezu, Y. A., Mugera, A., Piggin, C., Haddad, A., Khalil, Y., ... & Aw-Hassan, A. (2016). Does zero tillage improve the livelihoods of smallholder cropping farmers?. Journal of Agricultural Economics, 67(1), 154-172.	PSM	Syria	Zero tillage adoption	CA	Net wheat income (SP/ha) and wheat consumption (kg/year adult qeuivalent)	Farm level Other	Medium
Faltermeier, L., & Abdulai, A. (2009). The impact of water conservation and intensification technologies: empirical evidence for rice farmers in Ghana. Agricultural Economics, 40(3), 365-379.	PSM	Ghana	Bund construction, dibbling seed, intensification technological package, dibbling seed and fertilizer. All dummies	SWC	Net rice returns in ghc/acre and average rice output in bags/acre	Farm level	Medium
Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. Journal of Agricultural Economics, 66(3), 640-659.	IV	Malawi	Crop diversification (maize–legume intercropping and/or rotations) and minimum tillage	ISFM CA	Expected maize yield (kg/acre)	Farm level	Medium

Kato, E., Ringler, C., Yesuf, M., & Bryan, E. (2011). Soil and water conservation technologies: a buffer against production risk in the face of climate change? Insights from the Nile basin in Ethiopia. Agricultural Economics, 42(5), 593-604.	IV	Ethiopia	SWC technology adoption (soil bunds, stone bunds, grass strips, waterways, trees planted at edge of farm fields, contours, and irrigation). All dummies	SWC	Value of crop production per ha	Farm level	Medium
Liverpool-Tasie, L. S. O. (2017). Is fertiliser use inconsistent with expected profit maximization in sub-Saharan Africa?“Evidence from Nigeria”. Journal of Agricultural Economics, 68(1), 22-44.	IV	Nigeria	Nitrogen application rate	ISFM	Rice yield (kg/ha)	Farm level	Low
Matchaya, G. C., & Perotin, V. (2013). The impact of cooperative patronage: The case of National Small Holder Farmers’ Association (NASFAM) of Malawi in Kasungu District. Agrekon, 52(2), 75-103.	PSM	Malawi	Participation in cooperative, one of the objectives is to improve land use management practices	Undefined	Income per capita – unclear if its per day or per year	Household level	Medium
Pender, J., & Gebremedhin, B. (2008). Determinants of agricultural and land management practices and impacts on crop production and household income in the highlands of Tigray, Ethiopia. Journal of African Economies, 17(3), 395-450.	IV	Ethiopia	Use of fertiliser, improved seeds, manure or compost, burning to clear the plot, contour plowing, reduced tillage, intercropping or mixed cropping	ISFM CA	Value of crop production per ha	Farm level	Medium
Ragasa, C., & Mazunda, J. (2018). The impact of agricultural extension services in the context of a heavily subsidized input system: The case of Malawi. World Development, 105, 25-47.	IV	Malawi	Quantity of fertilizer subisidy received (kg/ha), received advice (dummy’s) and interactions thereof	ISFM	Value of production per ha (maize + legume farmers) and three food security indicators (household dietary diversity score, food consumption score and food variety score)	Farm level Food security	Medium
Tambo, J. A., & Mockshell, J. (2018). Differential impacts of conservation agriculture technology options on household income in Sub-Saharan Africa. Ecological Economics, 151, 95-105.	PSM	Sub-Saharan Africa	Three conservation agriculture techniques (minimum soil disturbannce, residue retention, crop rotation) and combinations of the three	CA	Annual hh income (USD) and income per adult equivalent	Household level	Medium

Wainaina, P., Tongruksawattana, S., & Qaim, M. (2018). Synergies between different types of agricultural technologies in the Kenyan small farm sector. The Journal of Development Studies, 54(11), 1974-1990.	PSM	Kenya	Different technologies and combinations (improved seeds, fertilizer, terraces, soil bunds, crop residue, zero tillage, manure)	SWC ISFM CA	Total annual income generated by the household in KES and Total household income per person in KES	Household level	Medium
Zeitlin, A., Caria, S., Dzene, R., Janský, P., Opoku, E., & Teal, F. (2010). Heterogeneous returns and the persistence of agricultural technology adoption.	DiD	Ghana	Adoption of hi-tech package (fertilizer, pesticides and fungicides that had to be repaid and training on application)	ISFM	Cocoa output in kg	Farm level	Medium
Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M. (2015). Climate variability, adaptation strategies and food security in Malawi (No. 1008-2016-80228).	IV	Malawi	Adoption of modern inputs (improved seed or inorganic fertilizer) and sustainable land management practices (trees or soil and water conservation or organic fertilizer or intercropping)	ISFM Undefined	maize productivity (kg/acre)	Farm level	Medium
Kassie, M., Pender, J., Yesuf, M., Kohlin, G., Bluffstone, R., & Mulugeta, E. (2008). Estimating returns to soil conservation adoption in the northern Ethiopian highlands. Agricultural economics, 38(2), 213-232.	PSM	Ethiopia	Adoption of soil bunds	SWC	Value of crop production per ha	Farm level	Low
Schmidt, E., & Tadesse, F. (2014). Sustainable agriculture in the Blue Nile Basin: land and watershed management practices in Ethiopia. Environment and Development Economics, 19(5), 648-667.	PSM	Ethiopia	Adoption of sustainable land and watershed management techniques (terraces, bunds, check dams)	SWC	Value of crop production	Farm level	Low
Kassie, M., Köhlin, G., Bluffstone, R., & Holden, S. (2011, May). Are soil conservation technologies "win-win?" A case study of Anjeni in the north-western Ethiopian highlands. In Natural Resources Forum (Vol. 35, No. 2, pp. 89-99). Oxford, UK: Blackwell Publishing Ltd.	PSM	Ethiopia	Adoption of terraces	SWC	Net value of crop production per ha	Farm level	Medium

Schmidt, E., & Tadesse, F. (2017). The sustainable land management program in the Ethiopian highlands: An evaluation of its impact on crop production (Vol. 103). Intl Food Policy Res Inst.	PSM DiD	Ethiopia	Participation in sustainable land management program (watershed and land management structures, water retention, tillage practices, land tenure security)	SWC	Value of crop production	Farm level	Low
Liverpool-Tasie, L. S. O., Adjognon, S., & Kuku-Shittu, O. (2014). Productivity effects of sustainable intensification: The case of Urea deep placement for rice production in Niger State, Nigeria (No. 329-2016-13225).	PSM IV	Nigeria	Adoption of intensification practice urea deep placement (UDP)	ISFM	Rice yield (kg/ha)	Farm level	Low
Bravo-Ureta, B. E., Almeida, A. N., Solís, D., & Inestroza, A. (2011). The economic impact of Marena's investments on sustainable agricultural systems in Honduras. Journal of Agricultural Economics, 62(2), 429-448.	PSM DiD	Honduras	Participation in project with agroforestry and soil conservation components as well as coffee and livestock production and irrigation systems	Undefined	Value of crop production	Farm level	Low

Chapter 3

Building the evidence base for voluntary carbon offsets: The case of the Gola REDD+ project in Sierra Leone

REDD+ carbon offsets traded in voluntary carbon credit markets are playing a rapidly expanding role in meeting net zero climate change objectives, with a projected 100-fold increase in market value by 2050. Despite this surge, there are few independent and rigorous evaluations of the impacts of these projects. We provide one of the few of such evaluations using a difference-in-difference analysis of a voluntary REDD+ project in Sierra Leone. We use a panel of satellite and household survey data to provide causal evidence of the impact of this project on local deforestation rates, livelihoods, and conservation attitudes over the first five years of its implementation. We find that the project helped reduce deforestation by 30% relative to the control communities whilst bringing about no-net harm to their livelihoods. We find suggestive evidence of the mechanism of the project's impact in changing the opportunity cost of labour and creating sustainable income possibilities. Our study adds to the pressing need to build the evidence base for voluntary REDD+ projects and shows how such independent and rigorous assessments can be put in place.

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3.1 Introduction

Voluntary carbon offset markets are playing a rapidly expanding role in meeting net zero climate change objectives. These markets sell carbon offsets (or credits) accredited by a third-party agency to firms, organisations or individuals that wish to voluntarily reduce their carbon footprint beyond levels that are legally required. Over the last several years we have witnessed a surge in such voluntary carbon credits with a market value of $473 million in 2020 catapulting to $748 in August 2021 and projected to surpass the $1 billion mark by the end of 2021 (Forest Trends' Ecosystem Marketplace, 2021). The accumulated market value of these offsets since 2008 has surpassed $6.7 billion while this volume is expected to display a 15-fold increase (compared to 2020) by 2030 and a 100-fold increase by 2050 for industries and governments to meet the 1.5°C Paris target (Taskforce on Scaling Voluntary Credit Markets, 2021).

Such voluntary carbon offsets can be sourced from different sectors and programmes, including the forestry sector from which the market has produced so-called 'voluntary REDD+ projects'. REDD+ (reducing emissions from deforestation and degradation) operates predominantly in low-income tropical countries with high rates of deforestation and forest degradation. REDD+ projects essentially provide incentives to (individual or communal) owners of carbon-rich forests to reduce the baseline rate of deforestation and degradation and thereby increase the storage of carbon (known as 'additionality'). Incentives can be either financial (cash subsidies) and/or in-kind (e.g. goods or training), but because REDD+ schemes are results-based, carbon payments should be conditional on climate impacts.[1]

Despite this context of 'voluntary carbon market euphoria', the scientific literature assessing the effectiveness of voluntary carbon offsets remains surprisingly scant. Though carbon credit accrediting agencies do include monitoring and evaluation efforts and protocols as part of their processes to issue new, and renew previous, carbon credits, the objectivity, transparency, and robustness of their assessments have been brought into question (West et al., 2020). This has led to an increasing

[1] In practice, conditionality is not always realistic due to difficulties in identifying property rights and ownership, complications of enforcement, and political opposition to conditionality (Börner et al., 2017). Moreover, even schemes that are conditional by design, often have enforcement problems, making them *de facto* unconditional (Engel, 2016; Honey-Rosés et al., 2009)

number of voices calling for significantly more independent and rigorous assessments of specific REDD+ projects (Duchelle et al., 2018; Simonet et al., 2018) which would play a crucial role in establishing the credibility and viability of such markets.

The two most crucial elements of REDD+ projects to be evaluated are their ecological additionality (Angelsen, 2008) and the degree to which they do not lead to adverse impacts on local communities (Herr et al., 2019). As undertaking randomised controlled trials of actual REDD+ projects is practically extremely difficult, research has focused on using observational data, relying on quasi-experimental methods. Rigorous evaluations as such, require the use of empirical methods that can compare locations that have received REDD+ inducements with credible comparison sites (or counterfactual sites) as well as have access to relevant data from both the pre- and post-REDD+ project period. This would allow researchers to undertake a difference-in-difference analysis (or a Before-After-Control-Intervention analysis) (Correa et al., 2020; Simonet et al., 2018; Duchelle et al., 2017; Sills et al., 2017). But even the latter type of studies is remarkably sparse, with very few exemptions. (West et al., 2020; Correa et al., 2020; Ellis et al., 2019; Simonet et al., 2019; Bos et al., 2017). The scientific literature does contain a larger body of work (using both experimental and observational data) that assesses various Payment for Ecosystem Service (PES) type programmes that include a carbon reduction element (see Salzman et al. (2018) for a review). Some of these studies use RCT methods (Wiik et al., 2019; Wilebore et al., 2019; Jayachandran et al., 2017) while others employ quasi-experimental studies (Börner et al., 2017; Ezzine-De-Blas et al., 2016; Alix-Garcia et al., 2015). Yet, the programmes being evaluated are often small-scale pilot programmes or larger conservation PES programmes. These studies provide lessons about the effectiveness of conservation programmes but do not offer lessons on actual verified REDD+ projects.

In this study, we contribute with a rigorous assessment of site-level REDD+ effectiveness, five years post intervention, and consider the causal pathways through which REDD+ operates. Our evaluation focuses on the REDD+ project surrounding the Gola Rainforest National Park (GRNP) in Sierra Leone, West Africa between 2014 and 2018. The aim of the REDD+ project, which received accreditation from the leading accreditation agency Verra, is to improve both conservation and livelihood outcomes in the crucial but sensitive inhabited buffer zone of this global biodiversity hotspot. Communities residing within the buffer zone, are incentivised to shift to more sustainable, less extensive land management practices, (such as forest-friendly cash crops like cocoa and wetland rice farming) through a range of activities including agricultural extension, marketing support, and access to (co-managed) financial services.

We evaluate the impact of these interventions on deforestation, livelihoods, and conservation attitudes within the park buffer zone (in total, N=454 treated and untreated communities). We use both satellite imagery to assess causal changes in deforestation rates and detailed on-the-ground household-level survey data (in total, N=841 treated and untreated households) that allow us to estimate the impacts on livelihoods and assess potential mechanisms behind any impacts of REDD+ on deforestation rates. We employ a rigorous difference-in-difference analysis to measure the impact on communities within the buffer zone (N=126). Our counterfactual group is the communities that lie within the chiefdoms of the park, but outside of the 4 km buffer zone (N=328). To place deforestation rates in the GRNP into a larger context, we compare deforestation rates within the park and buffer zone to other protected areas in Sierra Leone and neighbouring countries. Finally, we conduct a simple cost-to-carbon analysis and compare the cost-effectiveness of the Gola REDD+ programme to similar interventions.

We find a reduction in deforestation of 30% for REDD+ communities compared to the counterfactual communities. We also find that the REDD+ project did not change communities' livelihood outcomes or attitudes towards conservation. We explore plausible mechanisms and find some suggestive evidence that households switched to more forest-friendly activities (non-timber forest product collection and cocoa). Descriptive assessment suggests that forest cover within the uninhabited GRNP has largely remained intact throughout the period of 2001 to 2018 and exhibits low deforestation rates compared to other protected areas within Sierra Leone, Guinea and Liberia.

Our study contributes to the nearly non-existent body of empirical work evaluating REDD+ projects by making several important contributions. First, we undertake an analysis of an operational, voluntary REDD+ project that actively sells carbon credits in voluntary markets and has been approved by a leading accreditation agency. The only other study that exclusively focuses on such REDD+ projects is West et al. (2020) which focuses only on assessing ecological additionally and does not explore livelihood impacts or mechanisms (West et al., 2020).

Secondly, we have collaborated with the agencies developing the Gola REDD+ project to instate an independent evaluation methodology from the beginning of the project which was conducted separately from the verification processes required by the accreditation agency. Our data evaluation methodology allows for a rigorous difference-in-difference analysis that can provide causal evidence of the impacts of the REDD+ project both on deforestation rates and livelihoods. What is novel in this study is that we have also collected detailed baseline survey household data both one year prior to the commencement of the project (in 2014) and corresponding endline data 5 years after the project began (in 2019). Hence, unlike nearly all other published work, our survey data allows us to uniquely and rigorously assess livelihood impacts as well as the likely mechanisms that lead to any observed changes in deforestation rates. Also, compared to prior work, we are able to assess changes over a longer time horizon, as most previous research evaluates immediate programme impacts (of up to one or two years).

Finally, our analysis strategy is based on a pre-registration plan which was submitted to an open-access repository before data collection was completed (EGAP id: 20190711AA). To our knowledge, no other evaluation study on a REDD+ project has utilised such a pre-registration plan. This aspect of our analysis contributes to the objective of furthering the transparency and credibility that is increasingly called for and supported by researchers working in the environmental policy domain (Wiik et al., 2019; Parker et al., 2019; Ferraro, 2009).

The rest of this study is organised as follows. In the next section, we discuss the currently available literature on voluntary REDD+ programmes. We then describe the intervention, data, and methods used in this study. We then follow with a results section consisting of our main results, plausible mechanisms, robustness checks, and a simple cost-to-carbon analysis. We then place our findings into perspective and discuss the policy implications.

3.2 Existing evidence of voluntary REDD+

Voluntary REDD+ programmes have received widespread attention based on their ‘triple-win’ promise: the ability to reduce carbon emissions, improve livelihoods, and conserve biodiversity (Wunder, 2007). Hundreds of such forest land-based REDD+ projects have been initiated globally, with substantial diversity across locations (Simonet et al., 2021). To date, the majority of voluntary REDD+ projects involve livelihood or social development components to compensate affected communities for restricted forest access and use rights (Simonet et al., 2021; Duchelle et al., 2017; Angelsen et al., 2018; Wunder et al., 2020). This additional focus on welfare rides on the hypothesis that conservation and development are synergistic rather than competitive outcomes (Alix-Garcia et al., 2015; Ferraro and Simorangkir, 2020).[2]

In theory, atmospheric carbon reductions can be achieved through REDD+ projects, since the credits sold need to be associated with the carbon stored in forest lands which are under a clear and imminent threat of deforestation (as established through an accreditation process). In other words, emission reductions need to display ’additionality’; requiring that any avoided carbon emissions from a REDD+ project (as compared to a counterfactual or baseline) should result directly from the REDD+ project themselves and would not have been achieved otherwise. Further, REDD+ payments should result in ‘no-net harm’ to local human livelihoods or biodiversity.

From the very limited body of published studies, most focus on sub-national REDD+ programmes under the United Nations Framework Convention on Climate Change (UNFCCC) that actually do not involve the sale of voluntary carbon credits. Instead, the carbon credits issued by the projects assessed in these studies are financed by grants and often have not even been accredited by an established agency. These are thus different type of offsets compared to those sold in voluntary carbon credit markets. Yet, it is the latter type of credits – financed by private market forces – that are being increasingly called for to meet climate change targets (Taskforce on Scaling Voluntary Credit Markets, 2021). Also, the few available

[2]See Jayachandran (2022) for a recent review of evidence on the environment vs. development debate

studies predominantly focus on assessing only deforestation effects and are not able to assess the livelihoods impacts of these REDD+ schemes nor the mechanisms that could explain any changes in deforestation. The reason for this is that these assessments rely predominantly on remote sensing data and do not have access to 'before and after' survey data for both the recipients of REDD+ payments and their comparable control groups.

The overall picture from the limited literature on the actual carbon-mitigating effectiveness of REDD+ projects remains opaque, to say the least. Bos et al. (2017) assess the deforestation performance of 23 sub-national REDD+ type initiatives in Brazil, Peru, Cameroon, Tanzania, Indonesia, and Vietnam. Not all of these projects involved issuing credits for voluntary carbon markets nor were they certified by an established accreditation agency. Using a difference-in-difference approach to assess deforestation they find very modest effects of REDD+ projects. Similarly, West et al. (2020) assess the additionality of 12 REDD+ programmes in Brazil (in this case all were accredited by an established agency) between 2008 and 2017 using synthetic control methods. In most cases, they find that observed deforestation rates cannot be causally attributed to REDD+ but reflect other background factors. Correa et al. (2020), Simonet et al. (2019) and Ellis et al. (2019) all use difference-in-difference analysis to assess REDD+ projects in Brazil but again most of which were never accredited to sell offsets in the voluntary carbon credit markets. The first two of these studies find that REDD+ had led to a decrease in deforestation while the others did not (Correa et al., 2020; Simonet et al., 2019). Ellis et al. (2019) use difference-in-difference and synthetic control methods to assess the impacts of sub-national REDD+ projects in the Yucatán Peninsula between 2010 and 2018. The authors find that the REDD+ projects have had largely insignificant impacts on deforestation rates, though results vary across locations.

Rigorous studies of livelihood impact also remain scant. The study by Duchelle et al. (2017) is perhaps the most robust of its kind. It uses using data from 23 REDD+ sites across six countries obtained from CIFOR's Global Comparative Study on REDD+. Survey data was collected for nearly 4000 households both before and after REDD+ projects were implemented. Results show that REDD+ interventions had a minimal impact on household and community-level well-being and income indicators. Similarly, a study by Jagger and Rana (2017) uses publicly available secondary data to assess the livelihood impacts of 18 REDD+ projects in Indonesia. They find evidence of negative impacts on livelihood measures, though most of the programmes evaluated were in an early stage of development. In a recent review of the literature by Duchelle et al. (2018), the authors also paint a less favourable picture of the impacts of REDD + on livelihoods, though the literature they refer to relies on less rigorous statistical methods that do not follow a difference-in-difference approach. Also, most of the REDD+ projects that are discussed in this review have not been accredited to sell carbon credits (and hence have lower standards to begin with when it comes to meeting social objectives).

3.3 REDD+ in Sierra Leone

The Gola Rainforest National Park (GRNP) is a 71,000-hectare remnant of the upper Guinean moist tropical forest, on the border with Liberia. It is part of the Upper Guinean Forests, classified as a global biodiversity hotspot by Conservation International, a global conservation watchdog. The GRNP was officially established in 2011 and the managing entity, Gola Rainforest Conservation (GRC) has been engaged in GRNP conservation efforts for over twenty years. Visual assessment of satellite images suggests that forest cover within the uninhabited GRNP has largely remained intact from 2001 to 2018 (Figure 3.1). To protect the park, GRC imposes restrictions on logging, hunting, and mining within the park and employs forest guards to enforce these rules. Yet from this figure, it also becomes apparent that the park is surrounded by land that has been substantially deforested. This so-called buffer zone of 4 km is the expected area of leakage caused by the displacement of agriculture. In addition, the buffer zone protects the park from encroachment resulting from growing population pressure and serves as a corridor for species migration between the different park sections. In 2014, the national park received REDD+ accreditation from the leading accreditation agency Verra, to protect the tropical forest inside the GRNP and safeguard the buffer zone functions. GRC has since then been implementing the REDD+ programme.

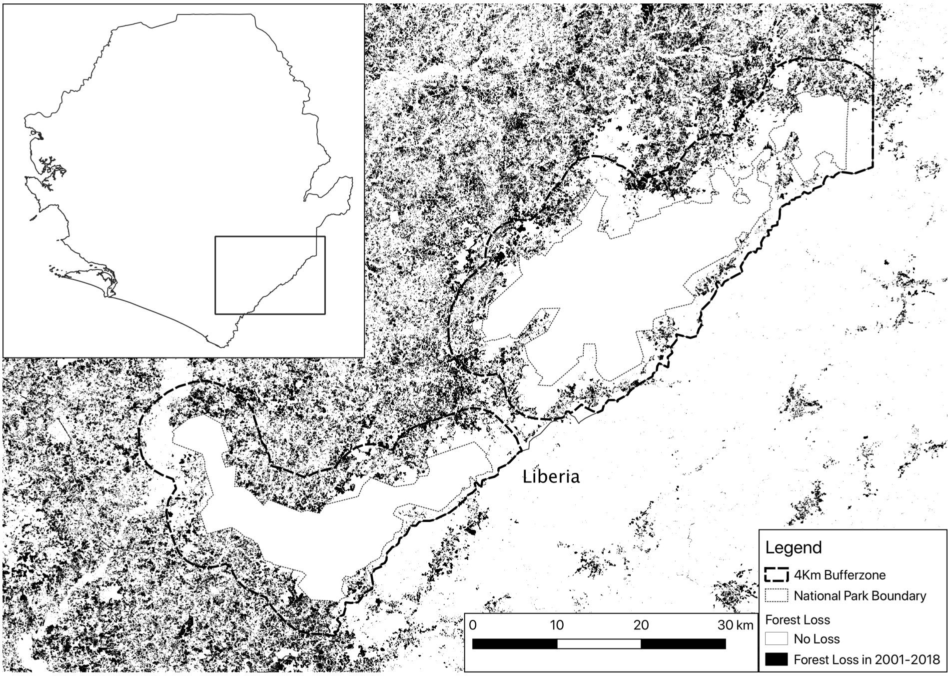

Figure 3.1: Yearly forest loss in the Gola Rainforest National Park area in Sierra Leone.

This figure shows for each pixel whether any deforestation took place from 2001 until 2018. The dashed line shows the 4km buffer zone in which the REDD+ programme took place. Source of data: Hansen et al. (2013)/UMD/Google/USGS/NASA.

As part of the REDD+ project, GRC offers several programmes to local communities to compensate them for direct losses of income from land usage restrictions. Part of the benefits is given to communities throughout the seven Chiefdoms in which the GRNP lies, including educational scholarships, surface rents to landowners and a Chiefdom Development Fund. In addition to these more general benefits, there are several activities directed specifically at communities located in the 4km buffer zone. These REDD+ activities focus mostly on reducing extensive agriculture (i.e. upland rice farming) and moving towards forest-friendly crops (e.g. cocoa), thereby aiming to reduce pressure on the buffer zone, which in turn reduces pressure on the GRNP. The three main REDD+ activities exclusively in the buffer zone are:

Agricultural programmes: Agricultural programmes consist mainly of training on crop production. Generally, a demonstration plot is established and farmers are invited to observe and learn new methods to improve yields. This is done specifically for wetland rice, groundnuts, and several vegetables. Crucially, the programmes do not include upland rice, the most commonly produced crop, as it requires slash-and-burn agriculture and large amounts of land. In fact, GRC actively discourages upland rice farming.

Cocoa programmes: Within the cocoa programmes, GRC provides training on production, farm management, and post-harvest processing. Cocoa in Sierra Leone is considered a 'forest-friendly' crop: cocoa farms are often created in secondary forests with very minimal land clearing. The shade provided by trees (which are rarely cut down) reduces the need for extensive weeding. GRC's activities are run through farmer field schools and by training master farmers within the communities. In addition, GRC established farmer associations of which community members of REDD+ communities can become a member if they own a cocoa plantation. These farmer associations are equipped with buying stations and trained buying officers. These buying officers are responsible for sourcing the cocoa from the REDD+ communities at a somewhat higher price. This price is based on the market price in the regional cocoa hub minus a transportation fee (this price is typically higher than the local price). The cocoa is used to produce high-quality single-origin niche chocolate which is sold at a premium. Some of this premium is returned to the cocoa farmers. Farmers are still free to sell cocoa to any other trader.

Savings and Lending Associations: GRC also established Village Savings and Lending Associations (VSLA) as part of the REDD+ programme. The aim is to improve financial access and facilitate investment, thereby increasing resilience. Participation is voluntary and participants can either save money or take out a loan from the saved money. The size of the loan depends on how much was contributed. The VSLA is run by a trained committee that decides on the interest rates for saving and lending and on membership. In addition, the VSLA has a separate fund for emergency loans. Members also receive business training and financial literacy training through the VSLA. GRC's role has been to establish the VSLAs and provide training on their functioning. They are currently only involved in monitoring and providing support when necessary.

In addition to these three interventions, GRC also promotes the collection of Non-Timber Forest Products (NTFP). This activity is considered forest-friendly and has the potential to generate income for households. During the study period, there was no formal programme regarding this activity, but GRC did interact with REDD+ communities about NTFP collection. GRC is also planning to include a formal intervention on NTFP collection in the future.

None of the provided interventions was conditional on deforestation outcomes and as such, we consider this an unconditional in-kind programme. Furthermore, as the REDD+ programme was not randomly assigned to communities, we employ a difference-in-difference analysis in which our counterfactual group consists of the communities that lie within the GRNP chiefdoms, but outside of the buffer zone. Within the buffer zone, the assignment of the three interventions was also not random, and often communities received multiple interventions, we are therefore unable to test the impact of each intervention separately but do so for the REDD+ program as a whole. Moreover, we do not examine the REDD+ activities that were targeted to communities beyond the buffer zone (educational scholarships, surface rents, and the Chiefdom Development Fund) for two reasons. Firstly, the main goal of the project was to improve outcomes in the buffer zone specifically and secondly, we lack the data to construct a convincing counterfactual for the area beyond the buffer zone. In Table A.3.1 the proportion of villages receiving each intervention is shown.

3.4 Data and methods

The analyses in this paper rely on three main sources of data: satellite data using a publicly available dataset by Hansen et al. (2013), border definitions (polygons) of all protected areas in Sierra Leone and survey data collected over 3 rounds in communities surrounding the GRNP (2010, 2014, and 2019). We discuss these sources of data in turn, before moving to the estimation strategy.

3.4.1 Deforestation data

The dataset by Hansen et al. (2013) gives worldwide, annual data on forest loss that is updated yearly. The dataset is high-resolution with pixel size at 30x30m (see Section 3.7.3 for more information on the Hansen dataset). This allows us to get detailed information and recognise small-scale deforestation (as is likely with slash-and-burn agriculture). Forest is defined as an area with >50% vegetation taller than 5 meters. Forest loss is defined as a change from a forested to a non-forested state. We disaggregate forest loss to the year and community level for the 2001-2018 period. To assign forest loss to specific communities we use the approach and dataset by Wilebore and Coomes (2016), a study on the same communities. The approach works as follows: first simple Voronoi polygons are drawn for all communities in the project and surrounding area (476 communities in total). Then, some of these polygons (228 in total) are adjusted in size based on the estimated size of the community obtained through a community survey. Unsurveyed communities are not weighted (our results are similar when we run the analysis for weighted polygons only (see Table A.3.14). The resulting predicted community polygons were verified using GPS boundary data collected for a sample of 98 of the communities (see Figure A.3.3 for the polygon map and Section 3.7.3 for more information on the estimation method). The data on locations and population sizes are based on a survey of 228 communities in 2010-11 by the researchers. Finally, we count the number of pixels lost in a community's polygon in a given year and calculate the percentage of forest lost by dividing the area deforested by the size of the polygon. By using the percentage, we can compare communities with different-sized land holdings.

3.4.2 Protected areas definition

We place the observed deforestation rates in the GRNP into a larger context by examining other protected areas in Sierra Leone. The locations thereof are based on a map provided by the Sierra Leonean Ministry of Agriculture, which we use to infer the exact borders. We examine all existing National Parks, forest reserves and game sanctuaries with a legal status protecting them. The Hansen et al. (2013) deforestation data is used to examine forest loss over the entire period for each protected area separately. We also examine forest loss in 4km buffer zones which provide important corridors for endangered species and prevent encroachment into the protected area. We use a 4km distance from the border to define this buffer zone, to be consistent with GRNP's buffer zone. We only consider buffer areas that fall within the national borders of Sierra Leone. Deforestation results for these national parks are shown in Subsection 3.7.1. We extend this analysis to Guinea and Liberia using data from the World Database on Protected Areas.

3.4.3 Survey data

We use data collected in Sierra Leone during three survey waves. In March/April 2010, Wageningen and Cambridge University researchers collaborated with GRC to implement a baseline survey in communities in the seven chiefdoms surrounding the GRNP. GRC selected 200 communities that were closest to the National Park and most likely to have community forests with high biodiversity value. From this list, 11 did not exist (anymore) and the survey was subsequently implemented in 189 communities. This survey is also the source of community locations and sizes, which are used in the Voronoi polygon definition by Wilebore and Coomes (2016). In each community, 15 households were randomly sampled and interviewed regarding demographics, economic outcomes, hunting and gathering behaviour, and attitudes towards conservation. We implemented a second survey in April 2014, just prior to the start of REDD+ activities. From the communities included in the 2010 survey wave, we randomly selected 30 REDD+ communities. These communities all lie within a 4 km buffer zone around the National Park. We also randomly selected 30 non-REDD communities located within 4-25 km from the National Park boundary (see Figure A.3.4 for the locations of the selected communities). The sampling was stratified by regional quadrants to ensure the representation of communities between the GRNP boundary and the border with Liberia. One of the REDD+ communities was removed from the sample as it no longer existed, bringing our full sample down to 59. The same households as in 2010 were interviewed. During this survey wave, in total 841 households were surveyed across the 59 communities, with an average of 14 households per community (some communities had fewer than 15 households). For the follow-up survey in April 2019 we revisited each household included in the 2014 survey. If the head of the household was not available we selected a representative of the household. Our recontact rate for the 2019 sample is 81% (at the household level).

3.4.4 Survey Outcomes

We assess two main survey outcomes: a family of outcomes related to livelihoods and a family related to conservation attitudes. By grouping our variables into families, we reduce the number of statistical tests necessary. We use the approach by Kling et al. (2007) to combine variables with different units into families. This is done by first normalising all variables, and then taking the raw mean of these z-scores. If some variables are missing for observations these are imputed at the own-group mean (by survey round and treatment status).

The first family is related to the livelihoods of farmers that are likely affected by the REDD+ programme. It consists of data on income, expenditures, resilience, productive loans and assets. Income is the sum of a very broad range of income categories which includes almost all sources of income, increasing our precision. We ask this question over the previous year. We also look at two forms of expenditures as more robust estimates of incomes. We ask about expenditures in the previous month on a set of common consumption items. We also ask about yearly expenditures on larger, less regular items. Resilience is a dummy on whether individuals were able to cope with an emergency in the previous year. Productive loans are the sum of loans in the previous year for productive activities. Assets is the sum of a common set of assets owned, such as tables, beds, and housing materials. Outcomes that are expressed in monetary terms (income, expenditures, and productive loans) are transformed using the inverse hyperbolic sine which is similar to a log transformation and reduces the variance of the outcome.

The second family is about conservation attitudes, which consists of stated attitudes, knowledge of conservation rules, sustainable farming, and perceptions of human-wildlife conflict. Stated attitudes are responses on a five-point Likert scale to four questions related to the GRNP and conservation in general. Knowledge is assessed by asking five questions about what is allowed and not allowed in the national park (on mining, gathering, fishing, logging, and hunting). Sustainable farming is the number of sustainable farming practices used, for example on lower land use.

Finally, we ask how big of a problem human-wildlife conflict is (on a 0-3 scale). Increased human-wildlife conflict is often associated with the establishment of the national park, which might have increased animal populations.

We also explore several mechanisms, mainly related to labour market changes. Labour is one of the main seasonal constraints for agricultural production in Sierra Leone, with over 65% of households reporting labour shortages in the agricultural season in a nationwide survey (MAFFS, 2011). To assess labour shortages we ask respondents how much of a problem it is to get labour (scale 0-3) for the three main types of farms and calculate the average value. We also assess income from farm wages in the previous year, and finally, also look at yearly income from NTFPs (Non-Timber Forest Products). NTFPs are an important alternative form of income associated with the creation of the national park, as these are explicitly allowed to be collected and will be more plentiful if the park is well-preserved. See Table A.3.2 for a definition of all outcomes used).

3.4.5 Empirical strategy

To estimate the average treatment effect of REDD+ we estimate a standard difference-in-difference model:

$$\mathbf{Y}_{ijt} = \beta_0 + \beta_1 REDD_j + \beta_2 post_t + \beta_3 post_t * REDD_j + \varepsilon_{ijt}$$

Where $\mathbf{Y}_{ijt}$ refers to our normalised set of outcomes (as a family or individually), $REDD_j$ is a dummy for REDD+ eligible communities, $post_t$ is a dummy referring to the second survey wave (2019). β_3 is our coefficient of interest. i indexes the household level, j indexes the community level and t the survey wave. For the livelihood indicators, we cluster standard errors at the community level. Only households for which we have panel data (e.g. they were interviewed in both rounds) are included in this regression. This estimator produces an unbiased estimate of the treatment effect if we can assume that without the project, the communities would have trended similarly (parallel trends assumption). We explore this in the next section.

3.4.6 Parallel trends assumption

Our main identifying assumption is that of parallel trends. That is, the REDD+ communities would have trended similarly, had the REDD+ project not been implemented. Though this assumption is fundamentally untestable, analysing pre-treatment trends can provide some confidence about the likelihood of this assumption. If trends are similar prior to the implementation of the project, it is more likely that they would have trended similarly had there been no project.

For conservation behaviour, we have many rounds of data available prior to the start of the REDD+ activities, shown in Figure 3.2. The break in trend lines in this figure shows the launch of a new, more accurate satellite (Landsat 8). As can be seen, trends (and levels) were very similar prior to the break, which gives confidence that this trend would have continued if REDD+ activities had not been implemented. We also have one year of observations measured with Landsat 8, prior to the commencement of REDD+ activities, showing very similar levels between the treated and control groups, after which they diverge strongly. This reassures us that the parallel trends assumption likely holds.

For our survey outcomes, we make use of the unique opportunity provided by having access to two rounds of pre-REDD+ data (the 2010 and 2014 rounds of data), to investigate parallel trends in our data prior to the commencement of REDD+ activities. We run the difference-in-difference model as defined above for the 2010-2014 data on our main outcomes and mechanisms (though not all outcomes were measured in the 2010 data). This is shown in Table A.3.11. In no case is the post*REDD+ coefficient significant: we find no different trends between the two groups. This reassures us that the parallel trends assumption is likely to hold.

3.5 Results

In the following section, we report on our results of the evaluation of the REDD+ project surrounding the Gola Rainforest National Park (GRNP) in Sierra Leone. We start by describing the effect of the project on deforestation in the buffer zone of the GRNP and subsequently place deforestation in and around the GRNP into context by comparing it to other protected areas. We then report on our livelihood and conservation attitudes outcomes. This is followed by a discussion of plausible mechanisms and a robustness section. We finally show the results of a simple cost-effectiveness analysis to compare our results to other carbon-mitigating strategies.

3.5.1 Deforestation

We first visually inspect average deforestation rates for the evaluation period 2002-2018, shown in Figure 3.2. These figures display the trend in percentage of forest loss in the REDD+ communities (black line) and non-REDD+ communities (grey line), with shaded areas representing 95% confidence intervals. The vertical line indicates the start of the REDD+ programme in 2014. This figure highlights that prior to the start of the REDD+ programme both groups of communities trended very similarly. After the start of the programme, the percentage forest loss is significantly and substantially higher in non-REDD+ communities compared to communities that received the REDD+ programme.

Table 3.1 displays our main results for the difference-in-difference analysis testing the impact of REDD+ on deforestation. Column 1 illustrates that pre-intervention deforestation rates are low at 0.740% annually, with no significant differences for REDD+ and non-REDD+ communities. During the five years of the REDD+ programme (i.e. after 2014), deforestation increases strongly, by 3.314%, in both areas. This stark increase can potentially be attributed to higher precision in the deforestation dataset due to the inclusion of additional satellite data imagery from the Landsat 8 mission. However, the difference-in-difference estimate shows that for REDD+ communities the increase in deforestation is 1.032 percentage points lower. This amounts to a 30% reduction in annual deforestation rates, a substantial slowing down of deforestation in this crucial buffer zone.

We compare GRNP and buffer zones to other protected areas (PAs) in Sierra Leone and neighbouring countries. Figure 3.3 shows forest loss in the GRNP (Panel A), as well as its buffer zone (Panel B) compared to other protected areas (PAs) in Sierra Leone. While inside the GRNP, deforestation was much lower, compared to other protected areas (from 2013-2018 GRNP deforestation rate is 0.17% and the

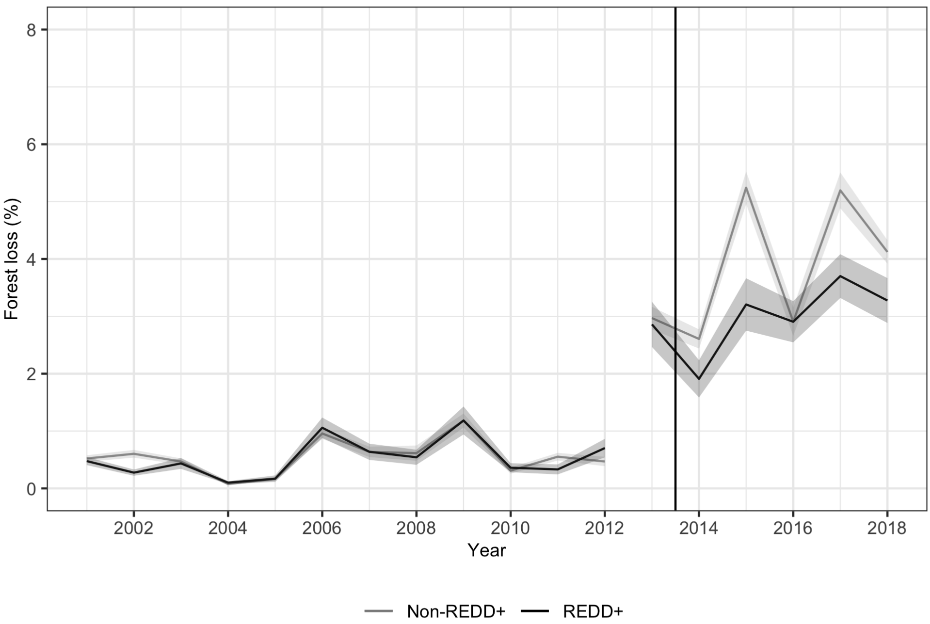

Figure 3.2: Total forest loss in REDD+ and non-REDD+ villages.

Total forest loss in REDD+ and non-REDD+ villages. This graph shows total forest loss from 2001 to 2018 in REDD+ versus non-REDD+ villages. The village polygons are estimated using population-weighted Voronoi estimations. The shaded areas in the graph denote confidence intervals and the vertical black line indicates the start of REDD+. The break in the lines in 2013 denotes the launch of a more precise satellite (Landsat 8). Source of data: Hansen et al. (2013)/UMD/Google/USGS/NASA.

average for other PAs is 1%), forest loss in the immediate buffer zone, has been similar to the national trend (from 2013-2018 GRNP buffer zone deforestation rate is 2.77% and the average of other PAs buffer zone is 2.48%) (see also Figure A.3.1 for detailed graphs for each PA in the country). We also extend our analysis to protected areas in neighbouring Guinea and Liberia and find similar trends (see Figure A.3.2).

Table 3.1: The impact of REDD+ on deforestation, livelihoods, and attitudes

	Forest loss	**Livelihoods**	**Attitudes**
Post*REDD+	-1.032^{***}	0.022	-0.017
	(0.114)	(0.132)	(0.218)
Post	3.314^{***}	0.222^{**}	-0.226
	(0.066)	(0.103)	(0.138)
REDD+	-0.052	-0.144	0.176
	(0.033)	(0.118)	(0.130)
Constant	0.740^{***}	0.000	-0.000
	(0.017)	(0.089)	(0.076)
Years	18	2	2
Villages	454	59	59
Num. obs.	8172	1320	1320

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for forest loss (satellite data) and livelihood and conservation attitudes families (survey data). Post*REDD+ is the project impact coefficient. Forest loss is the percentage of loss of forest (primary and secondary). The livelihood family outcome is a summary index (average of z-scores) of an income index, an assets index, a durable loan size measure, and a measure for resilience. The attitudes family outcome is a summary index (average of z-scores) of a conservation attitudes index, an awareness of conservation norms index, the number of sustainable farming practices practised, and an index for human-wildlife conflict perception. Family outcomes are standardised and centred on the control group at baseline. For survey outcomes, standard errors are clustered at the village level. Robust standard errors in parentheses.

3.5.2 Livelihoods and conservation attitudes

To measure how livelihoods and attitudes in the REDD+ communities were impacted by the project, we use detailed on-the-ground household survey data of 841 households collected before (2014) and after the programme started (2019). Results from our the difference-in-difference analysis are shown in Column 2 of Table 3.1. We find that our index for livelihoods increased by 0.222 SD over the five years of the programme, which is a substantial and significant improvement. However, there was no difference between REDD+ and non-REDD+ communities, the coefficient for that difference is small at 0.022 SD. Despite the interventions aimed at livelihood enhancements, we found no evidence that REDD+ induced income enhancements to participants.

We also find no evidence that household conservation attitudes changed due to the

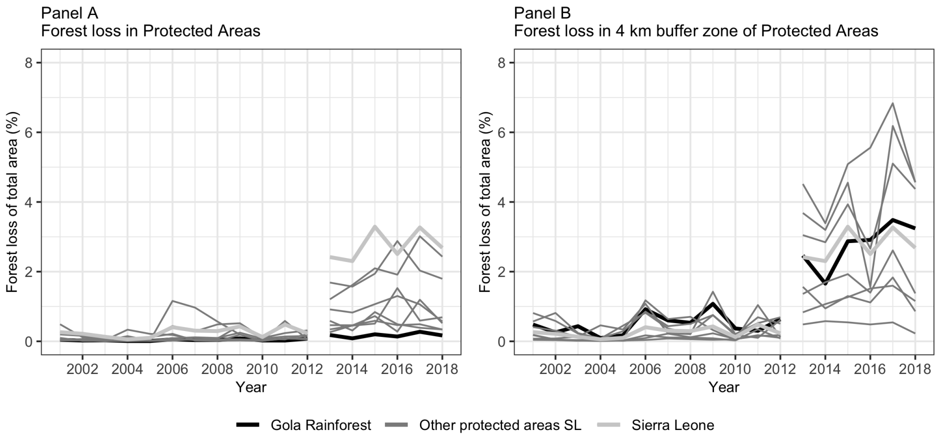

Figure 3.3: Total forest loss in Gola Rainforest National Park, other protected areas in Sierra Leone, and Sierra Leone as a whole.

Total forest loss in Gola Rainforest National Park, other protected areas in Sierra Leone, and Sierra Leone as a whole. The left panel shows the total forest loss from 2001 to 2018 in protected areas of Sierra Leone. The right panel shows the total forest loss from 2001 to 2018 in the 4km buffer zones of these parks. The break in the lines in 2013 denotes the launch of a more precise satellite (Landsat 8). Source of data: Hansen et al. (2013)/UMD/Google/USGS/NASA.

programme (Table 3.1, Column 3). Between the survey waves, attitudes lowered substantially, by about 0.226 SD, in both types of communities. However, attitude changes cannot be attributed to the REDD+ programme, as the impact on attitudes is small and insignificant (-0.017 SD). Though the conservation attitudes index is an outcome variable in its own right, it can also be viewed as a mechanism driving the change in deforestation trends observed in Column 1 in Table 3.1. We find no evidence of such a channel at work, so we explore other mechanisms below.

Hence, it appears that household's welfare (as measured by livelihood and conservation attitude indicators) has neither substantially improved nor been compromised by the implementation of the REDD+ programme. For all results on our survey indicators, as specified and published in the pre-analysis plan, we refer to Subsection 3.7.4. It is important to note that though our analysis does not show that the Gola REDD+ project has led to clear improvements in income or conservation attitudes, we can equally conclude that the project has not resulted in any harm to local communities or a lessening in pro-conservation sentiments. Whilst ideally REDD+ projects would improve livelihoods, this 'no-net social harm' finding is a vital feature for the viability of REDD+ projects that cannot be overestimated (Angelsen et al., 2018).

3.5.3 Mechanisms

We next turn to explore other likely mechanisms that could explain the observed sizeable reduction in deforestation rates. Earlier studies have pointed to changes in the local labour supply, labour productivity, off- and on-farm wages, and alternative income sources as key factors affecting slash-and-burn agriculture in Sierra Leone (Wilebore et al., 2019; MAFFS, 2011). Using the same household survey data collected before and after the intervention from both treated and control communities, we explore several such possible mechanisms in Table 3.2, and find suggestive evidence of these channels.

We first assessed an index of labour availability for the three main types of farms (upland, wetland and plantation). In REDD+ communities there is a sharp reduction in access to labour, of 0.545 SD (Column 1). This can be translated to a decrease in labour access of 0.534 on a scale from 0 to 3, where 3 indicates high labour access.

Second, we see that incomes from farm wages are substantially higher in REDD+ communities in the later time period, by 0.199 SD (Column 2). This amounts to an increase in income from farm wages of 43.5% which can be attributed to the REDD+ project. The non-REDD+ communities at baseline had a yearly income from farm wages of 28.930 Leones which amounts to 6.7 USD (1 USD was approximately 4320 Leones in 2014). We hypothesise that GRC's activities increased opportunity costs of labour by providing alternative income possibilities. When farmers choose to pursue these alternative income possibilities, this leaves fewer labourers available for the local labour market (and thus reduces labour access). This in turn leaves fewer labourers for conventional, labour-intensive slash-and-burn agriculture, which is associated with deforestation. This lower labour availability and higher opportunity cost increase the local labour price, which increases income from working on other

Table 3.2: Plausible mechanisms explaining reduced deforestation from REDD+

	Labour access index	Income farm wages	Income NTFP	Cocoa harvest
Post*REDD+	-0.545^{**}	0.199^{*}	0.343^{**}	0.196
	(0.257)	(0.106)	(0.153)	(0.129)
Post	0.365^{**}	0.037	0.021	-0.514^{***}
	(0.160)	(0.083)	(0.106)	(0.103)
REDD+	0.120	−0.014	−0.152	−0.123
	(0.133)	(0.096)	(0.101)	(0.126)
Constant	−0.000	0.000	0.000	−0.000
	(0.091)	(0.063)	(0.087)	(0.102)
Years	2	2	2	2
Villages	59	59	59	59
Num. obs.	1150	1228	1320	1320

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for mechanisms. Independent variables are standardised and centred on the control group at baseline. Labour access index is an index of three farm labour access variables (upland rice, wetland rice, and plantation) indicating to what extent there is access to labour. Income farm wages is a continuous variable (transformed with the inverse hyperbolic sine (IHS) function) measuring the yearly household income from farm wages. Income NTFP is a continuous variable (IHS transformed) measuring the yearly income from Non-Timber Forest Products collection. Robust standard errors in parentheses are clustered at the village level.

people's farms (as we find evidence for).

Third, we explore the possible alternative income source from the sale of Non-Timber Forest Products (NTFP). These are collected in forested areas (including within the GRNP). The collection is encouraged by the GRC, as it is non-invasive and increases incentives for protecting the national park. We found a substantial increase in incomes of 0.343 SD in REDD+ communities in the later time period (Column 3). This translates to a 56.7% increase in NTFP income attributable to the REDD+ programme. In contrast, non-REDD+ communities exhibited no statistically significant change in their NTFP income and had a baseline value of approximately 108.400 Leones or 25 USD per year).

A final mechanism that we explore is whether farmers switched to more forest-friendly crops, such as cocoa. We find a substantial increase in cocoa harvest size (0.196 SD, Column 4) in REDD+ communities in the later time period, though this is measured with substantial noise and the change is not statistically significant.

This amounts to an increase in cocoa harvests of 40.6%, with baseline values of cocoa harvests in non-REDD+ communities at approximately 35 kg.

3.5.4 Robustness

We run multiple placebo tests to ensure that higher precision Landsat 8 imagery from 2013 is not driving our result. A potential concern is that forest loss measurements are less precise as proximity to the national park increases. To test this, we run the same model but restrict our sample to all communities within 8 km of the park (thereby taking only communities in the 4-8km zone as the control group), this hardly changes our estimates. We run a second check by removing the REDD+ communities from our sample, and defining the 4-8km zone as the treatment group, comparing it to the remaining non-REDD+ communities. The deforestation result then disappears, indicating that proximity to the national park does not affect forest loss measurement. Finally, we run our model with Landsat 8 data only, for the years 2013-2018, excluding the lower-precision years. Again, this hardly changes our estimates. See Subsection 3.7.5 for the full results of this robustness analysis.

Another potential concern is that our result is driven by leakage from the REDD+ area to the control area. However, we argue that REDD+ communities have no incentive to move their activities elsewhere for three reasons. First, cutting trees is completely legal in the buffer zone of the park (i.e. the REDD+ communities). Second, the Gola REDD+ project is not conditional on deforestation outcomes in the buffer zone. Third, cutting down trees is labour-intensive and typically done on foot. Thus, it is unlikely that REDD+ communities moved to control areas for farming or other activities that require cutting trees. An additional source of leakage could be that treated communities buy more wood on the market sourced from the control areas. We deem this unlikely because wood demand in the area mostly stems from urban construction. Any market leakage is therefore expected to be negligible.

3.5.5 Cost-to-carbon analysis

We perform a simple cost-to-carbon analysis (see Subsection 3.7.6 for details). We find that the REDD+ project led to around 340,000 MtCO2 in avoided emissions per year and estimate costs per averted MtCO2 of $1.12 per year. Available cost-benefit analysis indicates that this is relatively high compared to other similar conservation programmes (e.g. Jayachandran et al. (2017) calculate a cost of $0.46 per avoided MtCO2 and Simonet et al. (2019) report $0.84 per MtCO2). Cost comparisons across different REDD+ type projects can be misleading, however, as calculation methods and assumptions vary considerably. Yet, we can nevertheless more safely conclude that this specific REDD+ project does appear to avert carbon at a cost which is considerably lower than the average sales price per offset within the evaluation period at approximately $3 per credit (Forest Trends' Ecosystem Marketplace, 2021). Further, the project appears to be more cost-effective than many other emerging policy options such as carbon capture and storage (CCS) technologies whose cost range from $40 to $400 per MtCO2.

3.6 Discussion

The market for voluntary carbon credits stemming from REDD+ projects is currently booming with a projected 100-fold increase in trade volume by 2050. Yet, evidence of the conservation and livelihood impacts of these projects originating from independent, robust causal studies is very limited. We contribute to this significant knowledge gap by examining the impacts of an actual voluntary REDD+ project implemented in the buffer zone surrounding the Gola Rainforest National Park in Sierra Leone. We find 30% lower deforestation rates yearly in REDD+ communities compared to those in the area outside the treated buffer zone. This shows that a relatively light-touch programme, in the form of in-kind interventions, that are unconditional, can have substantial beneficial effects on the natural environment.

We also assess if this type of REDD+ project is able to improve local incomes and conservation attitudes. Using rich survey data, we found no clear evidence of improved livelihoods nor of changed attitudes towards conservation. We also examine through which mechanism deforestation was reduced in the buffer zone.

We find no evidence that it is caused by improved conservation attitudes but hypothesise that the REDD+ project affected the opportunity cost of labour, which increased the local labour price through alternative income possibilities. Some of these possibilities are sales of Non-Timber Forest Products and (forest-friendly) cocoa farming. Our results thus contribute to the extensive debate about the potential impact of REDD+ projects on the social welfare of local communities. We find that light-touch interventions such as agricultural training programmes are able to slow the rate of deforestation and at the same time do not economically harm local communities. However, those interventions are not effective in generating positive changes to participants' livelihoods or significant economic benefits related to poverty reduction. Our findings suggest that it will likely need more 'heavy-handed' and holistic interventions that require considerable investment to achieve environmental protection and net positive economic development at the same time.

Previous impediments to undertaking rigorous evaluation studies of REDD+ projects were considered to be the costs of such evaluations, uncertainty as to the methods to be used, as well as hesitancy from funders and project developers because of the fear that any disappointing short-term evaluations could lead to jeopardising future financing of their projects (Simonet et al., 2018). Our experience from completing this exercise teaches us how these concerns are increasingly waning. Improvements in technology and capacity building have reduced the costs of such evaluations while there have been substantial advances in our understanding of the methods used. Further, we are now beyond the piloting phase of many of these projects and thus have data over longer periods of time. We have also witnessed a shift in the mentality of project developers who are eager to embrace best practice evaluation methods and support setting up independent rigorous assessment methodologies (as - to their credit- did the agencies involved in the Gola REDD+ project). Given the demand pressures to significantly increase the supply of these voluntary offsets, it is even more timely and necessary to call for more studies such as this one to add to the evidence base of voluntary REDD+ projects.

3.7 Appendix

3.7.1 Forest loss in protected areas

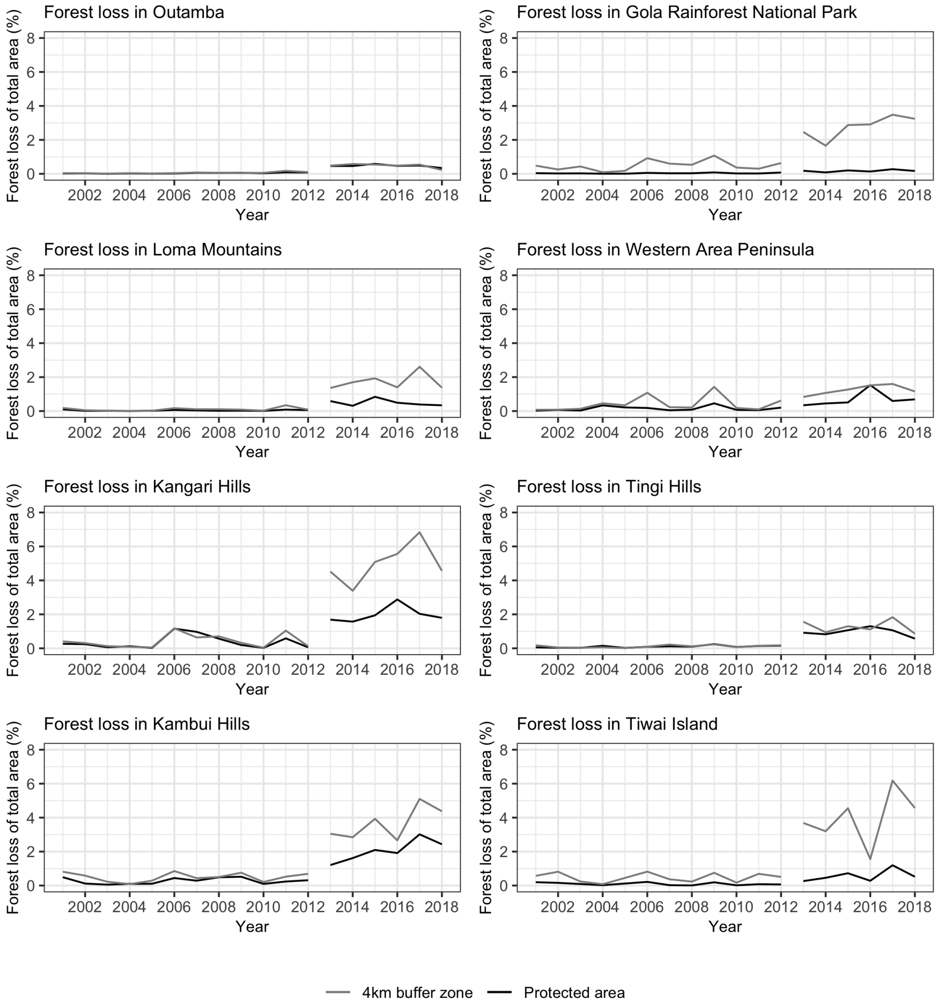

Figure A.3.1: Yearly forest loss in the Protected areas in Sierra Leone.

This graph shows total forest loss from 2001 to 2018 in protected areas of Sierra Leone and their 4 km buffer zones. The break in the lines in 2013 denotes the launch of a more precise satellite (Landsat 8). Protected area definitions come from the Sierra Leonean government. Source of data: Hansen et al. (2013)/UMD/Google/USGS/NASA.

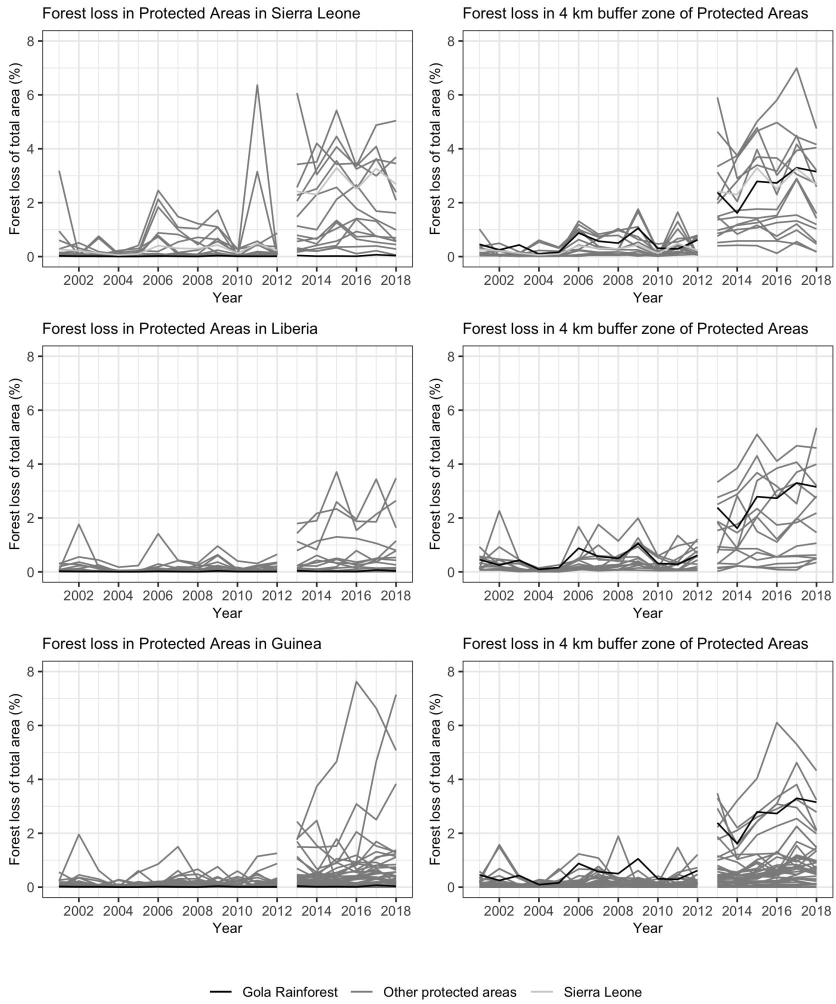

Figure A.3.2: Yearly forest loss in the Protected areas in Sierra Leone, Liberia, and Guinea.

This graph shows forest loss from 2001 to 2018 in protected areas of Sierra Leone, Liberia, and Guinea and their 4 km buffer zones. The break in the lines in 2013 denotes the launch of a more precise satellite (Landsat 8). Protected area definitions come from the Worldwide Database on Protected Areas. We exclude all polygons below a certain size (10.000 pixels) for readability of the graph and because we are unsure of the reliability of these data. Source of data: Hansen et al. (2013)/UMD/Google/USGS/NASA/WDPA.

3.7.2 REDD+ intervention in Sierra Leone

Table A.3.1: Interventions in sample of REDD+ villages

Intervention	# REDD+ vil. with intervention	% of total sample
Agricultural intervention	20	69%
Cocoa intervention	24	83%
Village savings and loans associations	18	62%
REDD+ villages in sample	29	

We only have data on which interventions were implemented in this randomly selected sample of 29 REDD+ villages.

3.7.3 Data generation and descriptives

Satellite data

We use the Hansen et al. (2013) dataset with worldwide, yearly data on forest loss for 2001-2018. This dataset maps global tree cover extent, loss and gain at a spatial resolution of 30m. The authors base the mapping on Landsat data. They define trees as all vegetation taller than 5m in height and forest as an area with >50% trees. Forest loss is defined as a stand-replacement disturbance (i.e. the complete removal of tree canopy).

There are two discontinuities in the Hansen dataset worth mentioning. The first is that the analysis method was adapted from 2011 onwards leading to improved forest loss detection in the 2011-2018 data. The second is that following the launch of Landsat 8 in 2013, more precise satellite imagery became available. In the data for Sierra Leone we especially see higher forest loss detected from 2013 onwards. Though it is not certain, this could be attributed to the Landsat 8 launch. To rule out that this discontinuity drives the result our forest loss result, we run multiple placebo tests in Subsection 3.7.5.

We use the Hansen dataset to aggregate yearly forest loss estimates at the village level. As administrative boundaries in Sierra Leone are not available at the village-level. we use the estimated village boundaries by Wilebore and Coomes (2016) to assign forest loss to villages. Wilebore and Coomes obtain point-locations of all 476 villages in the seven chiefdoms in which the Gola Rainforest National Park lies using existing maps or remotely sensed imagery. Of these, 228 villages are surveyed collecting census data and villages are asked to estimate of the village area. For 98 of these villages, handheld GPS devices are used to record point coordinates of the village boundaries. This data is used to verify the predicted village boundaries.

The authors subsequently use three models (circular neighbourhood buffers, unweighted Voronoi polygons, and weighted Voronoi polygons) to predict village boundaries, using the estimated village sizes collected in the survey. Performance of the three models is assessed by comparing the predicted boundaries to the 98 known village boundary point coordinates. Weighted Voronoi polygons perform much better than the other two models (the correlation of predicted and actual boundaries is 0.68, as compared to 0.18 for unweighted Voronoi polygons). In this model, the authors first draw simple Voronoi polygons for all villages. This process assigns every pixel in the landscape to the closest village point location, thereby dividing the landscape into regions. The 228 surveyed villages are then assigned a weight based on whether they are smaller (<1) or larger (>1) than the estimated area in the village survey. Unsurveyed villages receive a weight of 1. These weights are then used to adjust the predicted village size.

In our analysis we use the weighted Voronoi polygons as estimated by Wilebore and Coomes as shown in Figure A.3.3. We also run a robustness check excluding all villages that were not surveyed (and thus received a weight of 1) in Table A.3.14.

Further extending our analysis on forest loss, we use a classification of forests into primary and secondary forests. This allows us to disaggregate forest loss into primary and secondary forest loss. Primary forest loss is loss of old growth forest and secondary forest loss measures conversion of fallow to production agriculture. Both are classified through extensive ground measurements, which were done in 2013 and data is thus available from 2013-2018.

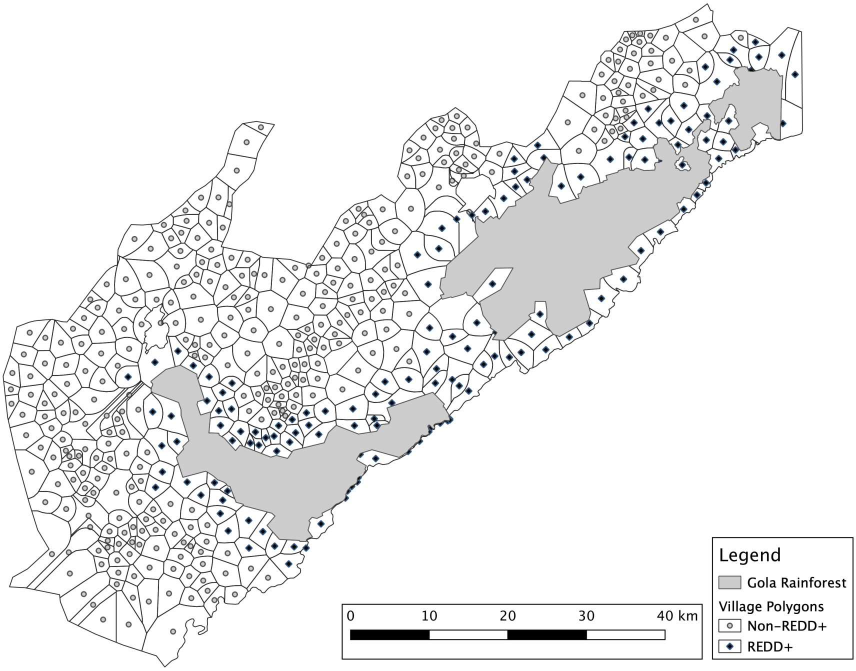

Figure A.3.3: Village polygons for satellite analysis.

This figure shows the village polygons used for the deforestation analysis. Polygons are estimated using the Voronoi method with weights based on village-estimates of the size. If this estimate was not available (not all villages were surveyed), the polygon was not weighted. REDD+ villages are defined as villages that were eligible for the REDD+ programme. Non-REDD+ villages are villages that were not eligible for the REDD+ programme and lie outside the forest edge. There are a couple of polygons excluded because they are part of another protected area (Tiwai island) or leased land by companies.

Survey data

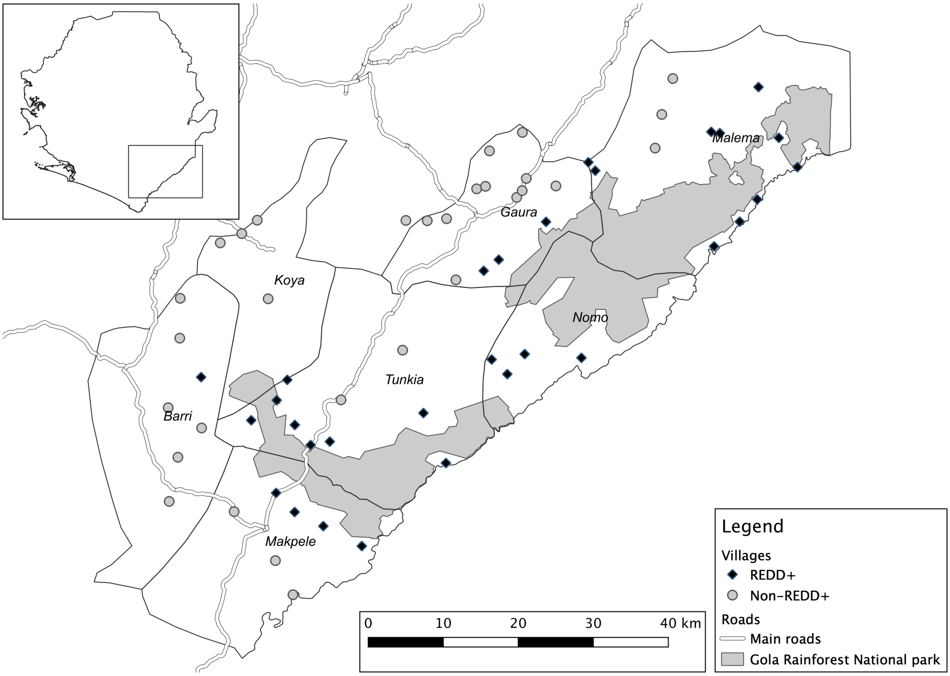

Figure A.3.4: Survey sample.

This figure shows the sample for the survey data. 30 REDD+ villages, i.e. those eligible for REDD+ benefits were randomly selected. These communities all lie within a 4 km band around the National Park. We also selected 30 non-REDD+ villages which were randomly selected from villages 4-25 km from the National Park boundary. The sampling was stratified by regional quadrants to ensure representation of villages between the GRNP boundary and the border with Liberia. One of the REDD+ villages was removed from the sample as it no longer existed bringing our full sample down to 59.

Table A.3.2: Family indicators and outcomes

Outcome	Description
Primary outcomes	
Forest loss	**Loss of forest (vegetation cover of >5m over >30% of the site) at a satellite resolution of 30m**
Primary forest loss	Loss of old growth forest (classified through extensive ground measurements)
Secondary forest loss	Loss of secondary forest measures as conversion of fallow to production agriculture
Livelihoods	**Summary index - average of z-scores of all components**
Income index	Summary index - average of z-scores of total income and expenditures in previous calendar year
Assets index	Assets summary index - weighted average of z-scores of all assets owned in previous calendar year
Durable loan size	Amount borrowed for durable investments in previous calendar year (1000 Le)
Resilience	Able to get money to deal with emergency in previous calendar year (y/n)
Conservation norms family	Summary index - average of z-scores of all components
Conservation attitudes	**Agreement with pro-conservation statements (sum of Likert questions, 4-20)**
Awareness of conservation norms	Number of questions about rules correctly answered (0-5)
Sustainable farming practices	Number of sustainable farming practices used (0-4)
human-wildlife conflict perceptions	Perception of how big of a problem crop raiding is (Scale, 0-3)
Mechanisms	
Labour access index	Average of three farm labour access variables (upland rice, wetland rice, plantation) (scale, 0-3)
Income farm wages	Income from farm wages in previous calendar year (1000 Le)
Income NTFP	Income from non-timber forest products in previous calendar year (1000 Le)
Cocoa harvest	Total cocoa production in previous calendar year (kg)

Summary indices are created following Kling et al. (2007). All variables are rescaled in the analysis such that a higher value=better.

Table A.3.3: Difference in means in outcomes in 2019

	non-REDD+			REDD+			
Variable	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Difference**
Total income (Leones, IHS)	364	6.702	2.477	296	6.487	2.535	-0.215
Monthly consumption expenditure (Leones, IHS)	364	5.846	1.552	296	6.135	0.838	0.289
Yearly irregular expenditure (Leones, IHS)	364	7.030	1.945	296	7.366	1.045	0.335
Durable loan size, (Leones, IHS)	364	0.257	1.415	296	0.338	1.491	0.081
Resilience (=1)	234	0.979	0.145	197	0.990	0.100	0.011
Conservation attitudes (4-20)	330	14.782	3.721	281	14.260	3.568	-0.522
Awareness of conservation norms (0-5)	301	3.150	0.375	277	3.350	0.493	0.201***
Sustainable farming practices (0-4)	354	0.370	0.783	294	0.565	0.879	0.195*
human-wildlife conflict (0-3)	354	2.249	1.007	292	2.517	0.932	0.269**
Yearly income farm wages (Leones, IHS)	334	1.385	2.356	282	1.786	2.567	0.401
Yearly income from NTFPs (Leones, IHS)	364	0.671	1.738	296	0.986	1.993	0.315*
Labour access index (0-3)	323	1.519	0.965	284	1.134	0.933	-0.385**
Cocoa harvests (kg, IHS)	364	0.023	0.320	296	0.174	0.810	0.152***

N is the number of observations, SD is the standard deviation. Difference gives the difference in means. IHS means the variable is transformed using an inverse hyperbolic sine function. P-values are calculated for a clustered difference in means t-test where * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.7.4 Additional results

Table A.3.4: The impact of REDD+ on primary and secondary forest loss (satellite data)

	Forest loss	Primary forest loss	Secondary forest loss
Post*REDD+	-1.032^{***}	0.058	-0.577^{**}
	(0.114)	(0.039)	(0.230)
Post	3.314^{***}	0.050^{***}	0.455^{***}
	(0.066)	(0.014)	(0.110)
REDD+	-0.052	0.212^{***}	-0.157
	(0.033)	(0.031)	(0.211)
Constant	0.740^{***}	0.082^{***}	2.527^{***}
	(0.017)	(0.011)	(0.096)
Years	18	6	6
Village polygons	454	434	434
Num. obs.	8172	2604	2604

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for forest loss (satellite data). Forest loss is the percentage of loss of forest (primary and secondary). Primary forest loss is loss of old growth forest and secondary forest loss measures conversion of fallow to production agriculture. Both are classified through extensive ground measurements, which were done in 2013. The number of observations is therefore lower for these two outcomes, as data ranges from 2013-2018. Robust standard errors in parenthesis.

Table A.3.5: The impact of REDD+ on livelihood indicators (survey data)

	Livelihoods family	Income	Assets	Durable loan	Resilience
Post*REDD+	0.022	0.017	−0.039	0.176	−0.080
	(0.132)	(0.143)	(0.094)	(0.107)	(0.070)
Post	0.222**	−0.020	−0.120*	−0.029	0.301***
	(0.103)	(0.111)	(0.068)	(0.079)	(0.062)
REDD+	−0.144	−0.090	−0.275**	−0.124	0.087
	(0.118)	(0.122)	(0.104)	(0.078)	(0.071)
Constant	0.000	0.000	0.000	0.000	0.681***
	(0.089)	(0.085)	(0.079)	(0.068)	(0.063)
N panel	660	660	660	660	416
Num. obs.	1320	1320	1320	1320	832
N Clusters	59	59	59	59	58

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regression for livelihood outcomes. The livelihood family outcome is a summary index (average of z-scores) of an income index, an assets index, a durable loan size measure, and a measure for resilience. The income index is a summary index (average of z-scores) of total household income, monthly consumption expenditure and yearly durable expenditure. Assets is the sum of all assets owned. Durable loan size is the amount borrowed for durable investments. Resilience is a conditional dummy (on whether the household suffered from an emergency) of whether households were able to deal with an emergency. All independent variables are standardised and centred on the control group at baseline. Robust standard errors in parentheses are clustered at the village level.

Table A.3.6: The impact of REDD+ on conservation norms indicators (survey data)

	Attitudes family	Attitudes	Knowledge	Sustainable farming	HWC
Post*REDD+	−0.017	−0.300	0.287	0.113	−0.040
	(0.218)	(0.206)	(0.250)	(0.157)	(0.135)
Post	−0.226	-0.822^{***}	0.210	−0.012	0.124^{*}
	(0.138)	(0.113)	(0.170)	(0.119)	(0.067)
REDD+	0.176	0.132	0.427^{***}	0.102	-0.204^{**}
	(0.130)	(0.132)	(0.154)	(0.112)	(0.096)
Constant	−0.000	−0.000	−0.000	0.000	0.000
	(0.076)	(0.091)	(0.087)	(0.090)	(0.074)
N panel	660	597	518	647	635
Num. obs.	1320	1194	1036	1294	1270
N Clusters	59	59	59	59	59

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regression for conservation norms outcomes. The attitudes family outcome is a summary index (average of z-scores) of an attitudes index, an awareness of conservation norms index, the number of sustainable farming practices used, and an index for human-wildlife conflict perception (HWC). Attitudes is an index of agreement with pro-conservation statements. Awareness of conservation norms is an index of knowledge on rules regarding conservation. Sustainable farming practices measures the number of practices used by a household. HWC measures how big of a problem crop-raiding is. All independent variables are standardised and centred on the control group at baseline. Robust standard errors in parentheses are clustered at the village level.

Table A.3.7: The impact of REDD+ on plausible mechanisms (unstandardised)

	Labour access index	Income farm wages	Income NTFP	Cocoa harvest
Post*REDD+	-0.534^{**}	0.435^{*}	0.567^{**}	0.406
	(0.252)	(0.233)	(0.252)	(0.269)
Post	0.358^{**}	0.082	0.034	-1.067^{***}
	(0.157)	(0.181)	(0.175)	(0.213)
REDD+	0.118	−0.031	−0.251	−0.254
	(0.130)	(0.211)	(0.166)	(0.262)
Constant	1.181^{***}	1.307^{***}	0.636^{***}	1.090^{***}
	(0.089)	(0.139)	(0.144)	(0.212)
Years	2	2	2	2
Villages	59	59	59	59
Num. obs.	1150	1228	1320	1320

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for mechanisms. Labour access index is an index of three farm labour access variables (upland rice, wetland rice, and plantation) indicating to what extent there is access to labour. Income farm wages is a continuous variable (IHS transformed) measuring the yearly household income from farm wages. Income NTFP is a continuous variable (IHS transformed) measuring the yearly income from Non-Timber Forest Products collection. Robust standard errors in parentheses are clustered at the village level.

Table A.3.8: The impact of REDD+ on primary outcomes (unstandardised)

	Durable loan	Attitudes	Knowledge	Sustainable farming	HWC
Post*REDD+	0.272	−0.829	0.086	0.103	−0.041
	(0.165)	(0.570)	(0.075)	(0.143)	(0.137)
Post	−0.045	-2.276^{***}	0.063	−0.011	0.125^{*}
	(0.122)	(0.313)	(0.051)	(0.108)	(0.068)
REDD+	−0.191	0.364	0.128^{***}	0.093	-0.206^{**}
	(0.120)	(0.367)	(0.046)	(0.102)	(0.098)
Constant	0.302^{***}	17.003^{***}	3.081^{***}	0.380^{***}	-2.382^{***}
	(0.105)	(0.252)	(0.026)	(0.082)	(0.074)
N panel	660	597	518	647	635
Num. obs.	1320	1194	1036	1294	1270
N Clusters	59	59	59	59	59

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regression for all primary (non-index) outcomes. Durable loan size is the amount borrowed for durable investments. Conservation attitudes is an index of agreement with pro-conservation statements. Awareness of conservation norms is an index of knowledge on rules regarding conservation. Sustainable farming practices measures the number of practices used by a household. HWC measures how big of a problem crop-raiding is. Robust standard errors in parentheses are clustered at the village level.

Table A.3.9: The impact of REDD+ on secondary outcomes

	Farm Income	Cocoa Income	Off Farm Inc	Upland Size	Wetland Size	Plantation Size	Health
Post*REDD+	0.220	0.078	0.099	0.014	−0.118	−0.006	−0.055
	(0.168)	(0.152)	(0.176)	(0.267)	(0.234)	(0.172)	(0.131)
Post	0.326***	0.278*	−0.115	0.178	0.333**	−0.064	−0.630***
	(0.109)	(0.135)	(0.148)	(0.169)	(0.156)	(0.152)	(0.074)
REDD+	−0.276**	−0.233*	−0.126	0.176	0.036	−0.017	−0.060
	(0.135)	(0.127)	(0.127)	(0.123)	(0.121)	(0.096)	(0.117)
Constant	0.000	0.000	−0.000	−0.000	0.000	−0.000	0.000
	(0.092)	(0.093)	(0.108)	(0.069)	(0.100)	(0.077)	(0.068)
N panel	660	660	660	607	600	616	660
Num. obs.	1320	1320	1320	1214	1200	1232	1320
N Clusters	59	59	59	59	59	59	59

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regression for secondary outcomes. Farm income is the total income from crop sales. Cocoa income is the total income from cocoa sales. Cocoa harvests is the total cocoa production. Off farm income is the total income from off farm activities. Upland farm size is the total size of the upland (rice) farm. Wetland size is the total size of the wetland (rice) farm. Plantation size is the total size of the plantation area. Health is the number of household members with malaria and/or blood in stool and/or diarrhoea in the previous month. All independent variables are standardised and centred on the control group at baseline. Robust standard errors in parentheses are clustered at the village level.

Table A.3.10: The impact of REDD+ on secondary outcomes (unstandardised)

	Farm Income	Cocoa Income	Off Farm Inc	Upland Size	Wetland Size	Plantation Size	Health
Post*REDD+	0.737	0.226	0.248	0.014	−0.100	−0.007	−0.267
	(0.562)	(0.441)	(0.443)	(0.261)	(0.198)	(0.193)	(0.640)
Post	1.092***	0.803*	−0.289	0.174	0.281**	−0.072	−3.074***
	(0.364)	(0.392)	(0.373)	(0.166)	(0.131)	(0.170)	(0.363)
REDD+	−0.925**	−0.674*	−0.318	0.173	0.031	−0.019	−0.294
	(0.453)	(0.369)	(0.319)	(0.120)	(0.102)	(0.108)	(0.570)
Constant	3.734***	1.691***	5.847***	1.612***	0.842***	2.028***	6.220***
	(0.307)	(0.269)	(0.271)	(0.068)	(0.084)	(0.087)	(0.334)
N panel	660	660	660	607	600	616	660
Num. obs.	1320	1320	1320	1214	1200	1232	1320
N Clusters	59	59	59	59	59	59	59

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regression for secondary outcomes. Farm income is the total income from crop sales. Cocoa income is the total income from cocoa sales. Cocoa harvests is the total cocoa production. Off farm income is the total income from off farm activities. Upland farm size is the total size of the upland (rice) farm. Wetland size is the total size of the wetland (rice) farm. Plantation size is the total size of the plantation area. All these outcomes are transformed using the inverse hyperbolic sine transformation. Health is the number of household members with malaria and/or blood in stool and/or diarrhoea in the previous month. Robust standard errors in parentheses are clustered at the village level.

Table A.3.11: Parallel trends 2010-2014 for available outcomes

	Livelihoods family	Income	Assets	Durable loan	Sustainable farming	Labour access	Income farm wages	Income NTFP
Post*REDD+	0.216	0.230	0.146	0.088	-0.157	0.219	0.088	0.221
	(0.152)	(0.284)	(0.126)	(0.096)	(0.158)	(0.189)	(0.124)	(0.145)
Post	0.291^{**}	0.333	0.663^{***}	-0.229^{***}	0.120	-0.208	-0.397^{***}	-0.470^{***}
	(0.117)	(0.209)	(0.066)	(0.080)	(0.122)	(0.148)	(0.101)	(0.097)
REDD+	-0.370^{***}	-0.298^{**}	-0.350^{***}	-0.128	0.307^{**}	-0.125	0.013	-0.268^{**}
	(0.109)	(0.122)	(0.121)	(0.084)	(0.120)	(0.108)	(0.112)	(0.123)
Constant	0.000	0.000	0.000	-0.000	0.000	0.000	-0.000	-0.000
	(0.076)	(0.089)	(0.087)	(0.055)	(0.081)	(0.088)	(0.089)	(0.082)
Years	2	2	2	2	2	2	2	2
Num. obs.	1312	1312	1312	1312	1225	1262	1310	1312
N Clusters	56	56	56	56	56	56	56	56

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions to test for parallel trends between 2010 and 2014. The livelihood family outcome is a summary index (average of z-scores) of an income index, an assets index, a durable loan size measure. The income index is a summary index (average of z-scores) of total household income, monthly consumption expenditure and yearly durable expenditure. Assets is the sum of all assets owned. Durable loan size is the amount borrowed for durable investments. Sustainable farming practices measures the number of practices used by a household. Labour access index is an index of three farm labour access variables (upland rice, wetland rice, and plantation) indicating to what extent there is access to labour. Income farm wages is a continuous variable (IHS transformed) measuring the yearly household income from farm wages. Income NTFP is a continuous variable (IHS transformed) measuring the yearly income from Non-Timber Forest Products collection. All independent variables are standardised and centred on the control group at baseline. Robust standard errors in parentheses are clustered at the village level.

3.7.5 Robustness

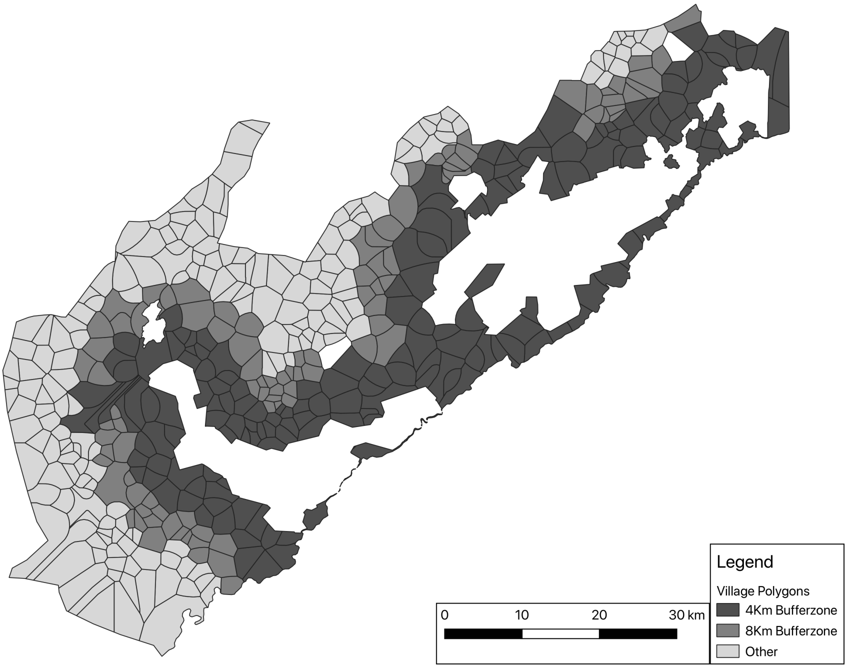

Figure A.3.5: 4km and 8km buffer zone for robustness analysis.

This figure shows the village polygons used for robustness check for the results on forest loss. It shows the eligible REDD+ villages in the 4km buffer zone. The surrounding band shows the 8km buffer zone that we use for the placebo tests. There are a couple of polygons excluded because they are part of another protected area (Tiwai island) or leased land by companies.

Table A.3.12: Robustness check forest loss: 8km buffer zone

	Original	Placebo 1	Placebo 2	Placebo 3
Post*REDD+	-1.032^{***}	-0.971^{***}		
	(0.114)	(0.147)		
Post*8km			-0.622^{***}	-0.090
			(0.109)	(0.140)
Post	3.314^{***}	3.253^{***}	3.343^{***}	3.343^{***}
	(0.066)	(0.114)	(0.080)	(0.080)
REDD+	-0.052	-0.123^{***}		
	(0.033)	(0.043)		
8km			0.036	0.104^{***}
			(0.029)	(0.039)
Constant	0.740^{***}	0.810^{***}	0.707^{***}	0.707^{***}
	(0.017)	(0.033)	(0.020)	(0.020)
Num. obs.	8172	4140	8172	5904

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for forest loss (satellite data). Forest loss is the percentage of loss of forest (primary and secondary). Robust standard errors in parenthesis. The Original column shows original regression with full sample. The first placebo test (column 2) shows sample restricted to polygons that lie within 8km of the forest. The second placebo test (column 3) shows the full sample where the treatment is defined as a village in the 8km buffer zone. The third placebo test (column 4) shows the same but excluding actual treated villages.

Table A.3.13: Robustness check forest loss: 2013-2018

	Forest loss 2001-2018	Forest loss 2013-2018
Post*REDD+	-1.032^{***}	-0.957^{***}
	(0.114)	(0.248)
Post	3.314^{***}	1.077^{***}
	(0.066)	(0.118)
REDD+	-0.052	-0.127
	(0.033)	(0.223)
Constant	0.740^{***}	2.977^{***}
	(0.017)	(0.099)
Num. obs.	8172	2724

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for forest loss (satellite data). Forest loss is the percentage of loss of forest (primary and secondary). Robust standard errors in parenthesis. The first column shows the original regression with forest loss data from 2001-2018 using both Landsat 7 and Landsat 8 imagery. The second column shows the same model with data from 2013-2018, all from Landsat 8 imagery.

Table A.3.14: Robustness check forest loss: weighted polygons

	Forest loss	**Primary forest loss**	**Secondary forest loss**
Post*REDD+	-0.972^{***}	0.073	-0.333
	(0.141)	(0.050)	(0.266)
Post	3.294^{***}	0.052^{**}	0.425^{***}
	(0.093)	(0.023)	(0.157)
REDD+	0.000	0.187^{***}	-0.390
	(0.040)	(0.041)	(0.240)
Constant	0.707^{***}	0.098^{***}	2.573^{***}
	(0.025)	(0.018)	(0.138)
Years	18	6	6
Village polygons	231	226	226
Num. obs.	4158	1356	1356

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
Difference-in-difference analysis using OLS regressions for forest loss (satellite data). Forest loss is the percentage of loss of forest (primary and secondary). Primary forest loss is loss of old growth forest and secondary forest loss measures conversion of fallow to production agriculture. Both are classified through extensive ground measurements, which were done in 2013. The number of observations is therefore lower for these two outcomes, as data ranges from 2013-2018. Robust standard errors in parenthesis. Sample is restricted to polygons that are weighted to village-estimated village size. Robust standard errors in parentheses.

3.7.6 Cost-to-carbon analysis

A simple cost-to-carbon analysis was conducted using three sources of data 1) estimated carbon stock per hectare of forest in the region from WCMS biomass maps, 2) estimated annual averted forest loss (this analysis), and 3) estimated annual costs of REDD+ community project from project documents in GBP (converted to USD using the 2014-2019 average exchange rate). The cost of an avoided tCO2 emissions in USD was calculated by dividing the total annual costs of the project by the total averted tCO2 emissions. See table G1 for the analysis.

Table A.3.15: Cost to carbon analysis

Item	Calculation	Value
CO2 emissions averted		
CO2 stocks per hectare	tCO2/ha	369.30
Annual hectares of averted forest loss	ha averted/year	928.66
Annual avoided CO2 emisssions	tCO2/ha*ha averted/year	342954.14
Costs		
Annual cost REDD+ in GBP		268965.00
Annual cost REDD+ in USD	Exchange rate, average 2014-2019: 1.43 USD/GBP	384620.00
Annual cost of avoided tCO2 Emissions in USD	Annual cost of REDD+/annual averted CO2 emmisions	1.12

CO2 stock data comes from WCMC biomass maps. Averted forest loss is from own calculations. REDD+ costs are community costs from REDD+ project documents.

Chapter 4

Land investments and chief political power: Evidence from a census in Sierra Leone

In the Global South, large-scale land investments have surged in the last two decades. Within academia, local impacts are still heavily debated, as is the question whether firms are attracted to weak or strong institutions. A lack of transparency and high-quality data often limits quantitative research. We contribute to this research gap by describing a unique census of land investments in Sierra Leone. Through working with national and local governments, firms, and host communities, the census yielded the location and characteristics of up to 232 land investments, far more than documented in other databases. We find large differences in how agricultural and mining investors operate. The latter require less land, are less likely to negotiate a lease agreement with host communities, and are less transparent about payments to communities. Disagreements between communities and investors occur more often in mining than in agricultural deals. We analyse whether institutions can explain within-country variation in the occurrence of investments. We find that mining deals are more likely to occur in chiefdoms where chiefs have more political power, suggesting that mining investors are attracted to more autocratic environments. We hypothesise that the extractive and small-scale nature of mining investments make it attractive for firms to move into chiefdoms where chiefs have more power.

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4.1 Introduction

The Global South has seen a large surge in large-scale land investments in the past two decades, driven by the food price spikes of 2007/2008. As of 2022, an estimated 2800 land deals have been concluded globally with a cumulative deal size of 133 million hectares of land. Deals in Africa comprise about a quarter of this, with a cumulative deal size of about 30 million hectares of land (The Land Matrix, 2022).

Large-scale land investments, and foreign direct investment in general, have a potential for economic development as they may raise agricultural productivity, stimulate (knowledge) spillovers and ultimately alleviate poverty (Lay and Nolte, 2018). However, civil society advocates are sceptical and the term 'land-grab' is used widely in discussions on land investments. In particular, some fear conflict with local communities, displacement, increased inequality, and the potential for elite capture. Especially for mining investments, there is ample discussion on whether natural resource dependence may stimulate corruption (Knutsen et al., 2017). Yet besides several case studies on specific investments, there is little detailed quantitative evidence of how investors operate and interact with local communities.[1]

The increase in large-scale land investments has sparked an academic debate on the type of institutions that attract investors. On the one hand, democratic countries with private property protection may attract investors because risk and transaction costs are reduced. On the other hand, investors in autocratic countries or countries with customary property rights face fewer stringent regulations and can potentially access land and other resources more easily, and for a lower price (Christensen et al., 2021; Li et al., 2018; Pandya, 2016). There is considerable qualitative evidence of the role of local institutions in land investments in Sub-Saharan Africa (e.g. Schoneveld 2017). In Sierra Leone, the context of this study, paramount chiefs have been shown to play a large role in negotiating lease agreements, mediating conflict between foreign companies and communities, and in some cases exerting considerable pressure on communities (Ryan, 2018b; Millar, 2017; Bottazzi et al.,

[1] A notable exception is Anti (2021) who studies, amongst other outcomes, the employment effects of large-scale land acquisitions in Cambodia.

2016).

Quantitative evidence of the relationship between institutional quality and land investments remains mixed and suffers from methodological issues. In particular, accessing reliable data on land investments is challenging as host countries often lack the institutional capacity to keep updated records. Hence, researchers usually rely on other sources like the often-used Land Matrix database. Datasets like these build mostly on media reports and thus may be biased towards larger deals. A second issue is the difficulty of measuring institutional quality. Most notably, institutions are endogenous to economic development, that is, they determine economic development but are also shaped by economic development, or they are simultaneously determined by a third factor. To deal with this, economists often measure institutional quality or specific dimensions of institutions with the help of an exogenous instrument. But such instruments are scarce. Another issue with measuring institutional quality is that existing measures are usually at the country level. Because of this, studies that do look at the relationship between institutional quality and land investments are almost exclusively cross-country studies. As such, there is little evidence explaining within-country variation in land investments.[2]

Our paper contributes to the literature in two ways. First, we present and describe a unique census of land investments in Sierra Leone. This census was conducted in 2017 and aimed to create a complete overview of all concluded agricultural and mining deals at that moment. Through working intensively with the National Government, local governments, firms, and host communities, the survey yielded the location and characteristics of up to 232 land investments, which is far more than the 37 deals documented by the Land Matrix.[3] We also present data on the interaction between firms and communities, namely on employment, disagreements, and firm investment in community development projects. To reduce reporting bias, data was collected from the perspective of the firm as well as the perspective of the host communities. This provides a unique view of how investors and

[2] An important exception is Christensen et al. (2021) who exploit the dual-tenure system of Liberia to test whether investors are attracted to the customary or the private property system.

[3] The Land Matrix (2022) documents 37 domestic and transnational deals until 2017, data accessed on 01-22-2022

communities perceive investor activities and their interaction with communities. Furthermore, where most existing studies focus on either agricultural or mining investments, our data also allows us to distinguish between agricultural and mining investments.

Our second contribution lies in our analysis of whether institutions can explain within-country variation in the occurrence and success of land investments. In Sierra Leone, where the vast majority of the country is governed by customary law, paramount chiefs play an important role in land management. For investors, obtaining land may be easier and cheaper in a chiefdom with a strong political chief, but this may come at a cost of lower tenure security. Using a plausibly exogenous proxy for chief political power constructed by Acemoglu, Reed, and Robins (2014), we test whether the occurrence and success of agricultural and mining investments are dependent on the political power of the chief. Our analysis contributes to understanding the institutional dimension of investments at a meso level, as opposed to the country level, where most studies focus on.

Our descriptive analysis shows some key differences between mining and agricultural investments in terms of size (mining deals require less land), investor background (mining investors are more likely to be foreign), and how rents are distributed (payments are less transparent for mining deals). We find that disagreements with host communities are common, and more so for mining deals. Furthermore, mining investors seem to hire fewer employees from host communities. We do not see large differences in community development investment between agricultural and mining deals but find that many promised projects are not delivered. Our institutional analysis consistently shows that mining deals are more likely to occur in chiefdoms where chiefs have more political power, suggesting that mining investors are attracted to a more autocratic environment. For agricultural deals, the political power of the chief is not related to the location of land investments. Interestingly, other potential determinants, like road infrastructure, agricultural suitability, rainfall and other geographic controls do not explain the within-country variation of land investments.

With our study, we show that a detailed census of land investments yields far more extensive data than the commonly used dataset. We also show that collecting data from host communities is a valuable exercise that contributes to much-needed transparency surrounding land deals. Furthermore, we present a nuance to the debate on institutions and land investments, showing that they may matter more for mining than for agricultural deals when considering within-country variation. We hypothesise that this might be explained by the small-scale nature of mining deals, making it easier to conceal mining revenue than for agricultural revenue.

In what follows, we describe some of the existing literature on large-scale land investments. We then discuss land and land policy in Sierra Leone, with a specific focus on the role of paramount chiefs. We then turn to the methodology section, where we describe how the census was conducted, how chief political power is measured, and how we conduct our analysis. The results section consists of two parts. First, we describe the census data, uncovering differences in characteristics of agricultural and mining deals and showing the perspective from both the firm and the community. Second, we present our analysis of the link between land investments and chief political power. We conclude with a discussion on potential explanations for our results and close by discussing the implications of our findings.

4.2 Institutions and land investments

Several studies examine the relationship between host country institutional quality and foreign investments. Theoretically speaking, how institutional quality affects the likelihood of investing is not immediately clear. If land rights are formally defined and private ownership is possible, it is easy for an investor to acquire land: they simply need to find the owners and offer them a high enough price. Ownership is then transferred to the investor, whose ownership is protected by formal law. By this logic, formal property rights should attract more investment. On the other hand, if ownership is based on customary land rights (often managed by a local leader like a chief), then the local leader also has the power to offer land to investors. These chiefs can offer a lower land price than is optimal for their constituents, sometimes in return for rents from investors. Transaction costs might be higher in this situation, as investors need to navigate an institutional environment that is not well-defined, at least to them. Similarly, tenure security might be lower if customary landowners disagree with the actions of the chief and pursue (legal) action. Empirical studies can assess which effect dominates (Christensen et al., 2021).

Many papers try to get at this effect using macro-level data. Arezki et al. (2015) are one of the first to do so. They use worldwide data on land deals from three separate datasets, one of those being the Land Matrix dataset. They use a Poisson dyadic regression, examining all country-pairs, which allows them to examine both push- (what types of countries invest) and pull- (what type of countries are invested in) factors. They find that investor countries are more likely to invest in countries closer to them by physical distance, as well as those they had a former colonial relation with. Destination countries are characterised by higher populations, higher values of net food imports and more potential productive land available. Looking at land governance, there is a clear negative relationship: countries with weaker land governance are more attractive to investors, which is highly significant throughout all their specifications and datasets.

Arezki et al. (2018) use a similar empirical approach, but first develop a theoretical model to examine investor motivation. They identify two main motivations: Platform FDI, wherein investors try to produce cheaply and then sell their product on the global market, or Food Independence, where the primary reason for production is re-import to the investor country. They use only data from the Land Matrix. They again find that countries with more land and a larger population attract more investments. They find no effect of land governance and argue that this might be because increased civil society monitoring in recent years has made predatory land investments less feasible. They find evidence for the Food Independence motivation for investments, indicated by investors preferring to invest in more remote countries, where competition for land is lower.

Lay and Nolte (2018) also employ a Poisson dyadic regression using Land Matrix data. They find a similar effect for distance, former colonial relations, and land availability. They also do not find an effect of land governance on the likelihood of investment. They dig deeper to recreate the governance effect found by Arezki et al. (2015). If they look at investments that are already in production or are below 10,000 hectares they can recreate the result: stronger governance reduces the likelihood of investment.

These papers suffer from a common set of difficulties: measures of institutional quality or governance at the country level suffer from measurement issues and cannot be readily compared across different countries. Furthermore, datasets such as the Land Matrix rely on media reports, so large deals might be over-represented. One exception to this approach is the paper by Christensen et al. (2021), who use a natural experiment in Liberia to examine how tenure security affects the number of investments. They exploit that Liberia has a dual tenure system: the region lying within 40 miles from the coast has a private property system while the rest of the country has a customary land tenure system. To examine concession activity they look at forest loss based on satellite imagery which, they argue, correlates with the types of large-scale land conversions of investors. They find higher clearing rates on the private property side of the 40-mile border, implying that more secure property rights are preferred by investors. A case study of one investment on the customary land tenure side finds that land prices were indeed lower there, but as soon as activities and displacement started, investor activities had to be halted because of push-back by local community members and advocacy organisations.

While the previous papers have all examined agricultural investments, some papers examine mining investments. Knutsen et al. (2017) use micro-level data from the Afrobarometer and spatial data on 496 mines to examine the opposite effect: how the opening of a mine affects local corruption. They point out that mining is unique in that firms can effectively conceal their revenue. They examine three groups: those close to a mine that has not yet opened, those living close to a mine that has opened, and those living further away. They use a difference-in-difference estimator to calculate this effect. They find that after a mine opens respondents are more likely to pay bribes to the police and to perceive more corruption. They show evidence that this is not caused by general economic growth, but is specifically associated with growth caused by a mine.

Blair et al. (2022) examine mining activity and conflicts. They compare firms that are at a conflict site (where production is likely disrupted by fighting), close to a conflict site (where production is not disrupted but state capacity is lowered) and within the country that has a conflict. Using a difference-in-difference approach they find that firms reduce investment at conflict sites, while they increase investment in buffer zones. They argue that lower government capacity reduces oversight, allowing firms to pay lower taxes, as firms can effectively conceal their revenues. Firms might also engage in other illegal behaviour (e.g. start production while still on an exploration permit, or expand the mine's geographic area).

Overall, these papers show that there is a tight link between state strength and foreign investments. This may be especially relevant for mining investments as firms can effectively hide their revenue to reduce taxation. We add to this literature by examining how chief political power affects investments. Furthermore, we compare both agricultural and mining investments. Agricultural investments have seen a large boom in the previous decade and might be subject to different constraints compared to mining investments.

4.3 Land investment policy in Sierra Leone

Sierra Leone is a primarily agricultural economy with 54% of the population employed in agriculture and 58% of its GDP stemming from agricultural production (World Bank, 2022). Since the end of the civil war in 2002, the country has known a relatively peaceful and politically stable period. This political stability, an active government policy to promote land investments, and the suitability of the country for agriculture and mining have contributed to a favourable investor climate.

The establishment of the Sierra Leone Investment and Export Promotion Agency (SLIEPA) following the election of President Ernest Bai Koroma in 2007, marks the beginning of an era in which the Sierra Leonean government expresses a proactive stance towards foreign investment. Under the Koroma presidency, agricultural productivity was an area of main concern and the government actively sought out foreign investors to promote the commercialisation of agriculture. SLIEPA, charged with the task of informing and supporting foreign investors, emphasises factors such as cheap labour, the vast availability of arable land and mineral deposits, and tax incentives to attract foreign investors.[4] The government also offers support to foreign investors by mediating lease agreements between foreign

[4]For examples see the SLIEPA website: *https://sliepa.gov.sl/investment/agriculture/* and *https://sliepa.gov.sl/investment/mineral-resources/*. Also see Sierra Leone Investor's Guide (2019): *https://sliepa.gov.sl/wp-content/uploads/3380O_Sierra-Leone-Investment-Guide_d8_print.pdf*. All accessed on 22-01-2022.

actors and the paramount chief and local landowners (Ochiai, 2017). Under the current presidency of Julius Maada Bio, Sierra Leone maintains an active policy to promote foreign investment. Following these active policies and the spikes in global food prices in 2008, Sierra Leone, like many African countries, has seen a surge in land investments. From 2002 to 2018, the value of exports in Sierra Leone increased fivefold (World Integrated Trade Solution, 2022). Agricultural exports, the second largest share of exports of Sierra Leone, were 191 million USD in 2019. Mining accounts for the largest share of exports with a value of 299 million USD in 2019 (World Trade Organization, 2022).

Whether the increases in exports have contributed to Sierra Leone and its constituents is not evident. Government revenue raised from the mining sector is low. In 2010, the mining industry accounted for 60% of exports but only 8% of government revenue came from the mining sector. Mining companies were found to negotiate advantageous tax and royalty agreements with the government (DAN Watch, 2011). Furthermore, there have been many calls for improvement of regulations after reports of conflict between firms and local communities for agricultural as well as mining investments (Wilson, 2019; Conteh and Yeshanew, 2016; The Oakland Institute, 2011).

4.3.1 Land tenure in Sierra Leone

Sierra Leone is divided into the Western Area, where the capital of Freetown is situated, and four provinces, also known as the Provinces. The Provinces consist of twelve districts and are further subdivided into 149 chiefdoms. These chiefdoms are in turn divided into sections, and each section contains towns and communities. Chiefdoms, which are the most important unit in the administrative structure of the Provinces, are governed by the Chiefdom Council and headed by the paramount chief (Renner-Thomas, 2010).

Sierra Leone's land tenure system is characterised by a dual system. In the Western Area an English-style land system is in place, originating from the original British colony. Land ownership is under freehold administration, implying that land can be bought and sold. The rest (and the vast majority) of Sierra Leone's land, known as the Provinces, originate from the Sierra Leone Protectorate, founded in 1896 by the British colonial authorities. Land in the Provinces is governed mostly by customary law and follows the Provinces Land Act of 1961, which is in turn based on the Protectorate Ordinance of 1927. According to these laws, land is the property of indigenous land-owning families, known as natives, and land is inherited from one generation to another. Land cannot be bought or sold to non-natives (called strangers) or foreigners and can only be leased for a maximum of 50 years. Furthermore, the Provinces Land Act 1961 states that 'all land in the Provinces is vested in the Tribal Authorities who hold such land for and on behalf of the native communities'.[5] Ultimate ownership of the land is thus placed in the hands of the Chiefdom Council (formerly known as the Tribal Authorities), led by the paramount chief. In practice, the land is not actually owned by the Chiefdom Council, however, paramount chiefs, who are considered to be the 'custodians of the land', do *de facto* have a significant amount of power over the land (Ochiai, 2017; Conteh and Yeshanew, 2016; The Oakland Institute, 2011; Renner-Thomas, 2010; Unruh, 2008).

There is no binding regulatory framework for land investments in Sierra Leone. 2009 Guidelines by the Ministry of Agriculture, Forestry and Food Security stipulate that in the case of a land lease, the national government should be consulted first. There are however many cases known where the national government is bypassed and an agreement is reached with the paramount chief.[6] Other guidelines concern an environmental assessment and a minimum lease price of 12 USD per hectare, of which the latter has also been shown not to hold for all investments (The Oakland Institute, 2011). The Provinces Land Act of 1961 does stipulate that if a third party leases land in the Provinces, a surface rent is to be paid to the Chiefdom Council, however, there is no legal requirement for direct payments to landowners. In practice, rents are often distributed by the Chiefdom Council amongst the District Council (20%), the paramount chief (20%), the National Government (10%), and the landowners (50%).

In recent years, widespread calls for land reforms have caused the national gov-

[5] See Provinces Land Act 1961, *http://www.sierra-leone.org/Laws/1961-37.pdf*, accessed on 18-01-2022

[6] In a case study of five land investments by Ryan (2018a), all five investors first contacted the Paramount Chief. In the data collection efforts of this paper, more than 15% of initially listed land investments were unknown to the national government.

ernment to devise a new land policy (The Oakland Institute, 2011). The 2015 National Land Policy aims to improve tenure security for marginalised people and introduce better regulation for large-scale land investments (Government of Sierra Leone, 2015). At the time of the data collection for this study, this policy had not been rectified. The new policy has also not significantly changed the role of the paramount chief in managing its chiefdom's lands.

4.3.2 Paramount chiefs: the custodians of the land

Paramount chiefs are the political heads of the chiefdom and in this capacity have absolute jurisdiction over the entire chiefdom. Besides political authority, the paramount chief possesses several legislative and judicial powers. Its legislative powers come into practice through the Chiefdom Council by the creation of bylaws and issuing orders that affect the chiefdom. The paramount chief's judicial authority comes into play in processes of informal customary arbitration (upon request of both parties involved). As many disputes do not end up in court, this informal judicial role nonetheless grants paramount chiefs significant power (Renner-Thomas, 2010).

Paramount chiefs in Sierra Leone play a large role in the management of land, the settlement of land disputes and the distribution and leasing of land. The rights and interests in land of the paramount chief are all derived from customary law. One of the main ways in which the paramount chief's power manifests itself is that all land transactions within a chiefdom require the approval of the paramount chief. Furthermore, any land-related document, for example for the purpose of national registration of land titles, is considered invalid without formal recognition of the chieftaincy (Ochiai, 2017).

The paramount chief's power over its chiefdom's land extends beyond the provision of approval of land transactions and land registration. Paramount chiefs have influence over land management and exploitation within their chiefdom, for instance in the case of business development (Ochiai, 2017). As Acemoglu et al. (2014) describe: 'In chiefdoms with mining activity, chiefs are also eligible for direct payments of 'surface rent' from miners'. Furthermore, Conteh and Yeshanew (2016) describe that the majority of Sierra Leoneans consider chiefs as the major customary tenure dispute resolution system. In addition, paramount chiefs oversee the civil courts who are responsible for the adjudication of land. Maru (2006) documents instances where the paramount chief exerts power on the civil courts to favour family members in disputes over the payment of rent for agricultural land.

There are several qualitative studies on land investments in Sierra Leone documenting the far-reaching role of the paramount chief in negotiations and mediation between investors and communities. Bottazzi et al. (2016) argue that the legal ambiguity about foreign land leases within the customary land system of Sierra Leone, enables excessive concentration of power in the hands of the paramount chief. Similarly, Ryan (2018a) documents how the Sierra Leonean government and investing companies are capitalising upon the role of patronage in relations between the paramount chief and communities in the lease negotiation and through rent distribution (which often takes place through the chief), further asserting the already powerful position of the chief. Ryan describes a specific situation where a landowner stated that the landowners consented to the lease of their land to a foreign company only because the Paramount Chief had asked them to. Through a case study of a sugarcane plantation, Millar (2017) describes how paramount chiefs are deployed by foreign companies as central mediators in conflicts between communities and the companies. He argues that the paramount chief, who is the most highly respected figure within communities, becomes a biased mediator, ensuring a compliant population for the company. This is backed up by a report of a meeting between a paramount chief and a host community, in which the paramount chief explicitly warns community members that any disruption of the company's operations will be met with police action and arrests of community members (Millar, 2017).

4.4 Methods

This section describes the data and methodology used for this study. The data used are a collected census of land investments in Sierra Leone, institutional data from Acemoglu et al. (2014), and a range of geographical and institutional controls from various sources. We conclude with a section on the methods used for the analysis of this data.

4.4.1 Data on land investment

The main source of data for this study is a nationwide census conducted in 2017, tracking agricultural and mining investments in Sierra Leone. In collaboration with the Sierra Leonean government, a list of administrative data on all commercial agricultural and mining projects that were active in the country was compiled.

As the administrative data was not always updated and accurate, the data was cross-validated with local district and chiefdom officials. District officials were asked to validate the list of agricultural and mining businesses within their respective constituency and to include any unlisted projects. Following this, paramount chiefs or other chiefdom representatives were asked to validate and add to the list. The latter step was especially crucial to obtain a complete overview of land investments in Sierra Leone, because, as discussed, paramount chiefs typically play an important role in negotiating lease agreements with agricultural and mining firms, sometimes without contacting the central government.

Enumerators then visited all projects and conducted a survey with firm representatives (ideally with the site manager or community liaison officer). In this survey, basic information such as the size of the operation, start date, lease agreements, and precise location were obtained. Enumerators also visited the community in which the firm operates. If a firm operated in multiple communities, all communities were visited. In the community, the person identified as the most knowledgeable about the firm and its operations was interviewed about community-firm interaction. This interview was supervised by other community members, to ensure the quality of the answers given. Finally, phone surveys were conducted with the firm representatives to gain more detailed information on the operations of the firm, including information on the interaction with communities.

In total, the first listing exercises with the national government yielded 387 projects. Local consultations added another 75 projects to this list bringing the total to 462. More than half of these (218) could not be located and were dropped from the analysis. 13 projects were dropped because they are in the Western Area, where property rights differ from the rest of the country and chiefdoms do not exist. Of the remaining 232 projects, 106 projects had closed down and 2 projects had relocated at the time of the survey. For a couple of these (8 firms), former employees were interviewed, and as such, data is available for these closed projects. There are 124 projects that were active at the time of the survey. For our descriptive analysis we use a sample of at most 125 projects for which data was available, though, for some variables, data is missing. For our institutional regression analysis, we use all 232 deals that are located in the Provinces thereby excluding the 13 deals in the Western Area.[7] As for the communities, 275 communities associated with 247 projects were visited. On average, 1.11 communities per project were visited with a maximum of 13 communities.

4.4.2 Data on chief political power

We use data from the 2014 paper by Acemoglu, Reed, and Robinson, from here on referred to as 'ARR', on the political power of paramount chiefs in Sierra Leone. In their paper, the authors develop a plausibly exogenous proxy for chief political power and relate this to a range of development outcomes such as education, health and economic development. This proxy measures the number of ruling families in a chiefdom. Only members of a ruling family within a chiefdom can become the paramount chief in Sierra Leone. The more ruling families there are, the more likely that a paramount chief faces political competition and that its power is subject to constraints.

The number of ruling families in a chiefdom is thus used as a proxy for chief political power. In 1896, when the British colonial authorities instituted a system of local government in the novel Sierra Leone Protectorate, paramount chiefs were the only institution of local government. The chieftaincy system remains in place, though since 2004 a body of elected local councils was established alongside of it. The 2009 Chieftaincy Act describes that a paramount chief is elected for life by the Chiefdom Council (formerly Tribal Authorities), consisting of local notables. More importantly, only members of one of the ruling families within a chiefdom are eligible candidates for the paramount chieftaincy. Which families are considered

[7] As a robustness check, we run all descriptive analyses including Western Area land and find no substantial differences.

ruling families was determined mostly by the British colonial authorities and has not changed since it was fixed around 1920. Furthermore, there is consensus across chiefdoms on which families are considered ruling families. As such, ARR argue that the number of ruling families is unlikely to be causally related to any development outcomes today other than through the power of the chief. We extend this argument by arguing that it is unlikely that the number of ruling families directly affects the likelihood of a land deal being negotiated in a chiefdom today.

The number of ruling families is however expected to indirectly affect development outcomes. As the ARR paper demonstrates, paramount chiefs are likely to face more political competition when there are more ruling families in a chiefdom. It has been documented that surrounding the elections of a new chief, complex alliances are formed between families to secure votes from the Chiefdom Council. With a greater number of ruling families, a candidate for the chieftaincy will have to appease a greater variety of interests to be elected. When chiefs are constrained by greater competition, there will be fewer opportunities for rent-seeking or other exploitation of power.

We further hypothesise that chief political power is a likely determinant of whether a land deal is negotiated in a chiefdom. As explained in the previous section, paramount chiefs, by law, have ultimate ownership of the chiefdom's land. This has a far-reaching impact on the power of the chief in determining who has access to land, how land is managed, and whether and to whom land can be leased. In the ARR paper, the relationship between the power of chiefs and the security of property rights is an important mechanism of the relationships they find. In a nationally representative survey, ARR find that chiefs in chiefdoms with fewer ruling families have more authority to influence the usage and selling of land and that this relationship is stronger when people concerned were strangers or foreigners. We, therefore, argue that whether an investor is able to negotiate a land deal in a chiefdom, is dependent on the paramount chief and its power. In chiefdoms with fewer ruling families, the paramount chief has more authority over land, facilitating negotiations with land-owning families and other local stakeholders.

ARR collected their data on the number of ruling families in a survey with elders from all the ruling families and with local 'encyclopedias', elders who preserve the oral history of the chieftaincy. A potential concern for their analysis is that the number of ruling families is correlated with omitted variables that influence current development. They alleviate these concerns by studying the history of ruling families in six chieftaincies, showing that the origin of ruling families is often a result of historical accident. Furthermore, they show that the number of ruling families is not correlated with development prior to the creation of chieftaincies in the 1890s. Lastly, they show that their results are robust to the inclusion of geographic controls.

Because the extent of recall of the history of a chiefdom differed across chiefdoms, ARR include two variables to control for recall bias. The first is an amalgamation dummy, indicating whether a chiefdom originated from amalgamation in the late 1940s and 1950s (for these chiefdoms, lineages were not traced back for all component chiefdoms). The second is the number of paramount chiefs the historians could recall. Following ARR, we employ both these controls in all our models. The summary statistics of these variables can be found in the Appendix Table A.4.1.

4.4.3 Geographic control variables

In our model, we also control for a range of potential determinants of investments, following the literature on the drivers of investments: population size, road network length, distance to a port, distance to a river, elevation and ruggedness, night lights, forest cover and variability, average rainfall and variability, crop suitability, and the availability of a mining permit in 1930 (proxying mining suitability). See the Appendix for variable definitions and sources (Table A.4.1), and summary statistics (Table A.4.2) of these control variables.

4.4.4 Empirical strategy

Our analysis consists of two types of analyses: an exploratory descriptive analysis, in which we describe indicators from the land investment tracking census of Sierra Leone and an analysis exploring the relationship between chief political power and the occurrence of land investments.

For the descriptive analysis, we show a range of characteristics from the data collected in the land investment tracking census related to the size of the deal, lease agreements, payments of land rents, employment from local communities, disagreements between the firm and communities, and investment of the firm in community development. We segregate the data for agricultural and mining deals to uncover any diverging patterns. We use difference-in-means tests to see whether the characteristics of agricultural and mining deals are significantly different from each other. This exploratory analysis has value in itself, as such detailed datasets on land investments are rare, and additionally serves as input to explain some of the relationships we find in the further analysis.

For data on disagreements, employment and community development, i.e. firm-community interaction, we report on both the firm perspective as well as the community perspective. The analysis is thus either at the firm or community level for all firms and communities for which data was collected (i.e. mostly active firms at the time of the survey). For projects with multiple associated communities, we aggregate data at the firm level by computing the average for the communities. When comparing firm and community perspectives, we always do this pairwise, i.e. dropping any community observation that has no firm observation and vice versa. This ensures that we have one community observation per firm for all variables explored.

In the second part of our analysis, we use a standard linear regression model (OLS) to analyse the relationship between chief political power and the occurrence of land investments. We run all regression models separately for agricultural and mining investments. The outcomes that we consider are a dummy indicating whether any deal took place in a chiefdom (extensive margin) and a variable indicating the number of investments in a chiefdom (intensive margin). We run the following regression model:

$$\mathbf{Y}_i = \beta_0 + \beta_1 Chief_i + \beta_2 ChiefControls_i + \beta_3 Controls_i + \beta_4 District + \varepsilon_i$$

Where $\mathbf{Y}_i$ refers to the outcome measuring whether any or how many investments took place in chiefdom i. $Chief_i$ is the chief political power measured by the number of ruling families (logged). $ChiefControls_i$ refers to the two controls used by ARR, namely an amalgamation dummy indicating whether the chiefdom was created by amalgamation and the number of paramount chiefs that historians could remember. $Controls_i$ refers to the set of chiefdom controls. *Districts* is a set of district-fixed effects that control for all time-invariant district-level characteristics.

We further analyse how chiefdom power is related to the success of an investment. We define success as whether a deal actually follows through and measure it by looking only at active deals (i.e. excluding projects that were closed down or never materialised). The outcome variable is either a dummy indicating whether a successful deal took place in a chiefdom (extensive margin) or the number of successful deals that took place in a chiefdom (intensive margin). Because we are interested in whether chief political power is related to the success of a deal, we exclude chiefdoms where no deal took place. This means that for the extensive margin analysis, chiefdoms with a successful deal get a value of 1, whereas, chiefdoms with no successful deal are assigned a value of 0. Chiefdoms without deals are excluded. For the intensive margin, a similar approach is used where the value assigned to the chiefdom is the number of successful deals. Furthermore, we follow the same estimation procedure as above.

4.5 Results

4.5.1 Land investments in Sierra Leone

The census conducted in 2017 in Sierra Leone yielded a list of 232 land investments that were located by the survey team of which 114 are agricultural investments and 118 are mining investments (see Table 4.1).[8] 27 of the agricultural sites had already closed down at the time of the survey. 79 of the mining sites were closed down at the time of the survey, a far larger proportion (67%) compared to agricultural sites (24%) (see Table 4.1). The land investments identified by the census were spread out over 83 chiefdoms in Sierra Leone. Figure 4.1 shows a map with the locations and status of all agricultural and mining deals for which we have the GPS-location.[9]

[8]This number excludes all 13 (agricultural) deals in the Western Area, as this area has no chiefdoms and has a private property rights system in place.

[9]For 24 sites, the GPS-coordinate was missing but other location data like chiefdom was available. These sites were included in the data analysis but are not shown on the map.

The total number of investments recorded is far larger than documented by the Land Matrix, which documents a total of 37 land investments until 2017. The Land Matrix report on relatively more agricultural deals (29 agricultural versus 8 mining) and on larger deals (average deal size in the Land Matrix is 15782 ha compared to 3995 ha in the census). Crucially, detailed location information was often missing, yielding a chiefdom-level analysis as conducted in Subsection 4.5.3 impossible with Land Matrix data. This in itself undersigns the value of conducting an in-country census.

Table 4.1: Land investment type and status

	Agriculture	Mining	Total
Active	87	37	124
Closed	27	79	106
Relocated	0	2	2
Total	114	118	232

This table shows the number of land investments that were loated in the 2017 land investment tracking survey.

Figure 4.2 shows the five main crops grown and minerals mined. For agricultural investments, the most common crop produced is rice (mentioned by 45 firms), followed by cassava (18 firms), oil palm (16 firms) cocoa (14 firms), and groundnuts (13 firms). Other crops mentioned often are cashew, coffee, and maize. Note that multiple answers could be given, therefore it is likely that many of the projects cultivate a cash crop like oil palm, cocoa or groundnuts as the main activity but grow food crops on the side. This is likely why rice and cassava are mentioned most often. For mining companies, the most commonly mined minerals are gold (21 firms), diamonds (16 firms), iron ore (10 firms), bauxite (9 firms), and zircon (2 firms).

Table 4.2 presents some additional characteristics of the agricultural and mining deals surveyed including difference-in-means tests to see whether and how much agricultural and mining deals differ from each other. Note that data is not always complete for all sites and thus sample sizes can vary for different variables. There are a couple of patterns distinguishable. First, almost all (92.1%) mining deals for which we have data started in 2008 or later, as opposed to 66.2% of agricultural

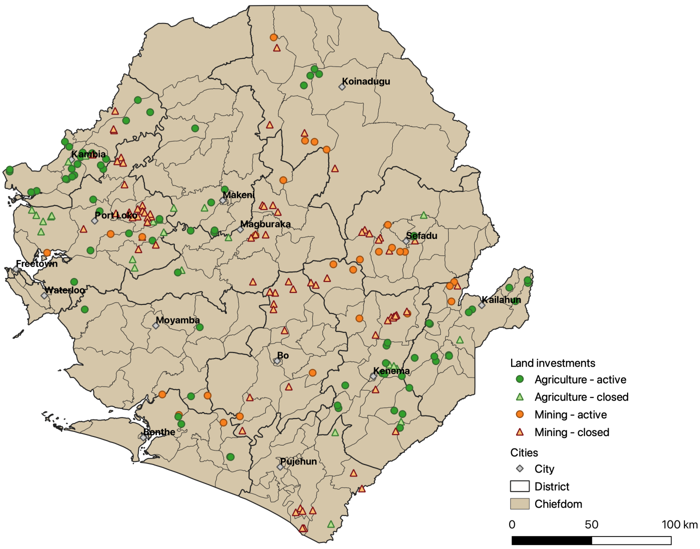

Figure 4.1: Land investments in Sierra Leone

This map shows the locations and operational status of all land investments located through the census. It excludes land investments in the Western Area.

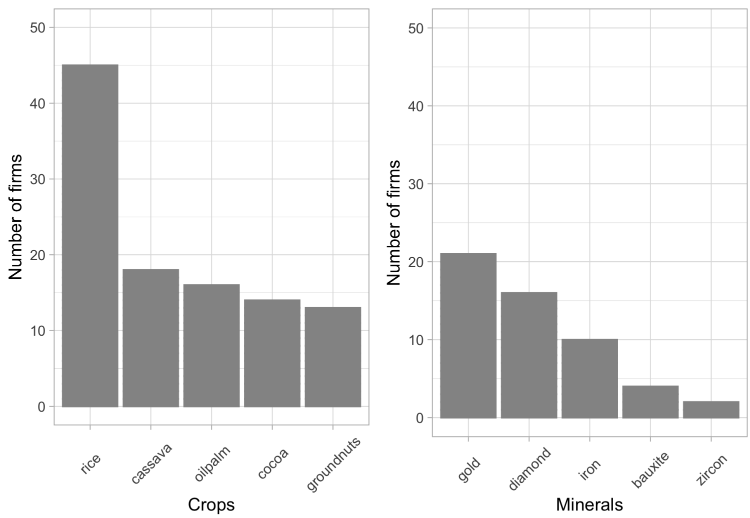

Figure 4.2: Common crops and minerals

This figure shows the five most commonly produced crops mined and minerals in land investments in Sierra Leone. Multiple answers per firm could be given.

deals. Between agricultural and mining deals the nationality of the investor differs substantially. For agricultural deals, the majority of investors are Sierra Leonean (59.5%), much lower than the 17.1% of mining investors. The biggest group of mining investors is European or American (43.9%).

Official lease agreements are more common for agricultural deals than for mining deals. What is more striking is that for almost half of all agricultural deals and almost two-thirds of mining deals there was no official lease agreement signed. Lease sizes vary greatly for agricultural and mining deals, but also within those two groups variation is large. On average, an agricultural lease size is 4539.14 hectares, whereas, for mining deals, the average lease size is merely 5.76 hectares. Furthermore, lease sizes for mining deals are on average 10 years shorter than for agricultural deals, though this difference is not statistically significant.

Data on payments of land rents to communities offer an interesting view: for agricultural deals, it is much more common to directly pay landowners rents (54.8% for agriculture vs. 20.0% for mining). Around 15% of both agricultural and mining

Table 4.2: Summary statistics of land investment characteristics

	Agriculture			Mining			
Variable	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Difference**
Started in 2008 or later (=1)	77	0.662		38	0.921		0.259***
Nationality investor							
Sierra Leonean (=1)	84	0.595		41	0.171		-0.425***
European/American (=1)	84	0.143		41	0.439		0.296***
Chinese (=1)	84	0.000		41	0.171		0.171***
Lebanese (=1)	84	0.095		41	0.000		-0.095***
Other (=1)	84	0.167		41	0.220		0.053
Lease							
Lease agreement (=1)	84	0.548		41	0.366		-0.182*
Lease size (hectares)	44	4539.138	17552	6	5.763	8	-4533.375*
Lease duration (years)	44	35.636	43	10	25.200	37	-10.436
Payments							
Directly to landowners (=1)	46	0.457		15	0.200		-0.257*
Through chief (=1)	46	0.174		15	0.133		-0.041
Nothing paid (yet) (=1)	46	0.130		15	0.067		-0.064
Other (=1)	46	0.130		15	0.067		-0.064
Don't know (=1)	46	0.109		15	0.533		0.425***

N is the number of land investments for which data is available. All land investment sites are located and most were active at the time of data collection. There are a couple of land investments that were already closed where data was collected through former employees. SD is the standard deviation, provided for continuous variables only. Difference gives the difference in means between mining and agricultural deals. P-values are calculated using OLS, where * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

deals report that payments are made through the chief. For 13% of agricultural deals, no payments were made at the time of the survey. For mining deals, this applies to 6.7% of deals. Interestingly, for more than half of mining deals, it is unclear to the respondent how payments are made.

Agricultural and mining deals differ substantially from each other in their size and lease agreement. Agricultural investors require much more land for a longer period. Where agricultural investors are mostly Sierra Leonean, the majority of mining investors is foreign. In terms of payments of rents, agricultural deals are commonly made directly to landowners, whereas, for mining deal payments are less transparent.

4.5.2 Firm-community interaction

In this section, we explore data on interactions between the firm and the communities where the project site is located. Because both firms and communities were interviewed, we are able to compare firm and community perspectives. The comparison is pairwise, meaning that we only show data for firms for which a community was interviewed and vice versa. We also distinguish between agricultural and mining investments in order to uncover any diverging patterns. Table 4.3 shows data on disagreements, employment and data on community development projects.

Table 4.3: Summary statistics of firm-community interaction

	Agriculture			Mining			
Variable	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Difference**
Firm perspective							
Disagreements (=1)	76	0.132		35	0.343		0.211**
Disagreements (#)	76	0.184	0.5	35	0.514	0.9	0.33*
Employees community (=1)	69	0.957		34	1.000		0.043*
Employees community (#)	69	71.464	253.7	34	31.500	49	-39.964
Employees community, skilled (=1)	63	0.619		31	0.581		-0.038
Employees community, skilled (#)	63	14.460	45.7	31	5.903	11.4	-8.557
Employees any (#)	74	214.608	606.5	36	187.639	525.6	-26.969
Employees community (% of total)	74	59.229	34.4	36	52.507	35.4	-6.722
Community liason officer employed (=1)	76	0.684		37	0.730		0.046
Dev. projects promised (=1)	79	0.494		38	0.395		-0.099
Dev. projects promised (#)	79	1.468	2.1	38	1.816	3.2	0.347
Dev. projects promised and delivered (#)	79	0.380	1	38	0.447	1.2	0.068
Dev. projects delivered (% of promised)	79	16.498	36.3	38	16.441	35.4	-0.057
Community perspective							
Disagreements (=1)	76	0.159		35	0.371		0.212**
Disagreements (#)	76	0.335	1.1	35	0.729	1.2	0.393
Employees community (=1)	69	0.947		34	0.868		-0.079
Employees community (#)	69	39.140	76.3	34	19.176	51.5	-19.964
Employees community, skilled (=1)	63	0.492		31	0.419		-0.073
Employees community, skilled (#)	63	5.905	10.2	31	1.484	2.9	-4.421***
Community liason officer employed (=1)	76	0.613		37	0.514		-0.1
Dev. projects promised (=1)	79	0.491		38	0.447		-0.043
Dev. projects promised (#)	79	1.704	2.4	38	1.711	2.5	0.006
Dev. projects promised and delivered (#)	79	0.370	1.2	38	0.632	1.6	0.262
Dev. projects delivered (% of promised)	79	13.217	31.5	38	15.702	32.4	2.485

This table shows firm and community perspectives for agricultural and mining deals. Disagreements are between firm and community. N is the number of firm or community observations. When there were more than one community per firm, the average for these communities was computed. SD is the standard deviation, shown for continuous variables only. Difference gives the difference in means between mining and agricultural deals. P-values are calculated using OLS, where * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Disagreements between firms and communities in which firms operate are not uncommon. We find that 13.2% of agricultural firms report that there were disagreements between firms and communities. This number is much higher for mining firms, where 34.4% of firms report disagreements with the community. Communities report a higher occurrence of disagreements, but the differences are modest (15.9% for agriculture and 37.1% for mining). We also measure the number of disagreements and find that agricultural firms report 0.184 disagreements on average. For mining firms, the number of disagreements reported is more than twice as high (0.514 disagreements per firm on average). Communities report many more disagreements: 0.335 for agriculture and 0.729 for mining.

When diving deeper into the reasons for disagreements between communities, we also see differences between agricultural and mining investments (refer to Figure A.4.1 in the Appendix)[10]. Communities with an agricultural project most often report issues concerning delays or amounts of surface rents (29% of disagreements) and disagreements on employment and treatment of workers (29% of disagreements). For mining investments, the most common reason for a disagreement mentioned by communities concerns land, for example the (absence) of a lease agreement, forced resettlement, or no information about activities to communities. This is reported as the reason for 36% of the mining disagreements, compared to less than 5% for agricultural investments. The second most often mentioned reason for mining is environmental degradation (15% of the disagreements).

Employment from local communities differs for agricultural and mining firms and we also find differences in firm and community perspectives. From the firm perspective, nearly all agricultural and mining firms employ unskilled employees from local communities. The number of employees is lower for mining than for agriculture (71 versus 32 employees). Skilled employment shows similar patterns and is generally much lower than unskilled employment. On average agricultural firms employ 14 skilled employees as opposed to 6 skilled employees per mining firm. To rule out that these differences are caused by differences in scale between agricultural and mining projects (i.e. the latter may require fewer employees), we also measure total

[10] Because firms report fewer disagreements, a pairwise comparison of reasons for disagreements between the firm and community perspective results in a very low number of observations. We, therefore, discuss the community perspective here. Figure A.4.1 in the Appendix shows the data for all observations (i.e. also for firms for which we have no community perspective and vice versa) and this shows similar patterns between firms and communities.

employment and the percentage of employment coming from local communities. Community employment makes up 60% of employment by agricultural firms and 53% for mining firms. Mining firms thus employ around 7 percentage points fewer local employees. Note that all the differences in employment between agricultural and mining firms are not significant, likely due to the high variance of the variables. According to communities, skilled and unskilled employment is on average much lower than what firms report. This is the case for both agricultural and mining deals. Communities report little over half of the number of skilled and unskilled employees reported by firms.

We find that less than half of firms promise investment in any community development projects and a very low percentage of projects was actually delivered at the time of the survey. Trends are similar for agricultural and mining firms and from the firm and community perspective. On average, agricultural firms promise investment in 1.5 community development projects and mining firms promise investment in 1.8 community development projects. For agricultural firms 16.5% of promised development projects are delivered, for mining this figure is 16.4%. It should be noted that mining firms are generally younger: the majority of mining firms started after 2014, whereas, most agricultural firms started after 2010.

4.5.3 Land investments and the political power of the paramount chief

This section shows the results of our analysis of the relationship between land investment occurrence and paramount chief power. In Table 4.4 we report on our two dependent variables: the extensive margin (the likelihood of a deal occurring in a chiefdom) and the intensive margin (the number of deals occurring in a chiefdom). For the full regression results, refer to the Appendix Table A.4.3 and Table A.4.4.

Panel 1 shows the relationship between the political power of the paramount chief and land investments at the extensive margin. In these specifications, the dependent variable is a dummy indicating whether there is any land investment in a chiefdom. The regressions are done separately for agricultural and mining deals. Column 1 shows the results for agriculture without any geographic controls

Table 4.4: Land investments and chief political power

	Agriculture	Agriculture	Mining	Mining
Panel 1: Extensive margin				
Number of ruling families, logged	0.2091**	0.1047	-0.1231	-0.1914**
	(0.0825)	(0.0867)	(0.0872)	(0.0798)
Geographic controls	No	Yes	No	Yes
ARR controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Adj. R squared	0.183	0.2638	0.0858	0.1669
No. obs.	149	149	149	149
Panel 2: Intensive margin				
Number of ruling families, logged	0.3435	0.0876	-0.697**	-0.7657***
	(0.2429)	(0.2229)	(0.276)	(0.2657)
Geographic controls	No	Yes	No	Yes
ARR controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Adj. R squared	0.2226	0.2665	0.0777	0.1926
No. obs.	149	149	149	149

OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. In Panel 1 the dependent variable is a dummy indicating whether an agricultural or mining deal took place in a chiefdom. In Panel 2 the dependent variable is a count variable indicating the number of agricultural or mining deals that took place in a chiefdom. If indicated, a model includes the following geographic controls: population size, road network length, distance to a port, distance to a river, elevation, ruggedness, forest cover, rainfall, and night lights. For agricultural deals, additional controls are oil palm, cassava, and upland rice suitability. For mining deals the additional control is a dummy indicating whether the chiefdom had a mining permit in place in 1930, proxying mining suitability. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014) (the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation). All specifications include district-fixed effects. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

and Column 2 shows the results with geographic controls. In both cases, the coefficients are positive, though insignificant when we control for geographic factors. For mining, we find a negative, but insignificant, effect without controls. When we include controls, the effect becomes significant. This indicates that mining deals are more likely to take place in a chiefdom with fewer ruling families, and thus with a chief that has more political power. In Column 4, where we control for geographic factors, the coefficient is -0.1914. This means that a 1% increase in the number of ruling families leads to a decrease in the likelihood of investments of 0.1914 percentage points. This may seem like a small effect, but the average number of ruling families is 3.95, whereas, the standard deviation is 2.15 in the chiefdoms. As such, for an average chiefdom, one standard deviation increase, leads to a reduction in the likelihood of a mining investment of 10.4 percentage points. As the average likelihood of a mining deal is 29.9%, this is a sizeable effect. The results suggest that for mining investors, a chiefdom with a strong paramount chief is more attractive to invest in. For agriculture, a strong paramount chief does not seem to drive investments.

This is supported by the results in Panel 2 where we show the same relationship at the intensive margin, i.e. the number of deals influenced by the political power of the chief. We find similar results. For agriculture, the coefficients for the number of ruling families excluding controls (Column 1) and including controls (Column 2) are positive but not significant. For mining deals, however, we find a significant negative effect of the number of ruling families in both specifications (Columns 3 and 4). The magnitude is -0.7657 when we control for geographic conditions. This indicates that a 1% increase in the number of ruling families leads to 0.0077 more deals in a chiefdom. This results in 0.42 more mining deals in chiefdoms where the number of ruling families is one standard deviation higher than the average. This is quite a large increase given that the average number of mining deals in a chiefdom is 0.71.

In Table 4.5 we analyse whether *when* an investment occurs, the success of the investment depends on chief political power (for full regression tables see Table A.4.5 and Table A.4.6 in the Appendix). Patterns are very similar as in Table 4.4. For mining investments, the success of a deal is negatively associated with the number of ruling families. Hence, in chiefdoms with fewer ruling families (and thus more powerful paramount chiefs), mining investments are more likely to be successful (Panel 1), and more mining investments are successful (Panel 2). The magnitudes of the effects are larger than in Table 4.4. At the extensive margin, the effect of the number of ruling families is more than twice as high. At the intensive margin, the effect is 15 percentage points higher. For agriculture, we find no significant effects of the number of ruling families on the likelihood of success of an investment. Note that in this analysis, we exclude chiefdoms where no mining or agricultural deal took place. These results are robust to including chiefdoms where no deals took place (see Table A.4.7 and Table A.4.8 in the Appendix).

In conclusion, we consistently find a positive association between the political power of the paramount chief and mining deals in chiefdoms in Sierra Leone. Not only is the likelihood of a mining deal occurring higher in chiefdoms with more powerful

Table 4.5: Success of land investments and chief political power

	Agriculture	Agriculture	Mining	Mining
Panel 1: Extensive margin				
Number of ruling families, logged	0.0928	-0.1461	-0.3155*	-0.425**
	(0.1776)	(0.1699)	(0.1783)	(0.1863)
Geographic controls	No	Yes	No	Yes
ARR controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Adj. R squared	-0.0932	-0.0185	0.1158	0.446
No. obs.	50	50	50	50
Panel 2: Intensive margin				
Number of ruling families, logged	0.389	-0.0286	-0.7789**	-0.8855**
	(0.4687)	(0.6213)	(0.377)	(0.3239)
Geographic controls	No	Yes	No	Yes
ARR controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Adj. R squared	0.2643	0.4122	0.1002	0.5311
No. obs.	50	50	50	50

OLS regression with robust standard errors in parenthesis. Observations are chiefdoms where deals took place. In Panel 1 the dependent variable is a dummy indicating whether an agricultural or mining deal was successful in a chiefdom. In Panel 2 the dependent variable is a count variable indicating the number of successful agricultural or mining deals that took place in a chiefdom. Success is defined as a deal that was still active at the time of the survey. If indicated, a model includes the following geographic controls: population size, road network length, distance to a port, distance to a river, elevation, ruggeddness, forest cover, rainfall, and night lights. For agricultural deals, additional controls are oil palm, cassava, and upland rice suitability. For mining deals the additional control is a dummy indicating whether the chiefdom had a mining permit in place in 1930, proxying mining suitability. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014) (the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation). All specifications include district-fixed effects. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

paramount chiefs, the number of mining deals is also higher. In addition, we find that the success rate of mining investments is also higher in chiefdoms where chiefs have more political power. For agriculture, we do not find a consistently significant effect, though nearly all coefficients are positive. It seems that chief political power does not have a strong influence on whether an agricultural deal takes place or whether it is successful. Interestingly, when we consider other likely determinants of land investments (i.e. our controls), we find very few significant effects, suggesting that geography and infrastructure are less important for driving land investments (refer to Table A.4.3 and Table A.4.4 in the Appendix for the full specifications). We explore potential mechanisms for the results in the discussion.

4.6 Discussion

Large-scale land investments have been heavily debated in and beyond academia, for their potential to spur economic development, but also because of fears of negative impact on local communities. In addition, an active debate is being held on whether investors are attracted to weak or strong institutions. Researching these questions proves difficult as transparency surrounding land investments is lacking. Obtaining reliable and complete data on land investments is challenging, as many host countries lack the institutional capacity to keep such records. Moreover, finding reliable and exogenous indicators for institutional quality is difficult.

In this study, we presented the results of a unique census of land investments in Sierra Leone, a country that has seen a significant increase in land investments following the food price spikes in 2007/2008. The 2017 census, conducted with input from national and local authorities, found a total of 232 land investments in the country; a far larger amount than reported in the often-used Land Matrix database.

We descriptively explored investor characteristics and interactions with communities. We find big differences in the way agricultural and mining investors operate. The latter require less land, they are less likely to provide communities with a lease agreement, and information surrounding payments to host communities is limited. Furthermore, disagreements between communities and investors are more likely for mining deals than for agricultural deals. We find some suggestive evidence that employment is also lower for mining deals. Investment in community development projects is similar for both mining and agriculture, though both types of investors rarely deliver the projects they promise. When we consider the perspective on these investments for communities, we generally see a less favourable picture for both agricultural and mining deals: according to communities, more disagreements occur and fewer locals are employed. This clearly shows that reporting bias regarding land investments can be a potential issue when collecting data on investments.

We also presented the results of a regression analysis of whether institutions matter for where investments occur. In Sierra Leone, where land is governed by customary law, paramount chiefs are known as 'the custodians of the land' and have far-reaching influence on land management. We find evidence that mining investments are more likely to occur and be successful in chiefdoms with chiefs with more political power, who face less competition and have fewer interests to appease. For agricultural investments, we find no significant effects of chief political power but do find consistently positive coefficients.

Based on our descriptive analysis, we hypothesise that the extractive, high-value (most common minerals mined are diamonds and gold) and small-scale nature of a mining investment makes it attractive for investors to move into areas where chiefs have more political power. The lower demand for land suggests that mining investments require less community approval. With the foreign background of mining investors, seeking out a strong chief potentially reduces the transaction costs of acquiring land. When a mining investment does take place in an area, this leads to more disagreements with communities, often because communities are discontent about the (absence of a) lease agreement and the environmental degradation caused by the project. The fact that we do not find this effect for agricultural deals could be explained by the large, ‘open’ and low-value nature of agricultural deals. A chiefdom with more democratic institutions may be more attractive for investors that require a large amount of land and more local labour, and as such, a good relationship with the community. Though this hypothesis is suggestive, our finding is in line with recent studies that show a tight link between local corruption and mining activity (Blair et al., 2022; Wilson, 2019; Engwicht, 2018; Knutsen et al., 2017; Dupuy, 2017).

Our findings contribute to the existing literature on institutions and land investments, namely because we find that institutions may matter for some types of investments (i.e. mining) but not for others. Furthermore, a within-country study can offer more detailed insights into investor behaviour compared to existing cross-country studies (e.g. Lay and Nolte 2018, Arezki et al. 2018 and Arezki et al. 2015). Furthermore, our result is an interesting addition to the work of Christensen et al. (2021), who show that investors favour private property rights over customary property rights in Liberia, indicating that investors are attracted to better governance. We argue that this does not necessarily contradict our result. First, Christensen et al. (2021) do not distinguish between mining and agricultural deals. Second, compared to Sierra Leone, there is much more land under private property law and investors thus can choose between the two tenure systems. In Sierra Leone, the vast majority of the land is under customary law, therefore investors face less of a choice. We show that at least for mining investors, when they choose an area to invest in within a customary property rights system, they prefer areas where chiefs are strong.

Our study has two main policy implications. First, the census shows that government data collection and monitoring of land investments in Sierra Leone is limited. The commonly used secondary source for land investment data, the Land Matrix, also does not give a complete picture of the land investment climate: many deals are not recorded and those that are recorded are relatively large. The approximate locations of these recorded investments are typically unknown. Better data collection and monitoring by the government can thus improve much-needed transparency surrounding land investments. Second, the results of the census lend credence to the calls for more regulation and accountability surrounding investments in Sierra Leone. Firms and communities have many disagreements on the terms of a lease agreement (if one exists), payments to communities, environmental degradation and local employment. These issues seem to be more common for mining firms than for agricultural firms. Improved accountability and conflict resolution mechanisms can ensure that firms and communities are able to benefit more from land investments. This holds particularly for mining investors, who tend to invest in areas where local political power is strong, raising concerns about corruption and local conflict.

4.7 Appendix

Table A.4.1: Control variables definition and sources

Variable	Definition	Source
Population size	Size of population in chiefdom in 2004	Acemoglu et al. (2014) from Sierra Leone Census 2004
Road network length	Road network length in chiefdom (m)	
Distance to port	Distance from chiefdom centroid to port (m)	
Distance to river	Distance to nearest 'large' river (m). Size according to OSM classification (only 8101)	
Elevation, mean	Mean elevation in chiefdom (m)	
Elevation, sd	SD elevation in chiefdom (m)	
Night lights	Mean of luminance in hexagon in 2007	DMSP
Forest cover	Percentage of chiefdom covered by forest in 2000	Hansen et al. (2008)
Forest cover, sd	SD of forest cover in 2000	
Rainfall, mean	Mean of monthly rainfall in chiefdom	TAMSAT
Rainfall, sd	SD of monthly rainfall in chiefdom	TAMSAT
Cassava suitability, mean	Mean of soil suitability class of cassava in chiefdom	FAO GAEZ
Oilpalm suitability, mean	Mean of soil suitability class of oilpalm in chiefdom	FAO GAEZ
Upland rice suitability, mean	Mean of soil suitability class of upland rice in chiefdom	FAO GAEZ
Mining permit in 1930	Presence of mining permit in chiefdom in 1930	Acemoglu et al. (2014)

This table shows variable definition and sources for all control variables used in the chiefdom-level analysis of land investments and chief political power.

Table A.4.2: Summary statistics

Variable	N	Mean	SD	Min	Max
Number of agricultural investments	149	0.765	1.5	0.000	8.000
Agricultural investments (=1)	149	0.336		0.000	1.000
Number of mining investments	149	0.792	1.6	0.000	8.000
Mining investments (=1)	149	0.336		0.000	1.000
Number of ruling families	149	3.946	2.1	1.000	12.000
Number of chiefs recalled	149	5.799	2.6	1.000	17.000
Amalgamation (=1)	149	0.309		0.000	1.000
Population size in 2004	149	23819.779	16168.5	2607.000	87366.000
Road network length (m)	149	202370.706	146424.8	15651.574	812530.096
Distance to port (m)	149	259699.372	81664.6	57390.368	422452.041
Distance to river (m)	149	4845.873	3704.9	13.387	19916.090
Elevation (m)	149	173.613	154.8	4.758	582.034
Night lights in 2007	149	0.021	0.1	0.000	0.536
Forest cover in 2000 (%)	149	46.634	11.9	19.227	75.885
Rainfall in 2007	149	217.102	29.7	138.621	290.231
Oilpalm suitability	149	0.339	0.3	0.000	1.265
Cassava suitability	149	4.065	1	2.000	5.889
Upland rice suitability	149	3.663	1.1	1.667	5.667
Mining permit in 1930 (=1)	149	0.174		0.000	1.000

This table shows summary statistics for all variables used in the chiefdom-level analysis of land investments and chief political power. Observations are chiefdoms. SD is the standard deviation and given for continuous variables only.

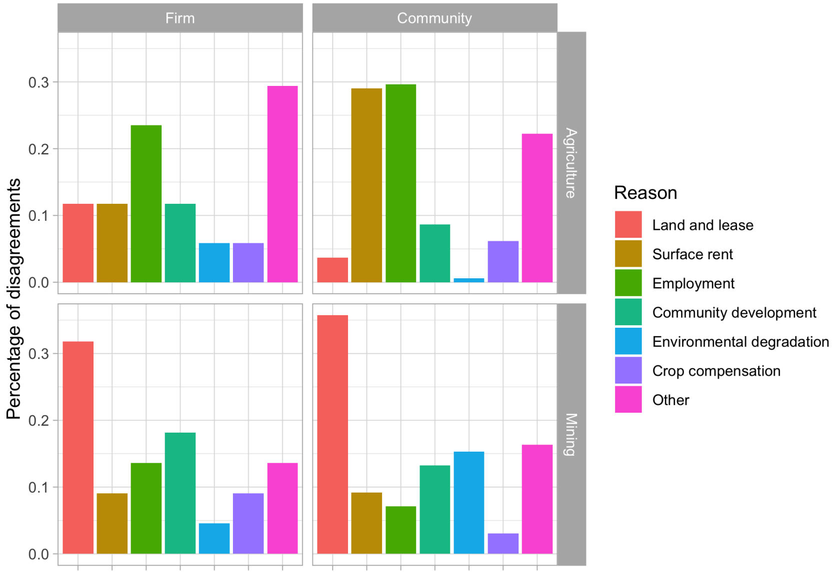

Figure A.4.1: Reasons for disagreement reasons in land investments.

From the community and firm perspective. Note that this is not a pairwise comparison, i.e. the figure includes community observations without firm observations and vice versa. Land and lease disagreements concern conflicts over the lease agreement, conflict over the extent of resettlement or conflict over forced resettlement. Surface rent disagreements concern either delayed payments or the amount paid. Employment disagreements are about the number of community members employed and treatment of employees. Community development disagreements concern the delay of projects or the number of projects promised. Environmental degradation disagreements are about degradation caused by the firm. Crop compensation disagreements concern delays of crop compensation or the amount paid.

Table A.4.3: Full table: extensive margin

	Agriculture	Agriculture	Mining	Mining
Number of ruling families, logged	0.2091^{**}	0.1047	-0.1231	-0.1914^{**}
	(0.0825)	(0.0867)	(0.0872)	(0.0798)
Population size in 2004, ihs		0.1789		0.1357
		(0.1391)		(0.1261)
Road network length, ihs		0.0714		0.0391
		(0.1270)		(0.1197)
Distance to port (km)		0.0007		0.0013
		(0.0012)		(0.0012)
Distance to river (km)		0.0071		-0.0009
		(0.0102)		(0.0105)
Elevation (100 m)		-0.0977		-0.1745^{**}
		(0.0690)		(0.0751)
Elevation, sd (100 m)		-0.3150^{**}		0.1653
		(0.1557)		(0.1811)
Night lights in 2007		0.2022		0.1058
		(0.6207)		(0.7553)
Forest cover in 2000 (%)		-0.0049		0.0111^{*}
		(0.0072)		(0.0059)
Forest cover in 2000, sd (%)		0.0019		0.0256
		(0.0217)		(0.0192)
Rainfall in 2007, mean		-0.0030		-0.0043
		(0.0030)		(0.0026)
Rainfall in 2007, sd		-0.0120		-0.0031
		(0.0078)		(0.0083)
Oilpalm suitability		-0.2464^{**}		
		(0.0989)		
Cassava suitability		0.0819		
		(0.1938)		
Upland rice suitability		0.0499		
		(0.2200)		
Mining permit in 1930				0.2353^{*}
				(0.1306)
District FE	*Yes*	*Yes*	*Yes*	*Yes*
ARR controls	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R^2	0.1830	0.2638	0.0858	0.1669
Num. obs.	149	149	149	149

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. Dependent variable is a dummy variable indicating whether an agricultural or mining deal took place in a chiefdom. Ihs means variable is transformed using the inverse hyperbolic sine transformation. All specifications include district-fixed effects. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014), i.e. the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation.

Table A.4.4: Full table: intensive margin

	Agriculture	Agriculture	Mining	Mining
Number of ruling families, logged	0.3435	0.0876	-0.6970^{**}	-0.7657^{***}
	(0.2429)	(0.2229)	(0.2760)	(0.2657)
Population size in 2004, ihs		0.5342		0.2958
		(0.4376)		(0.5167)
Road network length, ihs		-0.0637		0.2547
		(0.4158)		(0.3798)
Distance to port (km)		-0.0014		-0.0018
		(0.0025)		(0.0033)
Distance to river (km)		0.0464		-0.0104
		(0.0326)		(0.0379)
Elevation (100 m)		-0.0719		-0.1460
		(0.2039)		(0.2125)
Elevation, sd (100 m)		-0.3121		0.9996
		(0.5668)		(0.6865)
Night lights in 2007		2.4877		-0.5034
		(3.1470)		(1.6240)
Forest cover in 2000 (%)		-0.0026		0.0136
		(0.0239)		(0.0230)
Forest cover in 2000, sd (%)		0.0434		0.0825
		(0.0661)		(0.0761)
Rainfall in 2007, mean		-0.0045		-0.0101
		(0.0122)		(0.0073)
Rainfall in 2007, sd		0.0023		-0.0170
		(0.0257)		(0.0278)
Oilpalm suitability		-0.4817		
		(0.4168)		
Cassava suitability		-0.5210		
		(0.8847)		
Upland rice suitability		0.4080		
		(0.9016)		
Mining permit in 1930				1.0025^{*}
				(0.5775)
District FE	*Yes*	*Yes*	*Yes*	*Yes*
ARR controls	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R^2	0.2226	0.2665	0.0777	0.1926
Num. obs.	149	149	149	149

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. Dependent variable is a count variable indicating the number of agricultural or mining deals that took place in a chiefdom. Ihs means variable is transformed using the inverse hyperbolic sine transformation. All specifications include district-fixed effects. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014), i.e. the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation.

Table A.4.5: Active deals only: extensive margin, restricted sample

	Agriculture	Agriculture	Mining	Mining
Number of ruling families, logged	0.0928	−0.1461	−0.3155*	−0.4250**
	(0.1776)	(0.1699)	(0.1783)	(0.1863)
Population size in 2004, ihs		−0.0019		0.4646
		(0.2504)		(0.2912)
Road network length, ihs		0.3883		−0.1133
		(0.2672)		(0.3190)
Distance to port (km)		0.0000		−0.0011
		(0.0020)		(0.0025)
Distance to river (km)		−0.0016		0.0220
		(0.0180)		(0.0297)
Elevation (100 m)		0.0274		0.3414*
		(0.1870)		(0.1976)
Elevation, sd (100 m)		0.3313		−1.8424***
		(0.7052)		(0.6444)
Night lights in 2007		−0.5109		−3.1367**
		(1.3522)		(1.3829)
Forest cover in 2000 (%)		−0.0212		0.0511*
		(0.0170)		(0.0292)
Forest cover in 2000, sd (%)		−0.0510		0.1939**
		(0.0534)		(0.0788)
Rainfall in 2007, mean		0.0017		−0.0318**
		(0.0066)		(0.0136)
Rainfall in 2007, sd		−0.0370		−0.0082
		(0.0217)		(0.0196)
Oilpalm suitability		−0.0457		
		(0.1326)		
Cassava suitability		−0.4890		
		(0.2912)		
Upland rice suitability		0.3118		
		(0.3408)		
Mining permit in 1930				0.0894
				(0.2225)
District FE	*Yes*	*Yes*	*Yes*	*Yes*
ARR controls	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R^2	−0.0932	−0.0185	0.1158	0.4460
Num. obs.	50	50	50	50

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. Dependent variable is a dummy variable indicating whether there was an active agricultural or mining deal in a chiefdom during the survey. Chiefdoms without deals are excluded. Ihs means variable is transformed using the inverse hyperbolic sine transformation. All specifications include district-fixed effects. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014), i.e. the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation.

Table A.4.6: Active deals only: intensive margin, restricted sample

	Agriculture	Agriculture	Mining	Mining
Number of ruling families, logged	0.3890	−0.0286	-0.7789^{**}	-0.8855^{**}
	(0.4687)	(0.6213)	(0.3770)	(0.3239)
Population size in 2004, ihs		1.0039		1.0082^{*}
		(0.9999)		(0.5028)
Road network length, ihs		−0.7255		−0.2826
		(1.0334)		(0.6138)
Distance to port (km)		−0.0027		0.0029
		(0.0072)		(0.0060)
Distance to river (km)		−0.0244		0.1142^{*}
		(0.0562)		(0.0567)
Elevation (100 m)		−0.2298		0.6045
		(0.7716)		(0.3753)
Elevation, sd (100 m)		2.5349		-3.9417^{***}
		(1.7548)		(0.9930)
Night lights in 2007		0.3855		-3.8566^{*}
		(5.0783)		(1.9391)
Forest cover in 2000 (%)		−0.0014		0.1344^{**}
		(0.0530)		(0.0484)
Forest cover in 2000, sd (%)		0.1747		0.4879^{***}
		(0.1956)		(0.1693)
Rainfall in 2007, mean		−0.0076		-0.0897^{***}
		(0.0259)		(0.0281)
Rainfall in 2007, sd		0.0147		−0.0357
		(0.0726)		(0.0434)
Oilpalm suitability		−0.4469		
		(0.5230)		
Cassava suitability		-3.2181^{**}		
		(1.2809)		
Upland rice suitability		2.6862^{*}		
		(1.4066)		
Mining permit in 1930				1.6034^{**}
				(0.6038)
District FE	*Yes*	*Yes*	*Yes*	*Yes*
ARR controls	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R^2	0.2643	0.4122	0.1002	0.5311
Num. obs.	50	50	50	50

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. Dependent variable is a continuous variable indicating the number of active agricultural or mining deal in a chiefdom during the survey. Chiefdoms without deals are excluded. Ihs means variable is transformed using the inverse hyperbolic sine transformation. All specifications include district-fixed effects. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014), i.e. the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation.

Table A.4.7: Active deals only: extensive margin

	Agriculture	Agriculture	Mining	Mining
Number of ruling families, logged	0.1582*	0.0472	−0.1059	−0.1633**
	(0.0822)	(0.0871)	(0.0787)	(0.0757)
Population size in 2004, ihs		0.1249		0.2147**
		(0.1231)		(0.1011)
Road network length, ihs		0.1091		−0.0805
		(0.1149)		(0.0899)
Distance to port (km)		−0.0001		−0.0001
		(0.0011)		(0.0009)
Distance to river (km)		0.0035		−0.0047
		(0.0101)		(0.0080)
Elevation (100 m)		−0.0680		−0.0521
		(0.0671)		(0.0588)
Elevation, sd (100 m)		−0.2673*		0.0154
		(0.1437)		(0.1612)
Night lights in 2007		0.4399		0.1055
		(0.4995)		(0.5419)
Forest cover in 2000 (%)		−0.0078		0.0066
		(0.0064)		(0.0046)
Forest cover in 2000, sd (%)		0.0041		0.0385**
		(0.0206)		(0.0154)
Rainfall in 2007, mean		−0.0042		−0.0037*
		(0.0027)		(0.0021)
Rainfall in 2007, sd		−0.0174**		−0.0083
		(0.0072)		(0.0072)
Oilpalm suitability		−0.2693***		
		(0.0867)		
Cassava suitability		−0.0719		
		(0.1517)		
Upland rice suitability		0.1646		
		(0.1748)		
Mining permit in 1930				0.1069
				(0.1238)
District FE	*Yes*	*Yes*	*Yes*	*Yes*
ARR controls	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R^2	0.1497	0.2586	−0.0061	0.0556
Num. obs.	149	149	149	149

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. Dependent variable is a dummy variable indicating whether there was an active agricultural or mining deal in a chiefdom during the survey. Ihs means variable is transformed using the inverse hyperbolic sine transformation. All specifications include district-fixed effects. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014), i.e. the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation.

Table A.4.8: Active deals only: intensive margin

	Agriculture	Agriculture	Mining	Mining
Number of ruling families, logged	0.3195^{*}	0.0765	-0.2197	-0.2955^{**}
	(0.1882)	(0.1915)	(0.1331)	(0.1227)
Population size in 2004, ihs		0.3881		0.2149
		(0.3095)		(0.1544)
Road network length, ihs		-0.0156		-0.0824
		(0.2803)		(0.1354)
Distance to port (km)		-0.0012		-0.0015
		(0.0019)		(0.0014)
Distance to river (km)		0.0111		-0.0123
		(0.0229)		(0.0123)
Elevation (100 m)		-0.0215		-0.0745
		(0.1533)		(0.1003)
Elevation, sd (100 m)		-0.2436		0.2478
		(0.3855)		(0.3276)
Night lights in 2007		2.1164		0.5686
		(1.7841)		(0.7197)
Forest cover in 2000 (%)		-0.0002		0.0108
		(0.0189)		(0.0123)
Forest cover in 2000, sd (%)		0.0285		0.0561
		(0.0492)		(0.0405)
Rainfall in 2007, mean		-0.0023		-0.0063
		(0.0082)		(0.0046)
Rainfall in 2007, sd		-0.0177		-0.0107
		(0.0143)		(0.0125)
Oilpalm suitability		-0.2636		
		(0.2123)		
Cassava suitability		-0.8622^{*}		
		(0.4762)		
Upland rice suitability		0.6455		
		(0.4623)		
Mining permit in 1930				0.5152^{*}
				(0.2808)
District FE	*Yes*	*Yes*	*Yes*	*Yes*
ARR controls	*Yes*	*Yes*	*Yes*	*Yes*
Adj. R^2	0.2741	0.3268	-0.0161	0.1034
Num. obs.	149	149	149	149

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
OLS regression with robust standard errors in parenthesis. Observations are chiefdoms. Dependent variable is a count variable indicating the number of active agricultural or mining deals in a chiefdom. Ihs means variable is transformed using the inverse hyperbolic sine transformation. All specifications include district-fixed effects. All specifications include controls from Acemoglu, Robinson and Reed (ARR) (2014), i.e. the number of chiefs recalled and a dummy indicating whether a chiefdom was created through amalgamation.

Chapter 5

The economic nature of improved cooking stove adoption: Evidence from a randomised controlled trial in Ethiopia

More than three billion people rely on biomass as their primary cooking fuel with major implications for livelihoods and the environment. Energy-efficient biomass cookstoves are a potential remedy, providing economic, environmental and perhaps even health benefits. However, the uptake of such stoves in the Global South has been limited. This paper assesses whether economic incentives can improve uptake. Using a randomised controlled trial in Ethiopia for which different subsidy schemes were assigned to 292 villages, we show that subsidisation and information on the health and economic benefits together increase stove uptake substantially. For households who received a 70% or a 100% subsidy, uptake increases fourfold and tenfold, respectively. We find that households are twice as likely to collect an energy-efficient stove when they receive additional information on the economic benefits, compared to information on health benefits alone. Uptake remains low when information is not accompanied by high subsidies. The policy implication is that, even when technologies are promoted at a relatively low price, uptake will benefit substantially from high subsidisation.

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5.1 Introduction

Biomass cooking is a considerable cause of environmental degradation, related to deforestation (Jeuland and Pattanayak, 2012) and air pollution (Martin et al., 2011; WHO, 2021). In Ethiopia, biomass currently makes up more than 85% of energy demand. Despite considerable investment in hydro-power and other sources of energy, biomass demand is expected to increase by 15% by 2040 and will remain the primary source of energy demand (IEA, 2019). To alleviate biomass consumption and reduce deforestation, energy-efficient biomass stoves (EEBS) technologies have been heralded as a potential solution. EEBS could further alleviate deforestation pressures, and reduce the workload for firewood collection or monetary expenditures in case the fuels are purchased. Some even expect a reduction of smoke exposure. Despite efforts to stimulate households to use EEBS, in most countries, adoption remains low, especially in Sub-Saharan Africa. A growing body of literature examines effective strategies to improve EEBS adoption (discussed below).

In this paper, we test the impact of lifting financial and information constraints on EEBS uptake in rural Ethiopia. Our study is part of a project initiated by our implementing partners The Netherlands and Ethiopian Red Cross Society, to provide Ethiopian households with EEBS in order to measure the impact on cooking-related disease. The promoted EEBS is the Mirt-stove, which is specialised for *injera* baking, the main staple food in Ethiopia. Gebreegziabher et al. (2018) show through field-based cooking trials that the Mirt stove significantly reduces fuelwood consumption by 22% to 31% but does not reduce cooking time. In another recent study, Bluffstone et al. (2022) add to this finding that cooking time is initially higher than the traditional Ethiopian stove but declines over time as experience and learning-by-doing effects materialise.

Assessing the potential health effects that can – in theory – be expected in the project under evaluation here is complex. It is beyond discussion that smoke from cooking fires is harmful for the users, leading to 3.8 million premature deaths every year (WHO, 2021). It is much less clear how much household air pollution needs to be curbed to relieve users from this health burden. WHO has established air pollution standards, which have been proven hard to achieve even in interventions that provided clean fuels or clean stoves to users, probably because of ambient air pollution, fuel stacking or inappropriate stove usage. According to these air pollution standards, no health effects can be expected from the diffusion of EEBS in general, or the Mirt in particular, because the technical emission reduction is not sufficient to reach harmless levels. Yet, there is also some indication that EEBS lead to exposure reduction due to a shorter cooking duration, more outside cooking or higher awareness of the harmfulness of smoke – which all might be catalysed by EEBS usage. For Mirt, for example, LaFave found positive effects of the Mirt stove on young children's health, reporting a 0.3-0.4 standard deviation improvement in height-for-age for children among Mirt users in their first years of life. They do not find any health impacts for older children or adults. Smoke exposure does not decrease, so this meaningful health impact does not seem to be driven by a reduction of emissions.

The pilot project under evaluation here is based on the hope that the Mirt stove can improve the health situation of users, despite not meeting WHO standards. The study was initially set up to contribute to the ongoing public health debate by measuring the direct health impacts of the Mirt stove. Unfortunately, due to the ongoing conflict in Ethiopia, the evaluation of the intervention on health outcomes has not been realised to date. Instead, we report on a part of the experiment that aimed to test efficient ways to stimulate uptake of the Mirt stove (an intermediary step to realising health benefits.[1]

Using a randomised controlled trial implemented in 292 rural Ethiopian villages, we study the impact of subsidisation and information on EEBS uptake. Extension workers of ERCS visited these villages in 2019 to market the Mirt stove. Promotion events were organised, and villagers were gathered in cooperation with local authorities. The business-as-usual promotion event is to offer the Mirt at the usual market price of 100 Ethiopian Birr (ETB) (or 3 USD at the time of the survey) and provide information on the potential health benefits. In our study, there is no

[1] When the research team was invited to conduct the evaluation, the project was already in full swing, limiting our involvement in the design and data collection. Baseline data, which was collected without our input, could not be fully matched to our study sample. Much of the study design was already in place and time and budget constraints further limited our influence on the design. The intervention and follow-up data collection were fully implemented by the Ethiopian Red Cross Society (ERCS). Nevertheless, we believe this evaluation offers an important contribution to the literature, all the more because it focuses on an actual program by an NGO with little interference from the research team.

pure control group where no Mirt-stoves are offered. For the information treatment arm, the ERCS provided the same health information, complemented by additional information on economic benefits (namely the fuel and time-saving potential of the Mirt-stove). For the subsidy treatment arm, subjects received a voucher for either 0%, 40%, 70% or 100% price subsidy. This approach allows us to say something about the effective level of subsidisation with and without information on the economic benefits of the Mirt stove.

Our outcome variable is the number of sold Mirt stoves in each study village. We find that EEBS uptake is close to zero in the group receiving no subsidy and also adding the economic information package does not change uptake considerably. Uptake increases with subsidisation but does not significantly increase for the 40% subsidy groups. The 70% and the 100% subsidy, though, lead to a 548.8% and 1151.1% increase in uptake. Furthermore, households exposed to health and economic information treatment are almost twice as likely to collect a stove than households exposed to health information only when accompanied by subsidies of 70% and 100%.

Our paper contributes to the growing body of literature observing a high price sensitivity of EEBS adoption (Munyehirwe et al., 2022; Pattanayak et al., 2019; Mobarak et al., 2012) and that uptake is low even for very low-cost EEBS with short amortisation periods (e.g. Berkouwer et al. 2021; Bluffstone et al. 2021; Levine et al. 2018; Bensch et al. 2015; Beltramo et al. 2015). Appropriate use of chimney-based cookstoves has been found to decline over time in case maintenance requirements are high (Hanna et al., 2016). Yet recently, long-run randomised controlled trials have shown that prolonged EEBS adoption and intense usage are indeed possible over many years for EEBS that match the needs of households (Pattanayak et al., 2019; Bensch and Peters, 2015; Jeuland and Pattanayak, 2012). For free distribution, practitioners are sometimes concerned that EEBS received as a gift is not used – something that has been falsified in several different settings (Munyehirwe et al., 2022; Bensch and Peters, 2015), including for the Mirt stove in Ethiopia (Bluffstone et al., 2021).

We furthermore speak to the literature on the role that information plays in increasing adoption. Mobarak et al. (2012) show very low demand for EEBS if the information on health benefits is not accompanied by subsidies. Berkouwer et al. (2021) find that willingness-to-pay (WTP) for EEBS does not increase when insights into the saving potential of EEBS are gained. Similarly, Beltramo et al. (2015) find no evidence of increased willingness to pay for EEBS after providing marketing messages on health benefits, economic benefits, or both.

Our study contributes to this literature in three ways. First, we provide an important piece of evidence of the effective level of subsidisation, confirming previous studies in other countries (Munyehirwe et al., 2022; Bensch and Peters, 2020; Pattanayak et al., 2019). Second, compared to other studies, we have a relatively large sample size (292 villages) and study an actual intervention by a large NGO, which both contribute to the external validity and policy relevance of this study. Third, whereas previous research has found no effect of information on WTP or demand for EEBS, our study shows that depending on the type of information given, information can have substantial effects on uptake when combined with subsidies.

5.2 Empirical approach

5.2.1 Country and policy background

Biomass cooking in Ethiopia makes up around 85% of energy demand (SNV, 2018). As such, the National Government and NGOs have exerted considerable effort to stimulate adoption of EEBS. The country aims to switch 20 million households to using fuelwood-efficient stoves by 2030 (Federal Democratic Republic of Ethiopia 2011), yet an estimated 63.3% of Ethiopian households use a traditional three-stone stove as their primary stove and 13.6% use a self-built stove (Padam et al., 2018). Biomass cooking with energy-inefficient stoves places a significant economic and health burden on the household. 80% of all rural households collect fuelwood for cooking which takes up a significant amount of time and is mostly done by women and girls. Women and girls are also the ones exposed to cooking smoke and respiratory diseases, responsible for up to 5% of total deaths in Ethiopia. Lastly, fuelwood consumption levels exceed sustainable yields of fuelwood causing environmental degradation across the country (SNV, 2018).

Figure 5.1: Map of the study area in Ethiopia

ERCS carried out an intervention to improve the uptake of EEBS in Ethiopia, ultimately with the aim to improve health outcomes for households with children under five. The intervention was implemented in 2019 in Ebenat and Simada, two Woreda (or districts) in the Amhara region in the South Gondar zone in rural North Western Ethiopia (see Figure 5.1 for a map). The intervention was conducted in the 292 villages within 10 randomly selected Kebele (or subdistricts) in these two Woreda. Detailed household data was collected by ERCS but unfortunately, the households could not be completely matched to our study sample. To provide some study context nonetheless, we report the descriptive statistics of this data (Table 5.1). This data was collected for 237 randomly selected households with children under five in 17 randomly selected Kebele in Ebenat and Simada There is thus an overlap between our study sample and this baseline data, but we do not know the extent of this overlap.

Health status is poor. About 10% of households reported that one or more of their children had pneumonia symptoms in the two weeks prior to the survey. 26.6% of households perceive the quality of health care as poor or fair. 46.4% of households report a travel time of more than 1 hour to the nearest health facility. Through

Table 5.1: Baseline descriptive statistics for Ebenat and Simada

Variable	N	Mean	SD
Household head age	237	35.975	8.433
Household head education (1-4)	193	1.813	0.864
Single-headed household (=1)	237	0.211	
Number of children under 5	237	1.215	0.487
Prevalence of child pneumonia symptoms (=1)	237	0.105	
Cooking outside (=1)	237	0.105	
Separate cooking area (=1)	237	0.641	
Wood for fuel (=1)	237	0.494	
Charcoal for fuel (=1)	237	0.165	
Travel time to health facility >1hour (=1)	237	0.464	
Perceived quality of health facility is poor or fair (=1)	237	0.266	

This data is collected in the same region as our intervention. There is some overlap in the villages between this survey and our sample. N is the number of observations, SD is the standard deviation and is provided for continuous variables. Household head education is a categorical variable where 1 = less than one year, 2 = primary, 3 = secondary, and 4 = higher. The pneumonia symptom prevalence variable measures whether any pneumonia symptoms were present for a child in the two weeks before the survey.

focus group discussions held in ten villages in the study region, our implementing partner found that women are responsible for fuel wood collection and cooking. They typically spend 10 - 20 hours per week on fuel wood collection, and only 27% of households buy wood. Children are often around women when cooking, exposing them to cooking fumes. Men are in control of the household budget and since budget constraints are tight, the affordability of EEBS is a constraining factor. Other constraints for adopting EEBS mentioned during qualitative field visits were a lack of intra-household bargaining power by women, low or no supply of EEBS to the villages, and the distance to selling points.

The EEBS that was introduced in this intervention is the Mirt stove. This fuel-efficient biomass stove is specialised for *injera* baking, the main staple food in Ethiopia (see the Appendix Figure A.5.1 for a picture). The stove was developed by the Ethiopian Energy Study and Research Center in the 1990s (Gebreegziabher et al., 2018). The Ethiopian government as well as various organisations have supported the production and commercialisation of the stove. Despite this early introduction and promotion of the Mirt stove, adoption of Mirt stoves remains low. In Ethiopia just 4% of rural households use a Mirt stove (Gaia Association, 2014). The stove is produced locally and its market price at the time of the study ranged between 100-250 Ethiopian Birr (ETB), which amounted to 3 to 8 USD in 2019. The preparation of injera accounts for the majority of household fuelwood consumption (60%). As such, the Mirt stove has been found to significantly reduce fuelwood use by 30 to 40% in field tests, whereas lab tests have shown fuelwood reductions of up to 50% (Gebreegziabher et al., 2018; Dresen et al., 2014; GIZ, 2011). In our study region, households who rely on wood collection can save approximately 12 ETB/day and households who buy wood can save around 46 ETB/day when adopting a Mirt stove.[2] The relatively low cost of the Mirt stove thus quickly pays off, making the low adoption rates all the more puzzling. The impact of Mirt stove use on indoor air quality and respiratory health has been largely unexplored, but following WHO standards, the stove is not expected to have a health impact. Results of laboratory tests suggest that the Mirt stove can reduce emissions by 50% compared to the traditional stove (GIZ, 2013). Field studies on this topic are scarce except for the recent contribution by LaFave et al. (2021), who, surprisingly, found positive effects of the Mirt stove on young children's health.

5.2.2 Experimental design

We assess the causal effect of two treatments that aim to increase uptake of the Mirt stove using a randomised 2x4 factorial design (see **??** for a schematic overview). Treatments were randomised across 292 villages through a lottery session. To ensure geographical balance, randomisation was blocked at the Kebele level. In each of the ten Kebele two parallel promotion events were organised by ERCS in April 2019. From each village, all households with a child under five were invited to one of the promotion events, in which the information that participants received about the Mirt stove varied. It was emphasised that both husband and wife should attend the event. At the end of each event, participants received a voucher to

[2] These values were obtained through a back-of-the-envelope fuel-saving calculation. We assume fuel consumption for cooking of 5.3 kg/day, 14.3 hours/week of fuel wood collection, and a fuel wood price of 25 ETB/kg (all values from qualitative field visits). The daily wage is assumed at 125 ETB/day (from World Food Programme casual labour prices for Ebinat, South-Gondar in 2020), and a workday is assumed to be 8 hours long. Mirt stove fuel wood saving is set at 35%. Last, we assume a linear relationship between fuel wood collection time and the amount of fuel wood collected.

purchase the Mirt stove with varying subsidy levels of 0%, 40%, 70%, and 100%. There is hence no pure control group. We estimate the treatment effect of the subsidy using the two groups that received no subsidy (i.e. the 0% voucher) as a reference group. To estimate the interaction effect between the two treatments, we use the group that received no subsidy and only health information as a reference group.

		Subsidy treatment			
		0%	**40%**	**70%**	**100%**
Information treatment	**Health only**	37 villages	40 villages	37 villages	37 villages
	Health and economic	33 villages	37 villages	38 villages	38 villages

Figure 5.2: Study design of 2x4 randomised controlled trial

This table shows the 2x4 factorial design of this study. Villages were randomly assigned to one of eight treatment groups with varying levels of information and subsidies. The number of villages assigned to each treatment is shown in the table cells. To measure treatment effects and interaction effects of the treatments we use 'Health only-0%'-villages and 'Health and economic, 0% subsidy'-villages as reference groups, respectively (darker shading).

At the promotion event, the first meeting included a stove demonstration, comparing the Mirt stove and the three-stone stove. Then, extension workers provided information on the potential health benefits related to a potential smoke exposure reduction (e.g. fewer lung infections, eye diseases, abdominal pain) and the workload reduction (e.g. fewer back problems due to firewood collection). They also engaged in discussions about these benefits with the villagers. In the second meeting, participants received the same information plus extension workers provided additional information on the monetary benefits of the Mirt and engaged in related discussions with villagers. Participants also did an exercise to calculate potential money saved due to fuel-saving.

Participants could use the vouchers to buy a Mirt stove within one year after the promotion event. After purchasing the stove, the stove would be produced within 2 to 3 months. The stove would then be transported to a central location close to the village. The household would have to transport the stove (which was disassembled into smaller parts). Installation was done by the household with help of extension officers. Payment for the stove was due upon delivery of the stove and could also be fulfilled in two instalments. In April 2020, a year after the promotion events were organised, ERCS aggregated the number of Mirt stoves sold with the voucher per village. This village-level measure is used as the outcome of this study. There was no data collected on how many villagers received a voucher and hence we only know the absolute number of stoves purchased per village. For more details on the randomisation, stove promotion meetings, and information provided, please refer to Appendix Subsection 5.5.2.

Since different subsidy groups attended the same Kebele promotion event, treatment contamination was possible in principle by households exchanging vouchers across villages. We deem this to be unlikely, though, because the vouchers could only be handed in at Mirt sales points by the household that received the voucher. Stove use was monitored by ERCS after installation to minimise spillovers. ERCS came across two cases where households had sold their Mirt stove. Spillovers for the information treatment were attempted to be kept at a minimum by randomising at the village level and by holding the meetings in parallel sessions at different venues. However, since vouchers were valid for a whole year, we cannot fully rule out information spillovers. It was initially intended to include endline questions on social learning to measure spillovers, but this activity was ceased due to the conflict. We expect, however, that if information from the economic information treatment groups reached the groups receiving health information only, the measured effect would be a lower bound of the true treatment effect.

Based on the randomisation we estimate the following model to assess the effect of subsidy levels on EEBS uptake:

$$Y_{ij} = \beta_0 + \beta_l \mathbf{SUBSIDY_i} + \gamma_j + \varepsilon_{ij}$$

Where Y_{ij} refers to the number of stoves sold in village i in Kebele j after the meeting, $\mathbf{SUBSIDY}_i$ is a vector of dummies for each subsidy level, using the group without a subsidy as a reference group. γ_j are Kebele-fixed effects. ε_{ij} is a village-specific error term. β_l captures the intent-to-treat effect (ITT) of the subsidy level l.

To estimate the interaction effect between information provision treatment and the subsidy level, we estimate the following model:

$$Y_{ij} = \beta_0 + \beta_t \mathbf{TREAT_i} + \gamma_j + \varepsilon_{ij}$$

Where Y_{ij} refers to the number of stoves sold in village i in Kebele j, $\mathbf{TREAT}_i$ is a vector of dummies for each combination of the type of information provision and subsidy level that the village received. γ_j are Kebele-fixed effects. ε_{ij} is a village-specific error term. The estimated ITT on uptake for each information meeting-subsidy level interaction t is given by β_t.

5.3 Results

Table 5.2 shows the impact of the subsidy level on stove uptake, not yet accounting for the different information treatments. We find that households in villages that received no subsidy collected on average 0.686 stoves. Once subsidies are introduced, uptake increases substantially, but the effect is only statistically significant for subsidies of 70% or higher. For the 40% group, Mirt sales increase by 0.763, which amounts to a 211.2% increase, but the difference is not statistically significant. At a subsidy level of 70% household uptake increases by 3.078 stoves, amounting to a 548.2% increase, and is statistically significant. At a subsidy level of 100%, average stove collection per village rises by 7.235 - a more than tenfold increase compared to villages that received no subsidy. When we calculate the price elasticity of demand we find a price elasticity of -1.63 going from no subsidy to a 40% subsidy, -1.29 going from a 40% subsidy to a 70% subsidy and a price elasticity of -0.31% going from 70% to 100%. This means that demand for the Mirt stove is elastic at higher prices (i.e. lower subsidies), and inelastic at lower prices (i.e. higher subsidies).

Table 5.3 shows the results of the interaction between information type and subsidy level. For both the 'Health only' and 'Health and economic'-meetings, uptake increases as subsidy levels increase. We additionally find that uptake increases

Table 5.2: Impact of subsidy level on stove uptake

	Number of stoves	% change
40% subsidy	0.763	211.2
	(0.702)	
70% subsidy	3.078***	548.8
	(0.888)	
100% subsidy	7.235***	1155.1
	(1.987)	
Mean "No subsidy"-group	0.686	
Kebele FE	*Yes*	
R^2	0.229	
Num. obs.	292	

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. OLS estimation of the effect of subsidy level on stove uptake. The coefficients shown are estimated relative to the 'No subsidy'-reference group. The %-change column shows the percentage change relative to the reference group. Robust standard errors in parenthesis. Robust standard errors in parenthesis. Includes Kebele-fixed effects.

substantially when households receive information on both health and economic benefits. At the 70% subsidy level, in villages that received information only health information, uptake increases by 2.518 stoves, i.e. a 682.2% increase, relative to the 'Health only, no subsidy'-reference group, For 70% subsidy level villages who received additional information on economic benefits, stove uptake increases by 4.190, i.e. a 1069.0% increase relative to the reference group. At the 100% subsidy level, villages receiving health-only information collect on average 5.156 stoves more than villages receiving the same information but without a subsidy, amounting to an increase in uptake by 1292.3%. For villages receiving both health and economic information, average stove uptake increases by 9.821 compared to the reference villages that received health information and no subsidies, amounting to a 2371.1% increase in uptake.

Figure 5.3 summarises our results in a graph showing the coefficients and confidence intervals by meeting type and subsidy level. It is apparent that for all villages that visited the 'Health and economic'-information meeting uptake is higher. Furthermore, in both meetings, uptake increases greatly as the subsidy level increases.

Table 5.3: Impact of meeting type x subsidy level on stove uptake

	Number of stoves	% change
Health only, 40% subsidy	0.776	279.4
	(0.862)	
Health only, 70% subsidy	2.518**	682.2
	(1.124)	
Health only, 100% susbidy	5.156***	1292.3
	(1.445)	
Health and economic, no subsidy	0.613	241.8
	(0.816)	
Health and economic, 40% subsidy	1.311	403.2
	(1.032)	
Health and economic, 70% subsidy	4.190***	1069
	(1.336)	
Health and economic, 100% susbidy	9.821***	2371.1
	(3.367)	
Mean "Health only, no subsidy" meeting	0.432	
Kebele FE	Yes	
R^2	0.244	
Num. obs.	292	

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. OLS estimation of the effect of type of meeting x subsidy level on stove uptake. The coefficients shown are estimated relative to the 'Health only, no subsidy'-reference group. The %-change column shows the percentage change relative to the reference group. Robust standard errors in parenthesis. Robust standard errors in parenthesis. Robust standard errors in parenthesis. Includes Kebele-fixed effects.

5.4 Discussion

The large potential for environmental, economic and health benefits through the diffusion and adoption of EEBS has not resulted in desirable uptake rates in the Global South. Recently, studies have identified major enablers for adoption: subsidies or financing schemes for technologies that meet household needs, namely technologies that save time and fuel (Berkouwer et al., 2021; Bensch and Peters, 2020; Pattanayak et al., 2019). Our study contributes to this growing literature by experimentally testing whether lifting two potential constraints, i.e. a financial constraint and an information constraint, can improve EEBS uptake in Ethiopia.

Our finding, that subsidisation is highly effective in stimulating uptake, is in

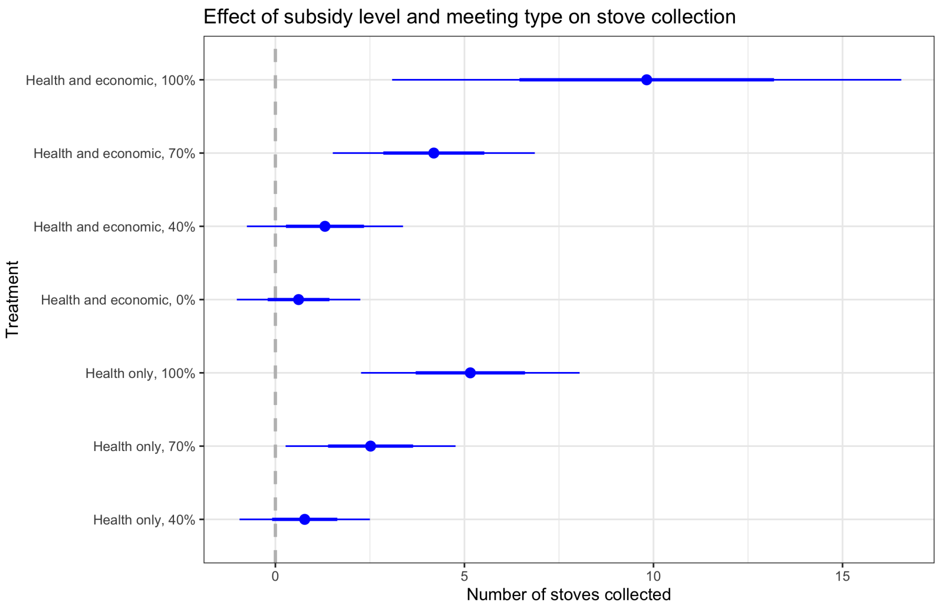

Figure 5.3: Effect of subsidy level and meeting type on stove collection

This figure shows the coefficients and 95% confidence intervals for each meeting type x subsidy level relative to the reference group 'Health only, no subsidy' on stove uptake. The average stove collection for the reference group is 0.432 stoves. Estimations include Kebele-fixed effects and robust standard errors.

line with previous research. Bensch et al. (2015) find suggestive evidence that in Burkina Faso a major barrier to adoption is the upfront investment cost, either caused by liquidity constraints or time preferences. Bensch and Peters (2015) find that free distribution in Senegal stimulates uptake substantially (leading to a near 100% take-up rate). Pattanayak et al. (2019) find evidence of highly price-sensitive demand in their study in India and conclude that with the right combination of provision of information and incentives, stove uptake can improve greatly. Because the level of subsidies was varied, we were able to show that only high subsidies (70% and 100%) are effective in increasing uptake substantially. Our results underline that demand for EEBS is highly price-elastic and can be increased with high levels of subsidies.

A novel insight from our study is that lifting information constraints can be beneficial and that uptake is dependent on the type of information that households receive. We find that households who receive information on the health and economic benefits of EEBS are twice as likely to adopt the technology than households who receive health information alone. However, this effect is only visible for high subsidy levels (70% and 100%). This confirms previous findings by Mobarak et al. (2012) who find that the health hazard for households is of insufficient priority to make an adoption decision in Bangladesh. The result can also be potentially explained by a lack of bargaining power by women in the household. As shown by (Miller and Mobarak, 2013), women have a stronger preference for healthier stoves but lack the authority to make purchases. By disseminating information on the economic benefits, men may be more inclined to approve of buying a stove. This was also mentioned as one of the constraints for adoption during the focus group discussions in this study.

Arguably, barriers to adoption are context-dependent and these results should be translated into a policy message with care and knowledge of the local context. However, this research does strengthen the notion of the considerable importance of economic incentives in uptake decisions of EEBS technologies. The fear of long-term market disturbance caused by subsidisation has been shown to be unsubstantiated in Senegal (Bensch and Peters, 2020). Another potential worry is that subsidies affect regular usage because receivers value the technology less or because psychological sunk cost effects that promote use are reduced. Bluffstone et al. (2021), who study the same EEBS technology in Ethiopia, find that households who received the Mirt stove for free used it just as much as households who received monetary incentives that encouraged regular use. Thus, policymakers and NGOs should seriously consider subsidies as a policy instrument. Complementary instruments, like the dissemination of information on the economic benefits, should be considered as well. Information without subsidies on the other hand is not effective in stimulating adoption.

5.5 Appendix

5.5.1 Mirt stove

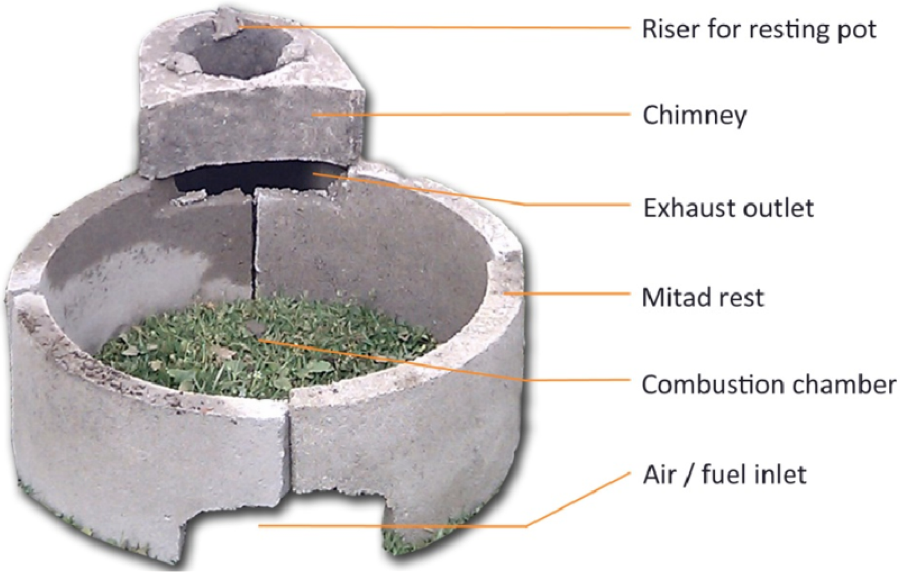

Figure A.5.1: The Mirt stove design

Source: Forest News (2014)

5.5.2 Details on stove intervention

Lottery

The randomisation of the treatment took place during a lottery. This lottery took place in a separate event prior to the stove information meetings. Representatives at the Woreda level from the following institutions were invited to the lottery meeting: Health Bureau, Women and Children Affairs Bureau, Ministry of Mines and Energy, WASH, Local Administration and Ministry of Agriculture. In addition, Kebele officials (chairperson and manager) as well as Health Extension Workers (HEWs), opinion leaders and the staff members of the involved RC branch team will be invited for the meeting as well.

At the meeting, the intervention was explained to the local stakeholders. Subsequently, the lottery was conducted. For each Kebele, a separate lottery was held with Kebele representatives and RC staff. The lottery was conducted by drawing a ticket for each village. Treatment assignments were noted down by RC (Red Cross) staff. Then Kebele representatives were given a list of villages with their assigned information treatment A (health only) or B (health and economic benefits). The HEWs and Kebele Administrators were asked to invite the households with children under five from the villages on the list according to their assigned meeting. They were also asked to emphasise the importance of male attendance. The subsidy treatment assignment was not given to the administrators.

Stove information meeting

The two information meetings A and B were held simultaneously in each Kebele at two different locations. At the locations where the meetings took place, music was played and the traditional stove and Mirt stove were installed while participants were waiting for the meeting to start. Before the meetings started, RC made sure that all households were present at the right location, that the groups for meeting A and meeting B did not mix. At both meetings, a drama piece was performed. Because there was only one drama team, the meetings had a slightly different order of activities.

For each of the two meetings, the activities are detailed below:

Meeting A – Health benefits

1. Drama piece on the comparison between three stone stove and Mirt stove. A cooking demonstration was integrated in this drama piece.
2. Discussion on the message of drama piece. What have you learned from it?
3. Introduction of project and stove component by RC staff members.
4. The health benefits of the Mirt stove were discussed by RC staff members. Also, safety of stove was been addressed. See below for the benefits discussed.
5. Presentation of representative of water and energy office on the Mirt stove.
6. Time for comments, testimonies and questions. HEW repeated lessons learnt.

7. RC staff members provided information on the lottery and its outcomes.
8. Issuance of the vouchers.

The following information was disseminated:

General information:

- The Mirt stove is very clean and safe (less burns and fires)
- The Mirt stove reduces smoke up to 50 percent compared to a traditional stove
- The Mirt stove reduces the negative effect of indoor air pollution on respiratory health and eyes
- The Mirt stove is very efficient. Reduction of deforestation and workload for women.

Health benefits:

- Eye diseases – e.g. trachoma, cataract
- ARI – infection chronic lung disease – use local names
- Severe fatigue (Yelib Dikam – local explanation) – as a result of carbon monoxide and particulate materials
- 1st degree burn – because of the flame and frequent exposure
- Stomach upset (GI) due to Poor hygiene and food handling practices
- Negative effect during pregnancy – could lead to low birth weight, early delivery (premature delivery)
- More time to take care of children under five, have good domestic hygiene practices, have adequate time to feed and breast feed children – this could have having direct and indirect effect on the nutrition status of the child, and child growth
- Putting more burden on pregnant mothers – during firewood collection, cow dung preparation – (Kebad Sira)

- Back pain and negative effect on posture – due to firewood collection, while working on traditional stove
- Benefit for men: healthy children, healthy wife/mother, health family

Meeting B: Health and economic benefits

1. Introduction of project and stove component by RC staff members.
2. The health and economic benefits of the Mirt stove were discussed by RC staff members. Also, safety of stove has been addressed. See below for the information disseminated.
3. An exercise was conducted to quantify the fuel consumption savings linked to Mirt stove usage. Attendants were asked the following questions: For how much could you sell the result of one fuel collection moment? How often do you collect wood in a week? How much is the cost of one bundle? How many bundles do you use per week? Then this information was used to calculate the fuel consumption savings. So, a reduction in fuel consumption could save you ... ETB in one week. This means that after ... weeks you have earned back the money that you have invested in the Mirt stove.
4. Presentation of representative of water and energy office on the Mirt stove.
5. Drama piece on the comparison between three stone stove and Mirt stove. A cooking demonstration is integrated in this drama piece.
6. Discussion on message of drama piece. What have you learned from it? 7.
7. Time for comments, testimonies and questions. HEW repeats lessons learnt.8.
8. RC staff members provided information on the lottery and its outcomes.
9. Issuance of the vouchers.

The following information was disseminated:

General information:

- The Mirt stove is very clean and safe (less burns and fires)

- The Mirt stove reduces smoke up to 50 percent compared to a traditional stove
- The Mirt stove reduces the negative effect of indoor air pollution on respiratory health and eyes.
- The Mirt stove is very efficient. It can reduce fuel consumption by 30 up to 40 percent (show piles to indicate difference in fuel usage). Reduction of deforestation.
- Other households that have adopted this stove have saved 33 ETB per month or approximately 6 hours of time per week.

Health benefits:

- Eye diseases – e.g. trachoma, cataract
- ARI – infection chronic lung disease – use local names
- Severe fatigue (Yelib Dikam – local explanation) – as a result of carbon monoxide and particulate materials
- 1st degree burn – because of the flame and frequent exposure
- Stomach upset (GI) due to Poor hygiene and food handling practices
- Negative effect during pregnancy – could lead to low birth weight, early delivery (premature delivery)
- More time to take care of children under five, have good domestic hygiene practices, have adequate time to feed and breast feed children – this could have having direct and indirect effect on the nutrition status of the child, and child growth
- Putting more burden on pregnant mothers – during firewood collection, cow dung preparation – (Kebad Sira)
- Back pain and negative effect on posture – due to firewood collection, while working on traditional stove
- Benefit for men: healthy children, healthy wife/mother, health family

Economic benefits:

- Saving money for other benefits e.g. health insurance, school fees, payment of Edir, buy more food
- Less time for fuel collection, have time for farming and other economic activities, take care of animals
- Less expenditure on medical care
- Reduce deforestation – reduce negative climate effect – improve productivity from farming
- Benefit for men: less money spent on purchase of fire wood, less money is spent on health problems, use of wood for other activities e.g. fencing, renovating houses, less labour on cutting woods, clean house, healthy children, healthy wife / mother
- Less time spend on referring sick child to the hospital
- More time for social activities

Explanation of the lottery

During the explanation of the lottery, RC provided arguments for why the lottery was justified (i.e. budget issues and because of the experience that when something is provided for free it is often not used properly). The process of drawing lottery tickets was explained and it was emphasised that since different tickets were drawn for different village, households from one village may pay 100 ETB for the stove, while others pay 40 or 70 ETB and others pay nothing. This was fairly decided by means of the lottery and is simply a matter of chance.

Issuance of vouchers

First, vulnerable households from the list prepared by the Kebele administrator and HEWs were asked to come forward to receive their voucher. These households received a 100% subsidy. For these vulnerable households, empty vouchers were filled in with their name, village, Kebele, date and stove price (see Figure A.5.2 for a voucher example).

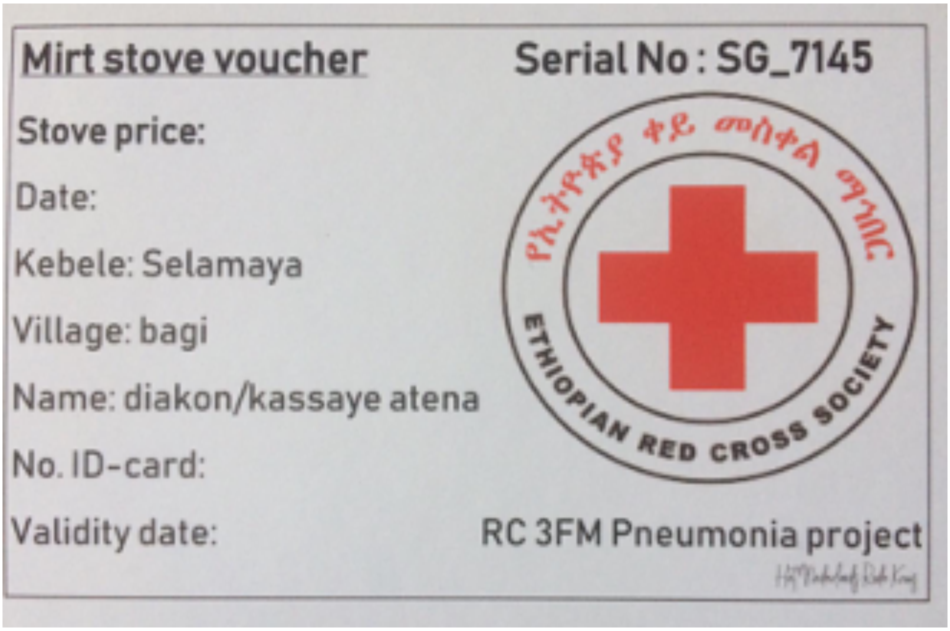

Figure A.5.2: Mirt stove vouchers issued to beneficiaries by Red Cross

Chapter 6

Better soils for healthier lives: An econometric assessment of the link between soil nutrients and malnutrition in Sub-Saharan Africa

Malnutrition, defined as the suboptimal consumption of essential nutrients, severely affects human health. One option to combat malnutrition is agronomic fortification, which remains ill-understood, primarily due to a paucity of field trials. We hypothesise that, if at all this is an effective strategy, there should exist a causal link between malnutrition and natural variation in the quality of soils to begin with. Until now, data limitations prevented the establishment of such a link, but new soil micronutrient maps for Sub-Saharan Africa allow for a detailed assessment. In doing so, we find statistically significant relations between soil nutrients and child mortality, stunting, wasting, and underweight. The effects of soil nutrients on health dissipate when malaria pressure increases. Yet, the effects are fairly small in magnitude suggesting that except for a few regions, agronomic fortification is a relatively cost-ineffective means to combat malnutrition.

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6.1 Introduction

Malnutrition –also dubbed hidden hunger– refers to a suboptimal intake of essential nutrients (proteins, minerals, metals and vitamins), even if and where calorific intake is at least sufficient. Globally, 2 – 3 billion people are estimated to be deficient in micronutrients, mostly iodine, iron (60% of the global population) and zinc (30% of the global population) (Teklić et al., 2013; Cakmak et al., 2010). Zinc deficiency prolongs (a.o.) episodes of diarrhoea leading to dehydration and is a leading cause of child mortality (Lim et al., 2012). Deficiencies are also associated with childhood stunting (height of child too low for age) and wasting (weight of child too low for height), impairing child cognitive and physical development (Black et al., 2013). This burden of malnutrition is particularly severe in low-income societies, including most countries in Sub-Saharan Africa (SSA) (Lim et al., 2012; Stein, 2014). Moreover, ill-health carries a considerable economic penalty. It is thought that zinc and iron deficiencies reduce GDP of low-income countries by 2-5% (Stein, 2014).

For these reasons, alleviating malnutrition is widely considered a top priority in development and development assistance. The Copenhagen Consensus Center, for instance, consistently lists alleviating malnutrition as one of the most cost-efficient development interventions (e.g. Lomborg 2014; Horton and Hoddinott 2014; Horton et al. 2009). By and large, five different interventions exist to address malnutrition. Three of these are post-harvest interventions: 1) the fortification of commonly consumed, processed foods, 2) supplementation in the form of powders or capsules and 3) the promotion of dietary diversity. The others, 4) genetic fortification and 5) agronomic fortification, fall within the realm of agricultural production and/or agricultural development assistance. The potential of agronomic fortification in SSA is the focus of this study.

Our study is motivated by the observation that relatively little information exists on the cost-effectiveness of these agriculture-based interventions in order to guide policy-makers in the choice for one, or combinations of these. Most insights into cost-effectiveness as put forward by the Copenhagen Consensus are based on food fortification or supplementation (Horton and Hoddinott, 2014). Ex-ante assessments of genetic fortification – breeding new crop varieties with higher nutrient content – do suggest it can be highly cost-effective (Meenakshi et al., 2010), but very few ex-post evaluations exist to date. Agronomic fortification entails the supplementation of micronutrients through inorganic fertiliser. The rationale is that micronutrient deficiencies in food may stem from inherently low densities in the harvested products, caused by missing nutrients in soils. The latter also provides a partial explanation for low agricultural productivity in SSA itself (Berkhout et al., 2017). In fact, genetic fortification may be an inefficient strategy when soil nutrient densities are low to begin with (Lyons and Cakmak, 2012). Moreover, the promotion of organic fertilisers, sourced locally in nutrient scarce regions, is likely to be insufficient for addressing soil nutrient deficiencies. The latter necessitates the supply of nutrients from external sources.

Agronomic fortification could thus be one stone to kill two birds, raising both agricultural productivity and production, as well as reducing incidences of malnutrition. Various scientists and organisations, not least the International Zinc Association (IZA), point to these perceived dual benefits (Joy et al., 2015; Bevis, 2015a; Dimkpa and Bindraban, 2016; IZA, 2018). But, little information is available to understand its actual impact and cost-effectiveness. This stems from a paucity of field trials, particularly in Sub-Saharan Africa. A recent systematic review for SSA, identifying only forty studies, indeed reveals a positive impact of micronutrient-enriched fertilisers on agricultural productivity (Kihara et al., 2017). One study does assess the ex-ante impact of agronomic fortification with zinc on human nutritional status, and suggests it can be cost-effective (Joy et al., 2015). But, to our knowledge, no studies have assessed impact of agronomic fortification on human nutritional status in Sub-Saharan Africa ex-post. Altogether, we know of only one detailed study documenting the impact of agronomic fortification on human health, being one on selenium-enriched fertilisers in Finland (Ros et al., 2016).

Whether or not agronomic fortification is a cost-effective means to alleviate the burden of malnutrition thus remains ill-understood. To circumvent this information scarcity this study follows a different approach. We hypothesise that if, at all, enriching soils with supplemental (micro-)nutrients has a beneficial effect on human health, such a relation should also become apparent when assessing the impact of natural variation in soil nutrient densities on human health. In other words, do differences in health outcomes become apparent and statistically significant when comparing two regions that differ with respect to average densities of soil nutrients only (or when differences are otherwise controlled for)? If so, we hypothesise that the magnitude of this effect provides a fairly robust proxy for the potential impact of agronomic fortification.

To our knowledge, such a relation between soil nutrients and human nutritional status has not been assessed before, mostly due to limited availability of soil data. This study, however, builds on a novel dataset that maps predicted nutrient densities for an array of macro- and micronutrients across Sub-Saharan Africa at a high spatial resolution (Hengl et al., 2017). We subsequently estimate several econometric model specifications to discern the causal effects of variation in such densities on spatial differences in child malnutrition (mortality, stunting, wasting and underweight). We find several statistically significant effects, for some nutrients on some of these health indicators. Mostly, the signs of these effects are plausible and as expected: increases in micronutrients manganese, zinc and copper translate into reductions in child mortality and stunting. Children living in areas with soils rich in calcium and magnesium are typically taller, thus reducing incidences of stunting but, all other things being equal, increasing wasting.

In the final step of this paper we use the estimated magnitude of the effect of additional soil micronutrients on child mortality to calculate the costs per child life saved and compare this figure with cost-effectiveness of other interventions. Even though the effects are statistically significant the actual magnitude of the effect is fairly small. This translates into costs per child life saved that are often greater than those of other alternative strategies available. The exceptions are regions where both population densities are high, soil nutrient densities and malaria pressure is low, specifically the Ethiopian highlands, Rwanda, Burundi and to a lesser degree Nigeria. We therefore conclude that the key merit of agronomic fortification should rest with increasing agricultural productivity but that other types of interventions are more cost-effective in combatting malnutrition.

6.2 Conceptual approach and methods

The analysis in this paper is based on the conceptual model described by Equation 6.1, in which we set to explain variation in four different health indicators H, from factors $\vec{F}$ describing differences in soil quality and a set of controls $\vec{C}$. Equation 6.1 is estimated for four different health indicators available in the Demographic and Health Survey (The DHS Program, 2018) (details available in the data Section 6.3). These are child mortality, prevalence of underweight children, prevalence of child stunting and prevalence of child wasting. Factors $\vec{F}$ describing differences in soil data are based on the detailed grid level data on soil nutrients estimated by Hengl et al. (2017). We use factor analysis to reduce the dimensionality of this dataset. This is both a useful exercise in itself, providing insight into spatial correlation amongst soil nutrients, as well as a means to reduce potential problems of multicollinearity in the estimation approach. The hypothesis is that increases in soil nutrient densities, i.e. increases in $\vec{F}$, translate into a reduction in incidences of mortality, stunting, wasting or underweight. In other words, we expect negative estimates for β which signal an increase in health due to soils richer in nutrients. Finally, a set of controls $\vec{C}$ is included, using variables used in other recent econometric spatial analyses of African development. Details on all of these variables is provided in the data Section 6.3.

$$H = \alpha + \beta\vec{F} + \gamma\vec{C} + \epsilon \tag{6.1}$$

There could be two distinct, though partially overlapping, pathways of impact. First, richer soils signal a greater agricultural production potential. This is a logical analogy to the finding that fertilisation with micronutrients has a positive effect on crop yields in SSA (Kihara et al., 2017). Or, if such nutrients are already naturally available in sufficient quantities this should also imply greater crop productivity. Then, all other things being equal, a greater production potential translates into greater income for local farmers. The relation between better soils, greater income and or reduced poverty has now been established in various studies across the developing world (Barrett and Bevis, 2015). Such an income effect allows farmers to consume more, not necessarily own produce, and/or to smooth income fluctuations and consumption shortfalls better. Greater income allows for increased spending on health services, the purchase of more and food of better quality including more animal-based food products. In all these cases the actual consumption of proteins and micronutrients may increase, both of which lead to reductions in malnutrition (Müller and Krawinkel, 2005). That increases in (agricultural) income translate into better nutrition security may seem straightforward, but empirical assessments of such a relation are relatively scarce and difficult to interpret due to contemporaneously confounding effects such as institutional quality (e.g. Deaton 2013). One study from Malawi did identify increases in nutrition resulting from the Malawi national fertiliser subsidy program (Harou, 2018). Since this program does not cover fertilisers enriched with micronutrients, this result primarily hints at improved nutrition through an income effect.

The second reason for a positive effect of soil nutrients on human health relates to increases in micronutrient availability in the harvested product. Since richer soils translate into greater production, the amount of nutrients contained in harvested product increases as well. But, it is more difficult to predict whether or not the relative content of nutrients in harvested product changes. So-called yield dilution could occur. For instance, the widespread application of macronutrients through fertilisers has been cited as a reason for decreasing relative micronutrient content in food items (Thomas, 2007). That said, the various agronomic field trials cited in Joy et al. (2015) and Kihara et al. (2017) do observe increases in nutrients stored in plant tissue as a result of agronomic fortification. Soils richer in soil nutrients could thus either translate into more production, or production with greater nutritive content, or both. Either way, the total volume of nutrients stored in harvested crop products is bound to increase, along with the harvested crop product itself. Furthermore, the share of Africa's agricultural production that is exported is small, and most of the production is consumed at locations close to the farm (Diao et al., 2007; Poulton et al., 2006). It is thus likely that the volume of nutrients stored in crops destined for local consumption, for feeding a given population in a grid cell, is greater in those regions with richer soils.

By estimating Equation 6.1, we estimate a reduced form and assume that all relevant income and consumption effects, resulting from variation in soil nutrients, have evolved into an equilibrium effect captured by parameter β. Our estimation approach closely follows the approach used by Michalopoulos and Papaioannou (2013), also including many of the same control variables. We estimate Equation 6.1 using OLS in Stata and since the soil data is a cross-section so is our estimation approach. Observations are arranged at the lowest possible grid cell level, in our case grid cells at a resolution of 5km x 5km. We cluster standard errors twice, using the multiway clustering approach developed by Colin Cameron et al. (2011)(available through the reghde command available for Stata developed by Correia 2014) in order to account for unobserved spatial correlations. In each specification, we cluster at the country level and either at the regional level (for which most health data is provided) or at the level of precolonial institutions (also see data description).

Our estimates of Equation 6.1 do not directly discriminate between either of two possible chains of causality. In line with virtually all other studies on malnutrition we can only rely on detailed data on the outcomes or symptoms of malnutrition, i.e., the anthropometric measurements, as spatially disaggregated food consumption surveys are mostly unavailable. However, cross-terms between soil nutrients and the share of marketed produce could reveal whether a positive effect between soils and health is stronger for households (or regions) in which own consumption of agricultural produce is more common. This could suggest that the nutrient supply mechanism dominates. Unfortunately, continent-wide data on the share of marketed produce (and subsistence consumption) is unavailable and we resort to proxies for market development.

In the final step, we monetise the costs underlying the estimated marginal effect β, by calculating the underlying market value of an increase in soil micronutrients. In other words, how much would it cost to buy a specific volume of micronutrients on world markets, and using this volume to increase the density of soil nutrients in a particular grid cell? We use recent market prices from the London Metal Exchange to monetise these costs. Obviously, this calculation reflects a lower bound as it does not account for actual fertiliser product development, transportation and marketing costs.

We make this calculation for one combination of nutrients and health outcome only, namely for micronutrients (zinc, manganese and copper) in relation to child mortality. To be precise, we calculate the costs of one child death averted resulting from increasing the soil nutrient content of these elements. Since much of current research on malnutrition focuses on the role of zinc in relation to mortality and stunting, it provides ample cost-estimates to compare our figures with. We leave the monetisation of costs and benefits of other elements, and their interpretation, to future research.

6.3 Data

In order to estimate Equation 6.1, several existing data sets have been adapted and merged into a Stata data file. This section describes key details of data sources and the adaptations carried out.

6.3.1 Health data

We set to explain variation in four health indicators (Table 6.1) commonly used to assess the impact of malnutrition in Sub-Saharan Africa. For instance, in 2010, childhood underweight was responsible for around 19% of under-five deaths and Disability Adjusted Life Year (DALY) loss, zinc deficiencies for around 5% of under-five deaths and DALY loss and iron deficiencies for around 0.6% of child deaths and 6% of total DALY loss (Lim et al., 2012). Indicators used in this analysis are those from the Demographic and Health survey (The DHS Program, 2018). Highly detailed maps revealing spatial variation in incidences of stunting and wasting (at 5km x 5km) across Africa have been published recently (Osgood-Zimmerman et al., 2018). The estimation procedure used to generate these maps relies on covariates that are similar to the ones underlying the estimates of soil nutrient maps used in this study (see Subsection 6.3.2). For this reason, these maps, and the underlying data, are unsuitable for use in our assessment for risk of identifying a spurious relationship. Luckily, the indicators are provided at subnational level for all African countries. As the spatial resolution of our soil data is greater, we assume that the average health indicators in each grid cell are equal to the district averages. Table 6.1 provides definitions, means and standard deviations. It shows, for instance, that the average child mortality rate is 44, meaning that for every

1,000 children reaching their fifth birthday, 44 children have passed away.

Table 6.1: Summary statistics of health indicators

Indicator	Description	Definition	Mean	SD
H1	Child mortality: odds of dying too young	Mortality rate (out of 1000 children surviving their first birthday) of children between first and fifth birthday.	44.47	24.28
H2	Child stunting: height of children too low for age	% of children with height for age more than two standard deviations below WHO reference.	38.53	9.00
H3	Child wasting: weight of children too low for height	% of children with weight for height more than two standard deviations below WHO reference.	9.74	6.08
H4	Child underweight: weight of children too low for age	% of children with weight for age more than two standard deviations below WHO reference.	21.33	9.23

SD is the standard deviation. Data is from the Demographic and Health Survey (2018).

6.3.2 Soil data

The detailed spatial predictions of soil nutrient densities by Hengl et al. (2017) form the basis of our analysis. Their approach is based on the compilation of a georeferenced dataset of soil samples across Africa from the past 50 years, together comprising a dataset of around 55,000 unique point estimates. Hengl et al. (2017) use machine learning to estimate variation in soil nutrient densities as a function of an array of geophysical/climatic variables. These estimates are subsequently used to predict soil nutrient densities in all grid cells for which no soil samples exist. Figure 6.1 shows such extrapolations for zinc and manganese concentrations.

Such predictions, for grid cells of 250m by 250m, form the basis for the soil factors F used in our analysis. We aggregate and average the soil data to grid cells of 5km by 5km as much of the other data used is not available on such a detailed scale. All data (Table 6.2) are an estimate of the nutrient content (macro- and micronutrients, as well as organic matter content) in the topsoil (30 cm) and are available for 813,704 point estimates across Sub-Saharan Africa (Hengl et al., 2017). The original data provides information on particles per million, which is converted to kilograms per hectare as discussed in Berkhout et al. (2017) This data considers Sub-Saharan Africa as all land mass below a latitude of 28 degrees north. Hengl et al. (2017) also provide estimates for phosphorus (P) and sulphur (S). As the fit of these estimates is very low (R^2 of 0.11 and 0.10 respectively) these elements are

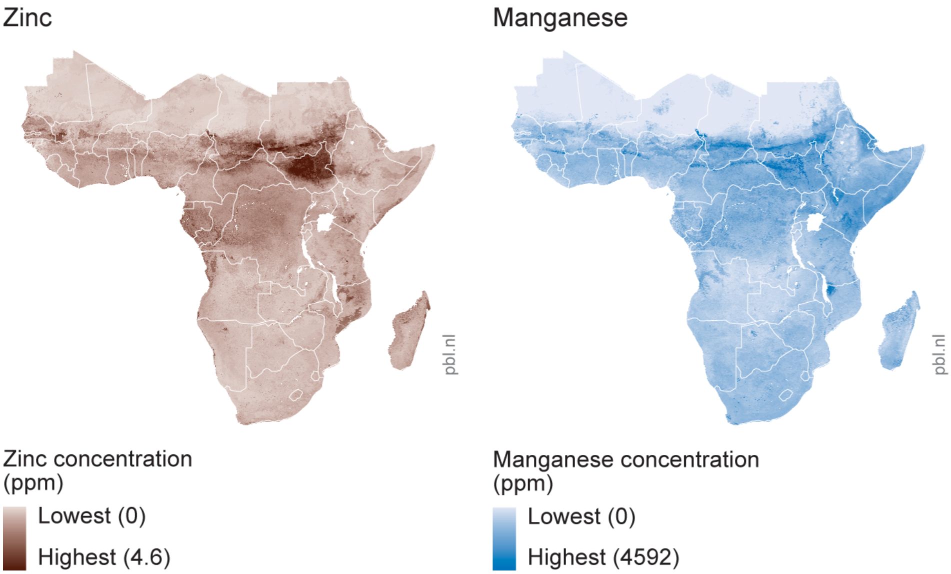

Figure 6.1: Estimated concentrations of zinc and manganese in soils across Sub-Saharan Africa

Sources: Hengl et al. (2017)

not included in this analysis.

Altogether 10 variables are thus available for inclusion in Equation 6.1. We use factor analysis to reduce the dimensionality of this dataset. If one or more variables co-vary strongly, the estimation of Equation 6.1 is affected by multicollinearity. In addition, factor analysis is likely to reduce the impact of measurement error underlying the variables in Table 6.2. Moreover, an understanding of which soil nutrients co-vary is insightful information in itself. In fact, strong communal variation between certain soil variables may stem from the fact that certain geological or soil formation processes affect soil nutrient densities similarly.

Table 6.3 and Table 6.4 display the outcome of a standard factor analysis, carried out in Stata using the commands factor and rotate with default options. Code of the full data adaptation and estimation procedures are found in the Stata do-files available with the publication. The goal is to reduce the 10 soil nutrient variables

Table 6.2: Key characteristics of soil data

Soil nutrient	Mean	SD
Boron (B)	0.29	0.21
Calcium (Ca)	1041.29	842.46
Copper (Cu)	1.06	0.86
Iron (Fe)	39.44	27.07
Potassium (K)	69.96	51.72
Magnesium (Mg)	166.06	136.09
Manganese (Mn)	41.18	22.56
Nitrogen (N)	315.00	162.88
Organic Matter Content (OMC)	4.64	3.39
Zinc (Zn)	1.58	1.18

Measured in kg/ha in 30cm topsoil. SD is the standard deviation. Data is for Sub-Saharan Africa and comes from Hengl et al. (2017).

to a smaller set of variables that still account for most of the variation present in the original data (e.g. DeVellis 2003). Such a reduction is possible if, and only if, two or more variables are strongly correlated. In such cases these correlated variables can be proxied by a single new variable (factor). The first step is the initial factor extraction (Table 6.3) and the second step involves a rotation of these extracted factors that allows for clearer interpretation (Table 6.4). The rotated factors displayed in Table 6.4 are the ones included in our analysis.

Table 6.3: Exploratory factor loadings

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Unique
Boron (B)	0.4318	0.0928	0.3736	0.4125	0.4953
Calcium (Ca)	-0.0505	**0.8511**	-0.3510	0.0815	0.1431
Copper (Cu)	**0.8337**	0.0314	0.1021	0.0894	0.2856
Iron (Fe)	0.2387	-0.6075	0.5614	0.0626	0.2549
Potassium (K)	0.2260	0.5141	0.1652	0.5745	0.3273
Magnesium (Mg)	0.2765	**0.7749**	-0.1161	0.1405	0.2898
Manganese (Mn)	**0.7647**	0.1015	0.1193	0.3781	0.2478
Nitrogen (N)	0.1758	-0.1981	**0.7975**	0.1497	0.2715
Organic Matter (OMC)	0.1245	-0.3049	**0.7808**	0.0199	0.2816
Zinc (Zn)	**0.8089**	-0.0140	0.2026	-0.0649	0.3002

This table displays factor loadings (correlations between original variables and constructed factors) resulting from a factor analysis carried out on soil nutrient variables in Sub-Saharan Africa. The strongest correlations (>0.75) are highlighted in bold. The column 'Unique' displays the variance of a particular variable that is not captured by the factors.

Table 6.3 displays the first four factors extracted, those with positive eigenvalues. The eigenvalues are a reflection of the accuracy by which the factors account for the original underlying variation. As a rule-of-thumb (the so-called Kaiser criterion) typically only factors with eigenvalues greater than one are used in further analysis

Table 6.4: Predicted factor loadings

Variable	Factor 1	Factor 2	Factor 3
Boron (B)	0.02394	0.01475	0.05746
Calcium (Ca)	-0.06596	**0.62579**	0.09460
Copper (Cu)	**0.36668**	-0.00885	-0.08382
Iron (Fe)	0.04641	-0.15850	0.15683
Potassium (K)	-0.07706	0.06731	0.07392
Magnesium (Mg)	0.09113	**0.28120**	0.10559
Manganese (Mn)	**0.29581**	-0.06854	-0.14837
Nitrogen (N)	-0.09126	0.16747	**0.45675**
Organic Matter (OMC)	-0.05701	0.08977	**0.42514**
Zinc (Zn)	**0.35496**	0.01262	0.01109

This table displays a Varimax rotation of the factors extracted in Table 6.3 explaining variance in soil nutrients. Highlighted in bold are the soil nutrients that are contribute the most to the respective factor.

(DeVellis, 2003). In Table 6.3, this holds for the first two extracted factors only (3.41 and 2.72 respectively). We do, however, also include the third factor (despite the lower eigenvalue of 0.76), primarily as it is the only factor that appears to capture variation in nitrogen and organic matter well (two important and often used indicators of soil fertility and quality).

Table 6.3 displays the exploratory factor loadings, which are the correlations between the original variables and the newly constructed factors. The strongest variations (>0.75) are highlighted in bold. Thus, factor 1 strongly captures communal variation in three micronutrients (copper, manganese and zinc). The second captures variation of macronutrients (calcium and magnesium) and the third factor captures communal variation between macronutrient nitrogen and soil organic matter content. The last column in Table 6.3 displays so-called uniqueness. This is a measure of the variance of the particular variable that is not captured in underlying communal variance. The higher it is, the more unique a variable is and the less of its variance co-moves with the variance in other variables. With the possible exception of boron, most of these uniqueness scores are fairly low, indeed suggesting that much of the variance is communal. We subsequently carry out a rotation (Varimax rotation) for these three factors allowing for easier interpretation (Table 6.4).

Table 6.4 lists newly constructed soil factors that are a linear combination of the original, but normalised, data from Table 6.2. It thereby maintains the strength of the factor loadings as presented in Table 6.3. For instance, $Factor_1$ is constructed as follows:

$$Factor_1 = f_B + \overline{B} + f_ca * \overline{Ca} + f_cu * \overline{Cu} + ... + f_zn + \overline{Zn} \qquad (6.2)$$

Hereby, $\overline{B}$, $\overline{Ca}$ and $\overline{Cu}$ (and so on and so forth) reflect normalised variables or z-scores. The factor loadings f_B, f_ca, f_cu in Equation 6.2 are those as presented in Table 6.4. Thus, the first factor is mostly a weighted mean of micronutrients based on the standardised variables of copper (0.36668), manganese (0.29581) and zinc (0.35496). Variation from the remaining soil variables only contributes very modestly to Factor 1. The second factor captures variations in calcium and magnesium densities and the third factor is strongly associated with nitrogen soil densities and organic matter content. The strong communal variation between some variables, like zinc, manganese and copper, also suggests that it is fairly difficult to isolate causal effects from one of these elements separately. Or, there is too little idiosyncratic variation in one element, while holding the others constant, to tease out its impact on health outcomes. We subsequently use these factors to estimate the effects of soil differences on health outcomes in the next sections.

6.3.3 Control variables

We further include a set of controls $\overline{C}$, largely in line with other recent spatial analyses of African development (e.g. Michalopoulos and Papaioannou 2013), to take account of various other variables that may explain differences in health outcomes. An overview of variables used and their data source is presented in Table 6.5. These variables describe differences in economic development, or potential, and as discussed in detail below may further shape nutrient availability and consumption.

In addition, we include the malaria stability index developed by Kiszewski et al. (2004). Malaria is one of several parasitic diseases that are known to interact with malnutrition. In addition, incidences of intestinal parasites, diarrhoea, pneumonia, measles and AIDS are known to impair nutrient intake leading to increased malnutrition (Katona and Katona-Apte, 2008). But, to complicate matters, in

Table 6.5: Control variables

Variable	Unit/values	Description and data source
Night time luminosity	0-63	NOAA (2017). Data from 2013. Greater values signal greater night time luminosity.
Night time luminosity	Grid cell is lit (=1)	Author's calculations using 2013 data from NOAA (2017)
Population density (log)	Log(# per km2)	Center for International Earth Science Information Network (CIESIN) Columbia University (2016). Data for 2015 used.
Institutional Hierarchy	0-4	Murdoch (1967) from the Ethnographic Atlas. Describes the number of political jurisdictions above the local level for each ethnicity. 0=stateless societies, 1=petty chiefdoms, 2=paramount chiefdoms, 3,4 = groups that were part of larger states.
Malaria stability index	0-39	Kiszewski et al. (2004). Greater values signal greater malaria pressure.
Location of water bodies	Water body covers grid cell (=1)	Author's calculations in ArcGIS using DCW Waterbodies
Locations of diamond mines	Diamond mine is located in grid cell (=1)	Gilmore et al. (2005)
Location of petroleum fields	Petroleum field is located in grid cell (=1)	Lujala et al. (2007)
Distance to country capital (log)	Log(m)	Distance of grid cell centroid to country capital, computed in ArcGIS using function near
Distance to nearest country border (log)	Log(m)	Distance of grid cell centroid to nearest country border, computed in ArcGIS using function near.
Distance to nearest sea coast (log)	Log(m)	Distance of pixel to nearest sea coast, computed in ArcGIS using function near.
Landlocked country	Landlocked country (=1)	Author's definition

some instances malnutrition may also increase the likelihood of contracting these diseases. The direct availability of the spatially disaggregated malaria indicator is one motivation for its inclusion, next to specificities on its interaction with malnutrition. Specifically, a hypothesis is that iron deficiency and resulting anaemia could actually aid with fighting off malaria infections as anaemia makes it more difficult for malaria parasites to propagate (e.g. Goheen et al. 2016). In other words, reductions in iron deficiency in areas where malaria proliferates, could actually worsen health outcomes. We include interaction effects between malaria and our soil nutrient factors to account for such possible effects.

Last, we include several location controls: distances from the centroid of each grid cell to the national capital, closest country border and distance to the closest sea coast (capitalDis, borderDis, coastDis). These variables account for differences in transport costs of commodities, and thus in net income and consumer prices, as well as the declines in the intensity of policy implementation as a function of the distance to the capital (see e.g. Briggs 2018). In addition, we include a dummy (Landlocked) signalling countries that do not have own sea coast. In these countries, trade also involves the crossing of a border with a neighbouring country, further adding transaction and transport costs.

In Section 6.2, we discussed the existence of two potentially different mechanisms that cause soil nutrient densities to affect health outcomes, one running through a change in income, the other through a direct increase in the local supply of nutrients in crops available for consumption. In the analysis, we investigate whether any of these mechanisms may dominate. For instance, if the share of consumption of own agricultural produce was known, this analysis is relatively straightforward. If the effect of soils on health is larger for households selling more own production, then the income effect dominates (and vice versa). Unfortunately, data on the marketed share of own production is not available for the full continent. Instead, we consider night time lighting and distances to capital, border and coast as proxies for market development and the importance of subsistence consumption, the latter being greater in dark and isolated areas. We estimate several models in which interactions of these variables with nutrients are estimated in order to explore the dominance of either mechanisms.

Most of the control variables are in line with those used by Michalopoulos and Papaioannou (2013), the key exception being the land suitability index. We hypothesize that the rich soil data in this study, and subsequent factors delineated in the previous section, are both a better proxy for land suitability and are more relevant to examining the effect on health and nutrition-related dependent variables. Moreover, the soil data itself is a function of various climatic and geophysical data such as temperature and rainfall differences (see Hengl et al. 2017 for more details). This does not invalidate our approach, but rather adds a logical layer of causality to the posited chain of causality. Thus, climatic and geophysical variables shape local soil nutrient contents, which determine agricultural potential and production, which in turn defines nutrient availability for local consumption and eventually determines nutrition and health outcomes.

Arguably, in a cross-section analysis as ours concerns on endogeneity of one or multiple variables can never be fully eliminated. Ideally, instrumental variables capturing deeper geological processes are available to instrument for current nutrient densities. Unfortunately, the original analysis (Hengl et al., 2017) provides no obvious and strong instruments. That said, by reasoning, endogeneity may only bias our estimation results to a very limited extent, given the structure of Equation 6.1 as well as the variables included above. First, it is unlikely that current health outcomes have a direct effect on soil quality, especially considering the fact that much of the underlying soil data has been collected over the past 50 years. A similar argument holds for the relation between precolonial institutional quality and health. All other variables, bar night time luminosity, are strictly exogenous. Health outcomes may, however, distinctively shape local economic activity and thus night time luminosity. For this reason, we use night time luminosity data of 2013, while the most recent (2013) health data is used. Unfortunately, for a few countries the most recent health data is from surveys before 2013. As a final means to test the stability of our findings we therefore estimate Equation 6.1 with the controls on night time lighting and population density omitted, variables that potentially harbour some endogenous interaction with nutrient densities.

6.4 Impact of soil nutrients on health

We estimate Equation 6.1 using the data and the methodology as outlined in the previous sections. Table 6.6 displays model estimates for child mortality. The differences between the models are explained in the footnotes and relate to differences in clustering variables, the inclusion of night time lighting as a continuous variable, and the inclusion of interaction effects between soil quality variables and malaria pressure. Altogether the differences between models with either single clustering (model a and b) or double clustering (models c-g) of standard errors are small. Much of the unobserved correlation between standard errors is observed at the country level, and to a much smaller degree at the precolonial institutional or regional level. Moreover, virtually no differences occur when double clustering either at the level of countries and precolonial institution, or at the level of countries and regions. Given these minor differences we continue using double clustering at country and region-level.

The estimates explain a considerable amount of the variance in current child mortality. Considering the statistically significant variables, variation in soil quality, malaria pressure, night time lighting and distance to coast and capital thus explain up to 26% of child mortality across Sub-Saharan Africa. The effects of soil quality are apparent and significant. Consider, for instance, the effect of the micronutrient Factor 1. A unit increase in this factor reduces child mortality in the range of 2 to 8 per mille points, thus reducing child mortality from around 44 deaths per 1,000 to a range of 36-42 deaths per 1,000. That said, the precise effects are somewhat obscured by the significant interaction effects between malaria and soil nutrients. We calculate the precise distribution of marginal effects later on.

The effects of the various control variables as documented in Table 6.6 are in line with a priori expectations. Increasing malaria pressure leads to increases in child mortality. Greater population densities lead to increases in mortality, possibly due to decreasing per capita nutrient availability. Child mortality is considerably lower in (more urbanised) areas with greater night time luminosity, possibly due to an income effect, the availability of more and better health services or the availability of more diverse diets. Distance to the coast increases mortality rates, likely reflecting an increase in transport costs. Such significant effects of soil factors on health outcomes are not confined to child mortality only and are observed in relation to child stunting, wasting and underweight as well.

Table 6.7 shows model estimates for the four health indicators together, each estimated similar to model (g) in Table 6.6. The signs of the control variables are mostly similar to the results for child mortality even though the effect of the control variables is not always significantly different from zero. For instance, there appears a fairly robust effect of the night time luminosity (i.e. greater economic activity and income) on the different health outcomes. Again, increasing distances to the coast seem to increase mortality rates as well as distances to the capital. The latter likely reflects declining government spheres of influence, for instance, with respect to health policies, including local availability of medical care. On the other hand, the effect of precolonial institutions (hierarchy) does not appear statistically significant in any of the models estimated.

Table 6.6: Relationship between soil nutrients and child mortality

Variable	**a**	**b**	**c**	**d**	**e**	**f**	**g**
Cu–Mn–Zn	-2.129***	-8.275***	-8.275**	-8.275**	-7.756*	-7.411*	-6.350*
	(0.0604)	(0.105)	(3.998)	(4.066)	(3.872)	(4.359)	(3.335)
Cu–Mn–Zn * Malaria Index		0.465***	0.465*	0.465*	0.436*	0.412	0.281
		(0.00565)	(0.268)	(0.259)	(0.249)	(0.261)	(0.225)
Ca–Mg	1.142***	1.695***	1.695	1.695	1.724	2.246	3.443
	(0.0501)	(0.0750)	(4.110)	(4.014)	(3.912)	(4.067)	(4.002)
Ca–Mg * Malaria Index		-0.181***	-0.181	-0.181	-0.188	-0.153	-0.215
		(0.00556)	(0.314)	(0.313)	(0.309)	(0.323)	(0.338)
N–OMC	-4.110***	-4.484***	-4.484	-4.484	-4.560	-4.163	-4.579*
	(0.0423)	(0.0612)	(2.981)	(2.910)	(2.778)	(3.047)	(2.667)
N–OMC * Malaria Index		0.0658***	0.0658	0.0658	0.0615	0.0128	0.100
		(0.00462)	(0.287)	(0.275)	(0.263)	(0.283)	(0.252)
Institutional hierarchy	-0.786***	-0.979***	-0.979	-0.979	-0.914	-1.735	-0.601
	(0.0361)	(0.0366)	(1.775)	(1.661)	(1.654)	(1.659)	(1.456)
Malaria Index	0.824***	0.775***	0.775**	0.775**	0.748**	0.738**	0.785**
	(0.00467)	(0.00491)	(0.329)	(0.334)	(0.328)	(0.345)	(0.320)
Population density (logs)	2.443***	2.877***	2.877***	2.877***	3.163***	3.384***	3.258***
	(0.0221)	(0.0233)	(0.890)	(0.914)	(0.897)	(0.989)	(0.834)
Night time luminosity (=1)					-14.06***	-14.20***	-11.18***
					(2.308)	(2.378)	(2.406)
Water body (=1)						-4.144	
						(3.695)	
Petroleum site (=1)						-5.369	
						(4.800)	
Diamond mine (=1)						6.184	
						(5.578)	
Night time luminosity	-1.072***	-1.067***	-1.067***	-1.067***			
	(0.0150)	(0.0150)	(0.194)	(0.193)			
Distance to capital (log)							1.186
							(1.423)
Distance to coast (log)							3.603***
							(1.103)
Distance to border (log)							-1.097
							(0.746)
Landlocked (=1)							-1.781
							(4.948)
Constant	31.95***	29.71***					
	(0.0753)	(0.0816)					
Observations	359,019	359,019	359,019	359,019	359,019	324,626	358,978
R-squared	0.201	0.218	0.218	0.218	0.231	0.237	0.259

*** p<0.01, ** p<0.05, * p<0.1. OLS regression with standard errors in parentheses. Dependent variable is child mortality in all specifications. Models differ in the following ways: (a) no clustering on standard errors, night time as continuous variable. (b) as (a), with interaction effects between malaria and soil nutrient factors. (c) as (b) with double clustering at country and precolonial institutions level, night time as continuous variable. (d) as (b) with double clustering at country and regional level, night time as continuous variable (e) as (d), with night time as dummy (0 dark cells, 1 lighting). (f) as (e), with geographic controls. (g) as (e), with location controls.

Table 6.7: Relationship between soil nutrients and child mortality, child stunting, child wasting and child underweight

Variable	Mortality	Stunting	Wasting	Underweight
Cu–Mn–Zn	-6.350*	-3.235*	-3.028***	-3.635*
	(3.335)	(1.727)	(1.076)	(1.967)
Cu–Mn–Zn * Malaria Index	0.281	0.183	0.0825**	0.139
	(0.225)	(0.111)	(0.0404)	(0.0907)
Ca–Mg	3.443	-2.559*	3.297***	4.566***
	(4.002)	(1.334)	(0.671)	(1.563)
Ca–Mg * Malaria Index	-0.215	0.162	-0.0859	-0.0811
	(0.338)	(0.0990)	(0.0767)	(0.138)
N–OMC	-4.579*	1.910**	-2.239***	-1.127*
	(2.667)	(0.839)	(0.567)	(0.662)
N–OMC * Malaria Index	0.100	-0.152	0.0542**	-0.0216
	(0.252)	(0.0922)	(0.0251)	(0.0716)
Institutional hierarchy	-0.601	0.0248	-0.429	-0.791
	(1.456)	(0.607)	(0.564)	(0.956)
Malaria Index	0.785**	-0.121	0.203***	0.222**
	(0.320)	(0.0774)	(0.0634)	(0.0929)
Population density (logs)	3.258***	1.166***	0.480	1.076**
	(0.834)	(0.298)	(0.291)	(0.410)
Night time luminosity (=1)	-11.18***	-6.069***	-0.462	-3.702***
	(2.406)	(1.082)	(0.507)	(1.020)
Distance to capital (log)	1.186	3.014***	0.870***	1.834***
	(1.423)	(0.551)	(0.298)	(0.549)
Distance to coast (log)	3.603***	0.600	0.673**	1.176*
	(1.103)	(0.808)	(0.324)	(0.697)
Distance to border (log)	-1.097	0.301	0.0113	0.0488
	(0.746)	(0.265)	(0.147)	(0.240)
Landlocked (=1)	-1.781	4.170***	1.552	3.125
	(4.948)	(1.489)	(0.997)	(2.006)
Observations	358,978	311,285	298,950	298,950
R-squared	0.259	0.353	0.372	0.311

*** p<0.01, ** p<0.05, * p<0.1. OLS regression with standard errors in parentheses. Dependent variables are child health outcomes.

We estimate the effects of multiple soil nutrients on multiple health outcomes, which could lend suggestion of being a form of specification mining. Given the number of t-tests in all of these regressions the likelihood of a Type 1 error occurring may indeed be fairly large. Options to control for such compounding errors exists by means of multiple hypothesis testing, most notably through the Bonferroni and derived corrections. But the usefulness of applying such corrections in more exploratory studies as ours remains under debate (e.g. Bender and Lange 2001). We therefore choose not to apply any such corrections, a choice further strengthened by the observation that our findings (of a link between soils and health) do not hinge on a single significant coefficient, but rather on a more consistent finding of multiple significant effects across the different health outcomes.

We subsequently explored whether or not the data provides insights into either of the mechanisms driving this effect between soils and health. We ran 48 additional regressions with interactions between each soil nutrient factor and night time lighting, or the three different geographical distance variables. Detailed results are available upon request. Such interactions with either the micronutrient factor, or with the nitrogen and organic matter factor are rarely significant. In few cases that they are, it suggests that the relation between soils and health is smaller in isolated areas, lending credence to an income effect as the driver of the effect on health. Yet, interactions with the calcium and magnesium factor point to the exact opposite. In fact, various interactions turn out significant (across the different health outcomes, for night time lighting as well as the geographical controls). Given these opposite findings a verdict on a dominating mechanism remains inconclusive and requires additional research, for instance, by using experimental approaches stratified across settings with different subsistence levels.

Two further methodological considerations are appropriate here. First, we noted that population density and night time lighting may be considered bad controls as these may be intricately linked with soil nutrients. We therefore investigated the stability of the estimates by omitting these potentially “bad” controls. The results are provided in the Appendix (Table A.6.1) but are largely similar to those reported in Table 6.7. The key difference being that micronutrients no longer explain child mortality. Second, our dataset is considerably large (around and over 300,000 observations) which is driven by the richness of the underlying soil dataset. Table 6.6 and Table 6.7 reflect an analysis in which we disaggregated, or rather transposed, the observed health outcomes of a specific district to the unobserved outcomes in each location within that district. To our knowledge there is no objection on econometric grounds to the approach followed, except for the fact that measurement errors in child health outcomes in a district now carry over to all observations in that district, making the followed clustering approach across subnational regions or countries imperative. That said, increasing the number of observations in this way may somewhat artificially raise the odds of finding significant effects. Therefore, as a robustness check, we estimated the same model for all health outcomes with all variables aggregated (averaged) to the district level at which health outcomes were measured. The results are presented in the

Appendix (Table A.6.2), showing that most of the key findings remain (with respect to significance levels and size of coefficients) in such a more parsimonious data set.

Because of the significant interaction effects between the malaria stability index and the soil factors, the marginal effects vary for different values of the malaria stability index. We therefore calculate the precise marginal effects of soil factor increases, conditional on different values of the malaria stability index. These calculations are provided in Table 6.8, as well as displayed in Figure 6.2 to Figure 6.5. Table 6.8 provides the approximate marginal effects at the 25%, 50% and 75% percentile of the malaria stability index, which corresponds to actual values of this index of around 0, 8 and 16 respectively. Figure 6.2 to Figure 6.5 show 95% confidence intervals of the marginal effects of additional soil nutrients on child mortality, stunting, wasting and underweight. The x-axis reflects the malaria stability index and the vertical lines partition the data on malaria stability index into four quartiles.

Table 6.8: Marginal effects of soil factors on child mortality, stunting, wasting and underweight conditional on the malaria distribution

Malaria distribution	**Mortality**	**Stunting**	**Wasting**	**Underweight**
(approx. percentile)				
Cu–Mn–Zn				
0 (25%)	-6.350*	-3.235*	-3.028***	-3.635*
	(3.335)	(1.727)	(1.076)	(1.967)
8 (50%)	-4.105*	-1.771	-2.368***	-2.520*
	(2.314)	(1.121)	(0.840)	(1.524)
16 (75%)	-1.861	-0.307	-1.708**	-1.404
	(2.464)	(1.051)	(0.680)	(1.353)
Ca-Mg				
0 (25%)	3.443	-2.559*	3.297***	4.566***
	(4.002)	(1.334)	(0.671)	(1.563)
8 (50%)	1.727	-1.262	2.610***	3.916***
	(3.170)	(1.119)	(0.605)	(1.355)
16 (75%)	0.0103	0.0344	1.923*	3.267*
	(4.320)	(1.406)	(1.017)	(1.919)
N-OMC				
0 (25%)	-4.579*	1.910**	-2.239***	-1.127*
	(2.667)	(0.839)	(0.567)	(0.662)
8 (50%)	-3.776**	0.691	-1.805***	-1.300
	(1.904)	(0.705)	(0.556)	(0.888)
16 (75%)	-3.776**	-0.527	-1.372**	-1.473
	(1.904)	(1.174)	(0.615)	(1.341)

*** p<0.01, ** p<0.05, * p<0.1. Marginal effects conditional on malaria occurrence, calculated with OLS. Standard errors in parentheses. Dependent variables are child health outcomes.

Figure 6.2 shows the impact of higher nutrient densities on incidences of child mortality. In Figure 6.2, the left and right panel show that for locations with a malaria stability index below the median greater densities of soil micronutrients (Cu-Mn-Zn), as well as greater density of N and organic matter, lead to significant (at 95%) reductions in child mortality. These reductions are substantial, as also shown in Table 6.8. For instance, at the 25% percentile and at the median (50% percentile), the expected marginal effect of a unit increase in the first soil factor (capturing variation in Cu, Mn and Zn) leads to a reduction of 6.3 and 4.1 per mille points in child mortality respectively. However, the reductions in mortality, due to increasing densities in soil micronutrients dissipate when the malaria pressure increases. In the next section, we further discuss how such unit increases in the soil factors translate to actual differences in soil nutrient densities.

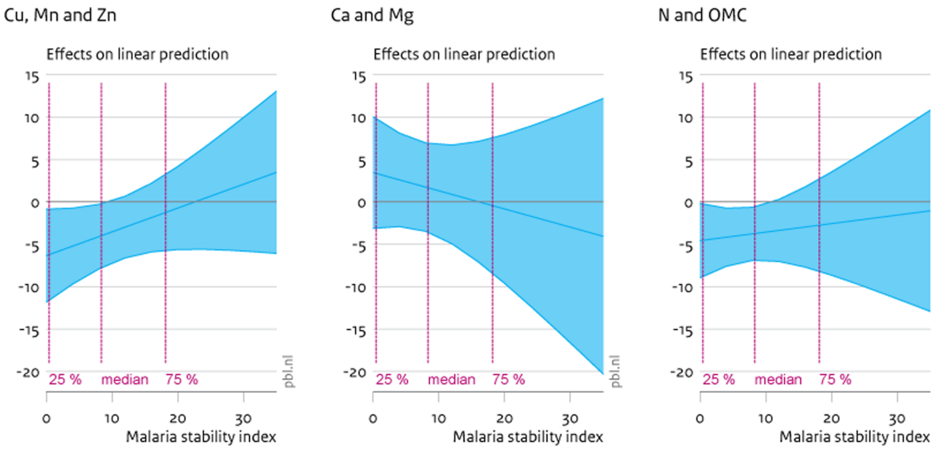

Figure 6.2: Marginal effects (90% CI) of soil nutrient increase on child mortality conditional on the malaria distribution

This graph displays 90% confidence intervals of the marginal effects of greater soil nutrient densities on child mortality. The left panel displays the effects of factor 1 (Cu, Mn and Zn), the middle panel of factor 2 (Ca and Mg) and the right panel of factor 3 (N and OMC).

The panels in Figure 6.3 are similar in set-up to Figure 6.2, but now quantify the marginal effects of increased soil quality on child stunting. The first panel illustrates that, again, micronutrients have a significant impact on rates of child stunting (i.e. height of children too low for age). There is also a significant effect of the second factor reflecting densities of calcium and magnesium. For this factor, at rates of malaria pressure below the median, there appears a significant reduction of more calcium and magnesium on stunting. This is not unsurprising as higher intake of calcium has been associated with increases in skeletal growth and increased bone mass, leading to increases in height (e.g. Johnston et al. 1992). This effect dissipates for higher rates of malaria pressure, where no significant effects of any soil factor on child stunting remains. Finally, at low levels of malaria intensity only, greater nitrogen densities and soil organic matter appear to increase levels of child stunting. While somewhat puzzling at first, the role of nitrogen and organic matter in child stunting is the precise inverse of the role in explaining child wasting (see Figure 6.4 below). More generally, nitrogen and organic matter, and to some degree micronutrients, are primarily weight enhancing, while calcium and magnesium are height-increasing.

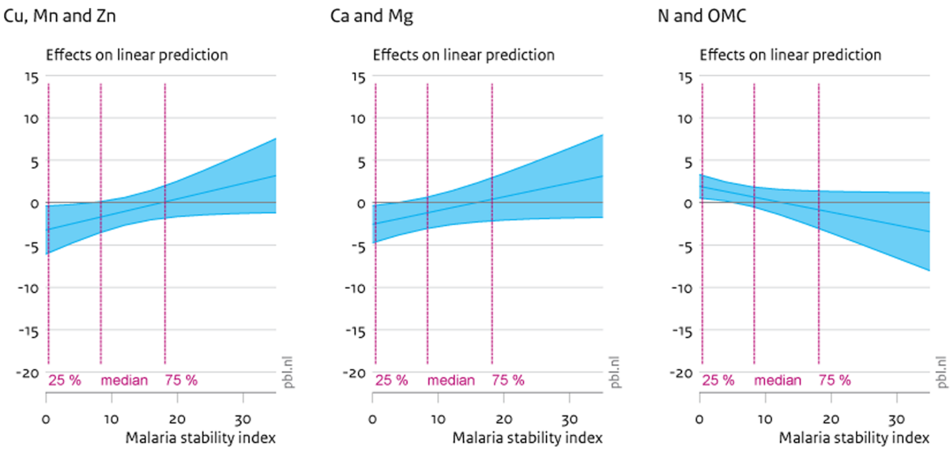

Figure 6.3: Marginal effects (90% CI) of soil nutrient increase on child stunting conditional on the malaria distribution

This graph displays 90% confidence intervals of the marginal effects of greater soil nutrient densities on child mortality. The left panel displays the effects of factor 1 (Cu, Mn and Zn), the middle panel of factor 2 (Ca and Mg) and the right panel of factor 3 (N and OMC).

Indeed, a similar effect of calcium and magnesium can be observed when assessing the marginal effects on child wasting (i.e. child weight too low for child height) (Figure 6.4). Here, the effect of calcium and magnesium is positive, i.e., it actually

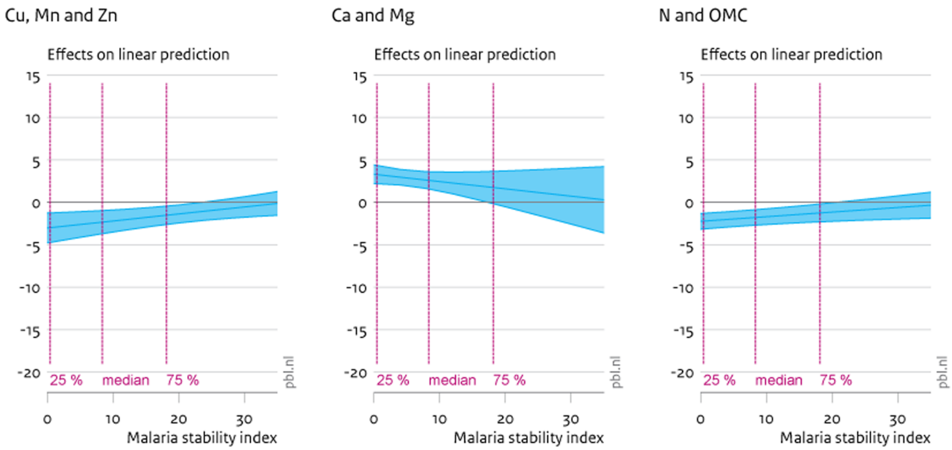

Figure 6.4: Marginal effects (90% CI) of soil nutrient increase on child wasting conditional on the malaria distribution

This graph displays 90% confidence intervals of the marginal effects of greater soil nutrient densities on child mortality. The left panel displays the effects of factor 1 (Cu, Mn and Zn), the middle panel of factor 2 (Ca and Mg) and the right panel of factor 3 (N and OMC).

increases rates of child wasting. This effect is a different side of the same coin. When calcium and magnesium increase height, it will simultaneously increase rates of wasting, all else being equal. On the other hand, the other two factors seem to counter these effects. Both increases in micronutrients as well as nitrogen and organic matter content lead to considerable reductions in child wasting for rates of malaria pressure up to the 75% percentile. This suggests more of these elements in soils lead to intake of more, and more nutritious, food, in turn increasing weight. Again, at higher rates of malaria pressure no significant effects of soil nutrients remain.

Finally, Figure 6.5 documents the effect of changes in soil nutrients on incidences of child underweight. Here, the effect of micronutrients (Mn, Zn and Cu) mirrors the effects on child mortality. For low instances of the malaria stability index, additional micronutrients appear to reduce incidences of child underweight. There is a weak increasing effect, at low levels of malaria pressure, of calcium and magnesium on child underweight and no significant effect of nitrogen and organic matter.

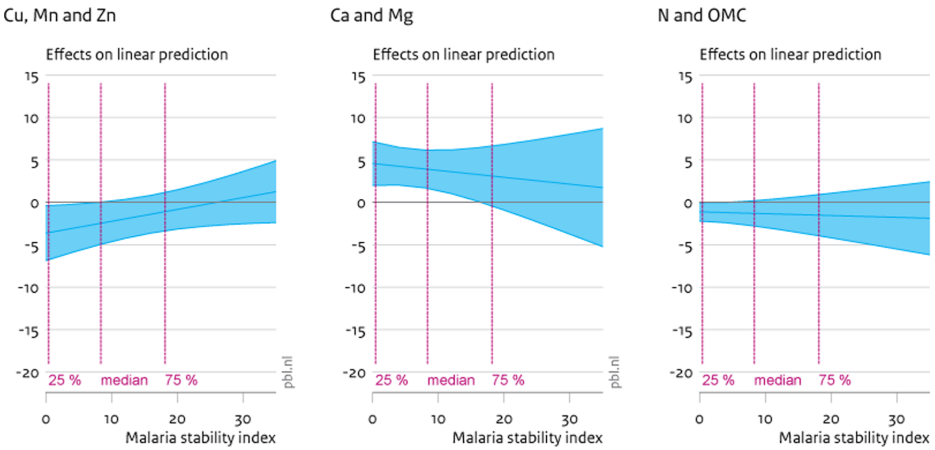

Figure 6.5: Marginal effects (90% CI) of soil nutrient increase on child underweight conditional on the malaria distribution

This graph displays 90% confidence intervals of the marginal effects of greater soil nutrient densities on child mortality. The left panel displays the effects of factor 1 (Cu, Mn and Zn), the middle panel of factor 2 (Ca and Mg) and the right panel of factor 3 (N and OMC).

6.5 Costs and benefits of increasing soil nutrient content

The previous section has provided detailed estimates of the, statistically significant, spatial relation between local soil nutrient densities and local health outcomes. We argue that in the absence of field trials assessing the impact of enriched fertilisers on human health, the spatial relationship between soils and health elaborated above provides a first order indication -and currently best available empirical alternative- of the potential costs and benefits of using agronomic fortification to combat malnutrition. Given the strong focus in the scientific literature on the role of micronutrients, particularly zinc, in alleviating malnutrition we focus on the effects of the first soil factor used in the previous section (including zinc, copper and manganese). We assess the costs of enriching soils with these elements and contrast these with the benefits of reductions of child mortality.

We first establish the costs of increasing the densities of soil nutrients. This calculation is relatively straightforward by considering the definition of the factors as explained in Subsection 6.3.2. Specifically, a unit increase of Factor 1 (capturing the variation in zinc, copper and manganese) implies that the underlying normalised soil nutrient variables each increase by one as well. Or, by virtue of the normalisation (see Subsection 6.3.2), each of the soil nutrient variables increases by one standard deviation. We make some simplifying assumptions. First, we ignore the other, smaller factor loadings, thus only calculating the costs for a standard deviation increase in zinc, copper and manganese. Second, we value these elements by considering recent price data from the London Metal Exchange. We thereby ignore all possible transaction costs involved in getting these elements included in inorganic fertilisers and transported to and applied at farmers' fields. Moreover, not all fertiliser-applied nutrients may directly be available for plant nutrition. In other words, the cost estimate is a lower bound of the actual costs involved. Table 6.9 shows the calculation of the costs involved (i.e. the lower bound as per the discussion above) of raising the soil nutrient densities in one grid cell (of 5km x 5km) by one standard deviation. Taken together these costs amount to a little less than USD 80,000 per grid cell using price data from London Metal Exchange (2017).

Table 6.9: Cost estimate of increasing soil nutrient contents in a grid cell by one standard deviation (SD)

Soil nutrient	**SD soil nutrients**	**SD increase per grid cell (25km2)**	**Unit price**	**Total value of SD increase**
	kg/ha	*1,000 kg*	*USD/1,000 kg*	*USD*
Copper (Cu)	0.86	2.145	5,710	12,248
Manganese (Mn)	22.56	56.395	1,053	59,384
Zinc (Zn)	1.18	2.957	2,785	8,238
Total across three micronutrients				79,870

This table shows the estimated costs of increasing copper, manganese and zinc content in a grid cell by one standard deviation (SD). Price data is from London Metal Exchange (2017).

Subsequently, the regressions in the previous section provide insights into the magnitude of the benefits. Recall from Table 6.8 that a unit increase of Factor 1 (Cu-Mn-Zn) results in a decrease of child mortality by 4.105 (at the median of the malaria stability index). Average (between one and five year) child mortality is around 44, thus a unit increase in soil Factor 1 leads to a decrease in mortality from 44 to around 40 children per 1,000 children surviving their first birthday. We consider the median of the population density to translate this figure into actual child lives saved. The median of the population density is 9.96 persons per km2 (249 persons per 25km2 grid cell) and across Sub-Saharan Africa on average 16% of the population is aged between 0 and 4 years (United Nations 2018, 2015 estimates) (40 per grid cell). The mortality rate (44 per mille) implies that 1.64 children per grid cell are likely to pass away between their first and fifth birthday. Thus, a unit increase in soil Factor 1 may reduce this figure by around 0.16 child lives (4 per mille points).

In the final step, we convert this figure to Disability Adjusted Life Years (DALY) saved by using the standard WHO formula: *DALY = Years of Life Lost (YLL) + Years Lived with Disability (YLD)*. As we focus on reductions in child mortality we calculate YLL only, by using: $YLL = N/r(1 - e^{-rL})$, with N the number of deaths, r the discount rate (0.03) and L the standard life expectancy at the age of death (Prüss-üstün et al., 2003). The latter is set at 57 as we assume an average age of death (within the 0-4 age category) of 3, while the average life expectancy in Africa is 60 (WHO, 2018). Under these assumptions 0.16 child life saved equals 4.47 DALYs. Finally, considering the investment of USD 79,870 in soil nutrients, the costs per DALY equal USD 17,866. These calculations are summarised in the first row of Table 6.10.

Table 6.10: Child lives saved due to increasing soil nutrient content (copper, manganese and zinc)

Percentile at the population distribution	Population density	Population per grid cell	Children (0-4) per grid cell	Children saved by SD increase in soil nutrient density	DALYs saved	Costs per DALY saved
	$\#/km^2$	$\#/25km^2$	#	#	#	*USD/DALY*
50%	10	249	40	0.16	4.47	17,866
75%	31	787	126	0.52	14.11	5,661
95%	156	3,910	626	2.57	70.12	1,139
98%	293	7,328	1,173	4.81	131.43	608

This table shows the costs per child life saved by increasing copper, manganese and zinc densities (as calculated in Table 6.8 with a median malaria stability index), for different percentiles of the population distribution. SD is the standard deviation. DALY is Disability Adjusted Life Years and is calculated using WHO standards. The total costs of investment is USD 79,870 as calculated in Table 6.9.

The subsequent rows in Table 6.10 display similar calculations carried out for different points at the distribution of the population density. The costs per DALY saved decrease substantially for higher population densities. For instance, at the 95% percentile of the population density the costs are estimated at USD 1,139 per DALY saved. Even though such grid cells are relatively densely populated, they are still distinctively rural. Various studies define urban areas as those region with a population density of over 400 inhabitants per km2. In this sample, this implies all areas from just below the 99% percentile of the population distribution and upward. Areas that fall in this 95% - 98% percentile range are thus often close to major urban areas, but still with considerable intensive agricultural activity. Marked by relatively low transport costs for agricultural in- and outputs and, by consequence, higher use of inorganic fertilisers (e.g. Boserup 1965), such areas may also be best suitable for projects aimed at promoting inorganic fertilisers enriched with micronutrients. Simultaneously, such a strategy has the benefit of raising agricultural productivity in regions where food demand is highest, the benefits of which are not included in the cost-benefit assessment above.

Thus, regions where the potential for agronomic fortification is greatest (high population densities and low soil nutrient densities) are shown in Figure 6.6. Across the three panels (showing the cases for zinc, manganese and copper in the upper, middle and lower panel respectively) the maps point to similar areas: in particular, the Ethiopian highlands, Rwanda and Burundi, and much of Nigeria and southern Niger. Furthermore, the results in Table 6.6 and Table 6.7 highlight the negative impact of high malaria pressure and whereby the link between health and soils mostly exists in areas with low malaria pressure. In other words, agronomic fortification is likely to have an impact only in these areas with low malaria pressure. These, somewhat unsurprisingly, overlap with high population areas (Figure 6.6). Nevertheless, malaria pressure is considerably high in Southern Niger and Nigeria, rendering agronomic fortification potentially less effective.

Nevertheless, the range of the cost per DALY saved in more densely populated rural areas (156 – 293 inhabitants per km2) –roughly between USD 600 and 1,000– puts agronomic fortification at the higher cost end, compared with those of available alternatives. Table 6.10 shows an overview of costs per DALY per averted as compiled in the recent review by Gregory et al. (2017), focusing on options

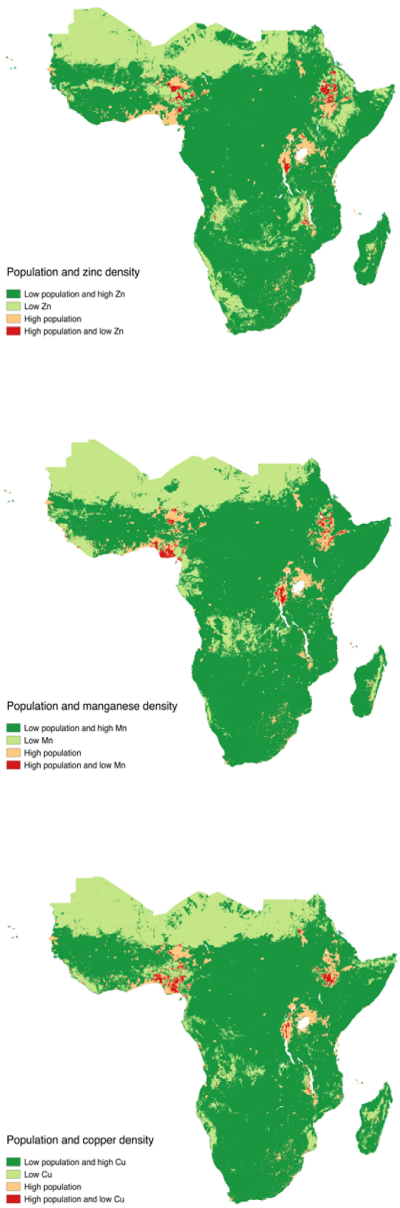

Figure 6.6: Regions with low micronutrient densities, high population densities, or both.

This figure shows regions where soil densities of zinc (upper panel), manganese (middle panel) or copper (lower panel) are low (<25% percentile) and population density is high (>95% percentile). Data on zinc, manganese and copper densities are from Hengl et al. (2017), data on population density is from Center for International Earth Science Information Network - CIESIN - Columbia University.

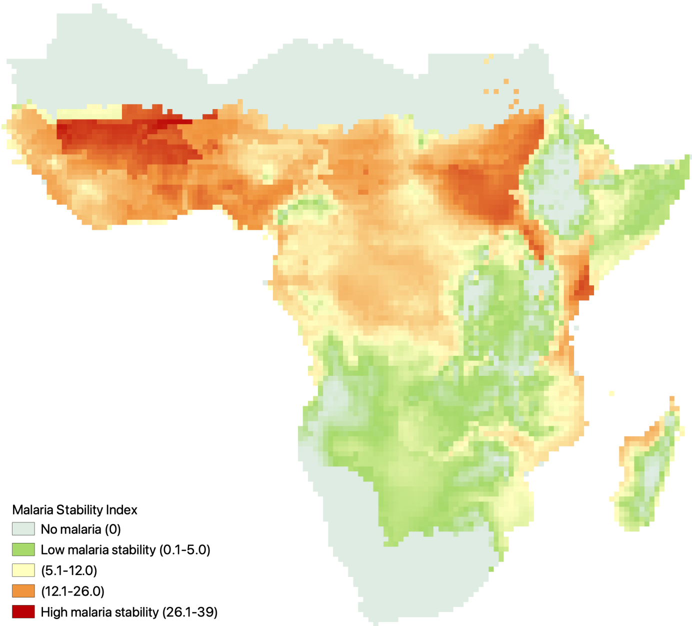

Figure 6.7: Variation in malaria pressure across Sub-Saharan Africa

This figure shows variation in malaria pressure based on the malaria stability index developed by Kiszewski et al. (2004). A low malaria stability index (in green) indicates low malaria pressure.

to alleviate zinc and iron deficiencies. The first four rows list various fertiliser approaches, the first two based on the ex-ante assessment by Joy et al. (2015) on micronutrient enriched fertilisers for Sub-Saharan Africa. Their cost ranges (USD 81 – 575 and USD 773 – 6,457) overlap with those estimated above. Either way these ranges, and ours, remain high when compared with alternatives like crop breeding (genetic fortification). Indeed, for genetic fortification the costs per DALY averted are assumed to be well below USD 100 for many nutrient-crop combinations (Meenakshi et al., 2010). That said, as argued earlier, genetic fortification may have limited potential when inherent densities of nutrients in soil are low to begin with. The ranges for food supplementation and fortification, as shown in Table 6.11 (from Gregory et al. 2017), may equally be on the high side. Another recent study, though not focusing exclusively on iron or zinc, puts the cost of saving a life of an infant or young child through micronutrient fortification and supplementation at USD 100 and 200 (Bhutta et al., 2013). Using the assumptions underlying Table 6.10, this translates to roughly USD 1- 3 per DALY averted.

Table 6.11: Estimated costs per DALY saved for a range of food system approaches to alleviate Zn and Fe deficiencies

Intervention	Cost per DALY saved (USD)	Notes	Source
Granular fertilizer	773 – 6,457	Sub-Saharan Africa	Joy et al. (2015)
Foliar fertilizer	81 – 575	Sub-Saharan Africa	Joy et al. (2015)
Soil + foliar fertilizer	256 – 549	Pakistan (Punjab and Sindh province)	Joy et al. (2017)
Foliar fertilizer (with pesticide)	41 – 594	China	Wang et al. (2016)
Crop breeding	0.7 – 7.3	India	Stein (2014)
Supplements	65 – 2,758	Prophylactic, 1-4 years	Fink and Heitner (2014)
Flour fortification	401	Zambia, vitamin A, Fe, Zn	Fiedler et al. (2013)

Table from Gregory et al. (2017)

It is worth noting two possible assumptions that may inflate our cost estimates in Table 6.10. First, the high costs per grid cell are strongly driven by the high costs of manganese (see Table 6.9). Of course, it could be that the results of soil nutrients on health are not driven by the combination of the three nutrients included in soil Factor 1, but that a single nutrient is responsible for changes in these health outcomes. Unfortunately, the strong correlation between copper, zinc and manganese makes it difficult to isolate such singular causes. If we assume, momentarily, that all changes in health outcomes can be attributed to, say, zinc alone (around 10% of the total costs in Table 6.9), then the costs per DALY averted drop to USD 1,746 at the median population distribution, or to USD 59 at the 98% percentile. But, except for the more densely populated and more intensively farmed areas, such estimates render agronomic fortification still less cost-effective than available alternatives.

A second reason is that we may overstate the costs for grid cells with low population densities. In these areas, the actual area allocated to agricultural production could be smaller than the full grid cell size. That said, putting the cost range of USD 17,465 (at the median) within a reasonable range of alternatives would imply an assumption on the agricultural share in such grid cells to fall below 1%. This, we consider greatly unrealistic. Moreover, we should reiterate that other reasons may actually understate the costs estimates. Like stated we do not account for product development costs, neither for transport and other market transaction costs. In fact, such costs are bound to be higher in areas with relatively low population densities.

6.6 Conclusion

This paper reveals a significant link between spatial variation in African soil fertility and spatial variation in child health. We are not aware of earlier studies that have identified such a relation in statistical detail. In establishing this link we use estimates on densities of nine macro- and micronutrients, as well as estimates on soil organic matter content, to proxy for variation in soil fertility. We subsequently assess the precise causal effect of spatial variation in these elements on incidences of child mortality, stunting wasting and underweight. We argue that these effects serve as a good proxy for assessing the magnitude of the impact of agronomic fortification -enriching inorganic fertilisers with micronutrients- as a means to alleviate malnutrition or hidden hunger.

We find that joint increases in micronutrients (zinc, copper and manganese) lead to significant reductions in incidences of child mortality, stunting, wasting and underweight, specifically in areas where malaria pressure is relatively low. In regions with higher malaria pressure the effect dissipates. Greater (joint) densities of soil calcium and magnesium lead to taller children, all other things being equal, leading to increases incidences of child wasting and underweight, but to reductions in the incidences of child stunting. Finally, joint increases in soil nitrogen and organic matter content reduce incidence of child mortality and wasting. Overall the magnitude of these effects is noteworthy. A joint standard deviation increase in zinc, copper and manganese densities reduces child mortality by 4 per mille points at the median malaria intensity (from an average mortality rate of 44 per mille). For relatively low malaria pressure (1st quartile) such a micronutrient increase leads to reductions in stunting, wasting and underweight of around 2-3 percentage points (from averages of 39, 10 and 21 percentage respectively). In other words, you are what you eat, at least in the case of Sub-Saharan Africa, which in turn is also shaped by local soil conditions.

These findings do suggest that building up soil nutrient stocks through agronomic fortification has its merit in reducing malnutrition and improving health. Various recent studies already document the benefits of including micronutrients in regular inorganic fertilisers as a means to increase agricultural production and productivity (Berkhout et al., 2017; Kihara et al., 2017) These effects on improving child health may thus be considered a co-benefit or external effect. These co-benefits inhibit a strong public good nature. Improved nutritional quality in agricultural produce is unlikely to attract a higher price in markets in SSA, next to various studies that reveal suboptimal individual spending on health goods and services to begin with. We are aware of only one study that links nutrient content of agricultural produce with actual farmer marketing decisions (Bevis, 2015b). This study reveals that Ugandan farmers typically market produce with lower zinc content and self-consume produce with higher zinc content. In other words, these reasons may justify government subsidisation of inorganic fertilisers enriched with missing (micro-)nutrients.

However, the cost-benefit analysis presented in the second half of this paper dampens the enthusiasm for presenting agronomic fortification as an omnipotent and efficacious instrument to combat malnutrition. We find that in many instances the costs per DALY averted are relatively high. Only in those areas where population density is high, as well as likely levels of agricultural intensification, is agronomic fortification likely to be a cost-effective alternative. This argument is shaped by both the fact that the per capita cost of agronomic fortification is lower in such areas, next to the fact that inorganic fertiliser use is more common to begin with. Conversely, in areas with lower population densities alternatives like nutrient supplementation (in capsules or powders), food fortification, possibly in combination with genetic fortification are likely to be more cost-effective.

Malnutrition continues to place a great burden on human health and development in Sub-Saharan Africa now and in the foreseeable future. The potential economic opportunities in reverting malnutrition are huge. But, solid information on cost and benefits of the various policy options, and how these differ, across regions and countries remain scarce. In filling this gap, this study makes a contribution to better understand the potential for using agronomic fortification to revert malnutrition. Even though we argue that our approach provides realistic and robust insights into the potential of agronomic fortification, it remains second-best to urgently needed on the ground experimental approaches. Hence, the results from this study point to areas –high population density and low micronutrient densities- that most likely harbour the greatest potential for using agricultural fortification as a means to combat malnutrition. Such locations should be targeted first with actual field trials in which micronutrient enriched fertilisers are distributed and impact on both agricultural productivity and health indicators are monitored. Moreover, combining such trials with data collection on actual food consumption will allow for a better understanding on the precise causal channel through which changes in malnutrition may come about.

6.7 Appendix

Table A.6.1: Regression results with controls for night time lighting, population density and institutional hierarchy omitted

Variable	Child mortality	Child mortality	Child stunting	Child stunting	Child wasting	Child wasting	Child weight	Child weight
Cu–Mn–Zn	-3.676*	-6.390	-1.433	-2.671	-2.283***	-1.685	-2.662**	-2.057
	(2.081)	(4.928)	(1.235)	(1.913)	(0.672)	(1.144)	(1.072)	(1.825)
Cu–Mn–Zn * Malaria Index		0.210		0.106		-0.0183		0.00379
		(0.283)		(0.104)		(0.0476)		(0.0862)
Ca–Mg	2.726	3.367	-2.010*	-3.679**	2.496***	3.570***	3.421**	4.711***
	(3.462)	(4.543)	(1.062)	(1.449)	(0.847)	(0.718)	(1.663)	(1.613)
Ca–Mg * Malaria Index		-0.108		0.139		-0.0997*		-0.128
		(0.220)		(0.103)		(0.0588)		(0.122)
N–OMC	-2.819	-1.292	1.150	3.818***	-1.767***	-1.540***	-1.057	0.356
	(2.390)	(2.782)	(1.108)	(0.958)	(0.528)	(0.350)	(1.064)	(0.641)
N–OMC * Malaria Index		-0.146		-0.307***		-0.0196		-0.147
		(0.245)		(0.104)		(0.0465)		(0.0876)
Malaria Index	1.129***	1.106***	-0.116	-0.112	0.262***	0.229***	0.315***	0.254**
	(0.349)	(0.343)	(0.113)	(0.108)	(0.0617)	(0.0578)	(0.0984)	(0.103)
Distance to capital (log)	0.656	0.657	2.989***	3.321***	0.775*	0.911**	1.448**	1.811***
	(1.477)	(1.192)	(0.887)	(0.744)	(0.452)	(0.434)	(0.629)	(0.638)
Distance to coast (log)	5.226***	4.953***	0.475	0.195	0.798*	0.737*	1.753**	1.498*
	(0.981)	(1.001)	(0.977)	(0.828)	(0.455)	(0.419)	(0.820)	(0.757)
Distance to border (log)	-0.975	-0.943	0.418	0.630**	0.0794	0.0363	0.170	0.184
	(0.637)	(0.601)	(0.314)	(0.292)	(0.128)	(0.126)	(0.295)	(0.248)
Landlocked (dummy)	-2.557	-2.939	4.065**	3.101*	1.317	1.282	2.675	2.260
	(5.645)	(5.738)	(1.779)	(1.802)	(1.572)	(1.542)	(2.745)	(2.544)
Observations	622,017	622,017	514,409	514,409	494,405	494,405	494,405	494,405
R-squared	0.221	0.227	0.184	0.252	0.337	0.348	0.254	0.276

Note:
*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses

Table A.6.2: Regression results for data aggregated at district level

Variable	Child mortality	Child mortality	Child stunting	Child stunting	Child wasting	Child wasting	Child weight	Child weight
Cu–Mn–Zn	-8.074**	-3.693	-3.556	-13.09***	-1.630	-2.522	-2.081	-5.573
	(3.404)	(6.180)	(2.132)	(4.484)	(1.095)	(1.900)	(1.826)	(3.381)
Cu–Mn–Zn * Malaria Index		-0.460		0.734**		0.0811		0.280
		(0.427)		(0.324)		(0.0861)		(0.203)
Ca–Mg	4.201	0.588	-1.366	-4.328	3.632***	5.368***	6.734***	8.532***
	(4.001)	(4.429)	(1.993)	(3.324)	(1.004)	(0.991)	(2.194)	(2.512)
Ca–Mg * Malaria Index		0.424		0.249		-0.169**		-0.195
		(0.388)		(0.256)		(0.0821)		(0.192)
N–OMC	-2.567	-2.838	-0.0880	1.046	-1.858***	-2.943***	-2.311**	-3.649***
	(1.950)	(3.109)	(1.088)	(1.703)	(0.517)	(0.750)	(1.067)	(1.208)
N–OMC * Malaria Index		0.0272		-0.161		0.105**		0.119
		(0.277)		(0.170)		(0.0491)		(0.0859)
Institutional hierarchy	-2.238	-1.840	1.559	0.855	0.625	0.512	0.212	-0.0893
	(1.438)	(1.619)	(1.202)	(1.088)	(0.597)	(0.548)	(0.867)	(0.768)
Malaria Index	0.986***	1.165***	-0.206	-0.00908	0.339***	0.259***	0.383***	0.300**
	(0.241)	(0.356)	(0.174)	(0.139)	(0.0542)	(0.0666)	(0.0868)	(0.143)
Population density (logs)	1.632	1.275	1.013	0.843	-0.226	0.0980	0.218	0.666*
	(1.052)	(0.965)	(0.749)	(0.553)	(0.241)	(0.278)	(0.409)	(0.388)
Night time luminosity (level)	-0.303*	-0.277*	-0.278*	-0.262**	0.0484	0.0116	-0.0707	-0.125
	(0.163)	(0.163)	(0.161)	(0.117)	(0.0414)	(0.0421)	(0.0841)	(0.0781)
Distance to capital (log)	3.101***	2.691**	4.056***	3.783***	0.540	0.633	2.205**	2.257***
	(1.051)	(1.074)	(0.934)	(0.835)	(0.449)	(0.398)	(0.833)	(0.798)
Distance to coast (log)	5.573***	6.057***	0.407	-0.234	0.362	0.694**	1.289	1.573*
	(1.500)	(1.699)	(1.404)	(1.410)	(0.290)	(0.339)	(0.907)	(0.878)
Distance to border (log)	-3.190*	-3.883**	-0.00429	0.817	-0.735	-0.862*	-1.501	-1.410
	(1.758)	(1.863)	(1.659)	(1.496)	(0.445)	(0.472)	(1.041)	(1.004)
Landlocked (dummy)	3.834	3.563	2.480	2.043	0.0683	0.639	1.520	2.224
	(4.809)	(5.044)	(2.289)	(2.138)	(1.190)	(1.161)	(2.054)	(1.996)
Constant	-46.76*	-39.28	-23.78	-22.10	2.250	-2.560	-12.60	-19.21
	(26.40)	(27.13)	(16.99)	(16.67)	(8.784)	(9.088)	(18.54)	(18.58)
Observations	301	301	288	288	267	267	267	267
R-squared	0.314	0.325	0.305	0.361	0.435	0.455	0.392	0.412

Note:
*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Standard errors in parentheses

Chapter 7

Synthesis

7.1 Overview

Currently, the international community is lagging behind in reaching the Sustainable Development Goals (SDGs); the goals set to guide global policy to improve environmental and socioeconomic conditions in the Global South. Underlying the disappointing lack of progress are gaps in our understanding of whether environmental and economic goals can be reached simultaneously and which actors and policies can drive sustainable development effectively. This thesis aspired to bridge, at least part of, these gaps by studying how development aid and private sector investments can contribute to improving both environmental and economic outcomes. Though the five core chapters in this thesis are standalone research outputs, there are several of crosscutting lessons that stem from them, pertaining to the following: economics for the environment, transparency and accountability in private sector involvement, and the use of data to advance sustainable development. In what follows, I discuss each separately and then present the implications for future research in an overarching section.

7.2 Economics for the environment

I introduced this thesis by questioning whether a trade-off between economic development and the environment exists. As Jayachandran (2022) shows in her review, economic development often produces negative externalities for the environment. But these externalities can be mitigated with appropriate environmental regulation. Similarly, the chapters in this thesis suggest that environmental policies aimed at changing household behaviour do not necessarily harm economic development, as long as economic processes are taken into consideration in their design.

The systematic review in Chapter 2 reveals that there is very little evidence showing that widely promoted land restoration methods have positive socioeconomic impacts. This lends credence to the theory that if these practices improve agricultural productivity (which does seem to be the case for at least some practices), they could potentially cause households to shift factors of production away from other productive activities, possibly offsetting any productivity gains (Takahashi and Barrett, 2013). If this is true, mainstreaming land restoration measures, as pursued under the policy agenda of the UN Decade on Ecosystem Restoration, may lead to disappointing results. Firstly, if aggregate socioeconomic impacts on households are not positive, practitioners will struggle stimulating widespread adoption of these practices. Secondly, if socioeconomic outcomes are negatively affected, widespread use of the practices obviously sets back other SDGs. Though this systematic review provides no direct evidence that socioeconomic outcomes are negatively affected, it certainly underscores that more research is crucial. Once we understand how aggregate household indicators are affected, this can then be considered when designing interventions to promote land restoration measures.

This notion is strengthened by the insights of Chapter 3, which is, in essence, an illustration of how environmental outcomes can improve by reallocation of production factors within a household. The design of the indirect and relatively light-touch REDD+ intervention was set up around the idea that households should be directed towards forest-friendly activities and receive access to alternative income strategies to reduce the need for deforestation. Though the study could only provide suggestive evidence of the mechanisms at work, there are indications that the labour supply was reduced in treated communities. Since prior research in the area already pointed towards a positive relationship between labour supply and deforestation (Wilebore et al., 2019), it is likely that a reduction in the community labour supply, caused by households' engagement in more labour-intensive activities, reduced labour availability for cutting down trees. Crucially, even though household income did not improve on average, the intervention did not make households worse off either. On the one hand, this shows that the environment and economic development is not a zero-sum game. Yet on the other hand, it shows that in order to improve both, a more heavy-handed approach is necessary than was the case in this particular REDD+ intervention.

A third piece of evidence undersigning the importance of economics for effective environmental policy stems from Chapter 5, in which I show that households are willing to adopt sustainable cooking technologies only if they receive substantial monetary incentives. This confirms the findings of several smaller-scale studies in other countries showing high price elasticity of demand for improved cookstoves (e.g. Pattanayak et al. 2019; Bensch et al. 2015; Bensch and Peters 2015). A new finding from this chapter is that households who, in addition to receiving high subsidies, also receive information on the economic benefits of the cooking technology, are twice as likely to adopt. This shows that households clearly respond strongly to economic incentives, and as such, these should be part of any environmental policy.

These chapters commonly suggest that if environmental interventions directed at changing household behaviour are to succeed, they should provide households with the right incentives, alternative income strategies, or even compensation for any potential loss of income. Though the chapters do not always provide direct evidence of this, the conclusions do point in the direction that economic development and environmental protection is not a zero-sum game if effort is placed in designing interventions that target both aspects.

7.3 Towards more transparency and accountability

The private sector is playing a growing role in conservation and development. On the one hand, companies are being held socially and environmentally responsible by governments and civil society. On the other hand, Northern governments are increasingly directing part of their development aid through the private sector. In traditional forms of aid, implemented by NGOs and international organisations, there is great emphasis on programme evaluation, in part because donors demand this. This is less the case for projects and investments by the private sector. Chapter 3 and Chapter 5 deal with two increasingly important forms of private sector involvement in reaching sustainable development goals: voluntary REDD+ and foreign direct investment in agriculture and mining. A cross-cutting problem underlying these chapters is an urgent need for improved transparency and accountability. With these two chapters, I show why this is important and illustrate how this can be reached.

In Chapter 3, I studied the impact of a voluntary REDD+ programme on conservation and economic outcomes in Sierra Leone. The value of the voluntary REDD+ market is skyrocketing and the market is expected to play a large role in reaching the 1.5°C target set by the Paris Agreement. The REDD+ projects that underlie the most commonly sold credits in these markets are evaluated by third-party agencies. Yet, there is ample criticism on the quality and lack of transparency of the evaluations. One example is a recent paper by West et al. (2020) who find that emission reductions were overstated for several voluntary REDD+ projects in Brazil. Existing barriers to undertake rigorous evaluations are high costs, challenges concerning the appropriate methodology and fear that disappointing evaluations could jeopardise future funding (Simonet et al., 2018).

This chapter shows that there is scope within academia to evaluate REDD+ programmes alongside existing evaluation mechanisms of accrediting agencies. By setting up a careful ex-ante evaluation strategy with a valid counterfactual and following a pre-analysis plan, transparency as well as the quality of evaluations of voluntary REDD+ projects can be improved. To illustrate, the data underlying this chapter was collected by an academic team independent from the implementer and was subsequently used as input for the accrediting agencies' evaluation. This deviates from standard practice in which agencies typically use data collected by the implementing partner, clearly generating a risk of bias. Lastly and arguably more importantly, once REDD+ evaluations enter the academic, and thus public, domain, this enables learning about the effectiveness of different aspects of REDD+. Not only can this knowledge be used for future programme design, but it also creates a space for holding programme implementers accountable. Ultimately, this creates incentives to improve REDD+ programmes that form the basis of the carbon credits that are increasingly used by private actors to reduce their environmental impact.

Sierra Leone is also the setting of Chapter 5, in which I quantitatively describe how private investors operate when acquiring land for agricultural and mining production. This chapter paints a worrisome picture. The data collection efforts reveal that the national government is sometimes bypassed when an investor acquires land and is, in a substantial number of cases, unaware of the activities of investors. There is evidence that mining investors are more likely to invest in chiefdoms where chiefs have more political power, hinting towards a climate of corruption and potentially elite capture (which has been found previously in qualitative case studies (e.g. Ryan 2018a; Millar 2017; Bottazzi et al. 2016). Transparency about how land is acquired, the contents of the lease agreement and who receives payments is often lacking. Furthermore, conflict with communities is common, especially for mining investments and especially concerning land and environmental degradation. Though firms do invest in community development projects and local employment, actual investment is much lower than promised.

Three recommendations emerge from these findings. First, this research highlights that there is room for improving regulation of large-scale land investments within host countries, as also emphasised by the aforementioned case studies on this topic. Second, though efforts such as the Land Matrix are already contributing to improved transparency, the data collection for this chapter shows that many investments are not recorded. Setting up a regularly updated data system can inform the national government and provide a channel for host communities to express grievances, thereby improving their position. Third, there lies a responsibility for Northern governments and international initiatives such as Aid for Trade to improve the framework for holding the companies accountable that receive support to conduct part of Northern government's development aid policy.

In sum, there is potential for the private sector to contribute to conservation and economic development, and such contributions are likely necessary if we want to overcome the challenges ahead. However, to reap the benefits of such private sector initiatives, this thesis suggests that effort should be directed towards improving transparency, accountability, and regulation. Host country governments and the Northern governments who enable investors through their development aid policy should provide an accountability framework in which they allow firms to operate. This is not to say that private sector involvement will necessarily advance sustainable development if these conditions are met, as this cannot be shown by this thesis. What this thesis does highlight is that there is a role for academia, who can initiate and support high quality and independent data collection and programme evaluation. This will, in turn, help advance our understanding of how private sector initiatives can contribute to sustainable development.

7.4 Data for better lives

The complex and intertwined challenges that form the background of this thesis crosscut the economic, environmental, and social domains. Understanding these problems and finding potential solutions therefore requires a crosscutting approach. The recent advances in data collection and availability can contribute to such an approach by creating new opportunities to combine and reuse different types of data. The 2021 World Development Report 'Data for Better Lives' undersigns that data can be a powerful tool to advance development objectives. It emphasises that re-usability of data can improve efficiency and that combining data can deepen its development impact (World Bank, 2021). This thesis is an illustration of how combining geospatial and survey data from various primary as well as secondary sources, collected at different scales, can be used to uncover relationships and evaluate policies. What this thesis is not able to show is that data can indeed advance development objectives, as this is clearly not the question researched. But it does offer some insights into the role that different types of data can play in policy evaluation.

Recent advances in remote sensing and machine learning methods provide us with useful datasets that can serve as objective outcomes in policy evaluations, or as control variables in analyses where causal identification is less straightforward. Chapter 3 combines a publicly accessible global remote sensing dataset on forests with spatially estimated community boundaries to compare yearly forest loss within communities that received the REDD+ programme with control communities. This allows for a rigorous causal approach to estimating actual conservation impact of the programme. Because the programme also contains a livelihood component, household survey data was collected to estimate livelihood impacts. Similarly, Chapter 4 combines survey data collected at the firm, community, and chiefdom level with a number of publicly accessible spatial databases such as road network length, elevation, rainfall, and night-time lights. In Chapter 6, using a comparable approach, well-known Demographic and Health Survey data is combined with newly estimated soil maps for Sub-Saharan Africa. The latter are produced using a machine-learning algorithm that combines soil sample databases from across the continent with spatial predictors of soil nutrient content.

The approach in Chapter 6 offers some additional insights as to how policies can be evaluated using only secondary data. The background of this study is a commonly proposed intervention to reduce malnutrition, agronomic fortification, in which soils are enhanced with essential nutrients to increase nutrient content in crops and ultimately consumption. Experimental evidence supporting that this intervention is effective is sparse. The argument underlying Chapter 6 is that if this intervention does indeed reduce malnutrition, there should exist an empirical relationship between soil nutrient content and health outcomes. Using the above described data and a simple regression analysis, I find that this relationship does exist for at least some nutrients. With the help of some simplifying assumptions on the costs of fortification, the results are then used to conduct a simple cost-effectiveness estimation. This, in turn, is compared to other common interventions aimed at improving malnutrition. The comparison suggests that agronomic intensification is relatively inefficient. Of course, such an approach should not replace rigorous experimental trials, but it does provide an inexpensive and fast way to assess different policy options. Finally, certain findings, for example that the relationship between soils and health is dependent on malaria pressure, highlight specific areas for future research.

7.5 Future research

The aim of this thesis is by no means to offer clear-cut solutions to the huge challenges ahead of us. But the overarching insights that this thesis reveals, as described above, do contribute to our understanding and thinking about how to approach these challenges. In addition, this thesis points to several areas for future research.

Countries worldwide have pledged to restore up to 1 billion hectares of land in the coming decade, but as Chapter 2 shows, we are far from understanding what the impacts of land restoration strategies are. An urgent area for future research is thus studying the impact of land restoration methods using rigorous experimental methods on a range of outcomes related to the environment, but equally important to (aggregate) socioeconomic outcomes. Such research should be conducted within different populations in a broad set of countries, as impacts are likely heterogeneous and context-dependent. This can in turn improve our understanding of how to make sustainable technologies profitable for end-users in a specific context. Such knowledge feeds directly into the policy realm and is crucial for policy makers to fulfil the restoration promises made.

As for Chapter 3, I presented just one evaluation of more than 500 REDD+ projects worldwide. There is obviously much more to learn about the aspects of REDD+ that make a programme successful. Chapter 3 has the clear limitation of not being able to disentangle which specific interventions of the programme are driving the results. It is therefore purposeful to conduct more rigorous evaluations of REDD+ programmes, perhaps by randomising programme components, and running evaluations in different contexts. This knowledge will be crucial to optimise the use of the vast amount of money streaming into the voluntary carbon credit market.

Chapter 4 has shown that institutions matter for where land investors acquire land. In addition, I provide evidence of some of the issues that arise between investors, local institutions, and host communities. There is, however, scope for significantly more research on the local impact of land investments. Land investments are diverse in terms of how they operate, the type of agreements that are made, how host communities are engaged, and how payments and benefits are distributed. Understanding under which conditions land investments can improve socioeconomic and environmental outcomes for host communities can guide policy makers to form the necessary institutional framework in which land investments should take place. Crucially, studies on this should consider heterogeneous effects, as previous research has shown that inequality within host communities increases depending on who in the community benefits from a land investment (Hofman et al., 2019).

In Chapter 5, I presented one of the largest experiments showing that subsidies can be effective to increase adoption of sustainable stove technologies. An obvious limitation of this study is the limited definition of adoption employed. Adoption is about more than just uptake, it is also about sustained use of a technology. There is already some research on how to stimulate prolonged use of sustainable technologies (Pattanayak et al., 2019; Bensch and Peters, 2015; Jeuland and Pattanayak, 2012), but there is scope for experiments with larger samples in different contexts.

Chapter 6 shows a preliminary inquiry into the potential for agronomic fortification as a strategy to reduce malnutrition. In this chapter, I show that a relationship between soil nutrient content and health outcomes exists. This is a promising result that can form the basis for more research on how such an intervention should work. It would, for instance, be useful to research in more detail to what extent agronomic fortification leads to a higher nutrient content in crops and subsequently, to what extent intake of such nutrient rich crops improves nutrition outcomes. Moreover, getting farmers to use fertilisers has proven to be a challenge on its own. This means that even if we find that agronomic fortification can be a meaningful intervention, there are other aspects that should be studied. A second strand of research could thus focus on ways to extend nutrient enriched fertilisers to agricultural households.

Bibliography

Abadie, A. (2005). Semiparametric Difference-in-Differences Estimators. *Review of Economic Studies 72*(1), 1–19.

Abadie, A. and M. D. Cattaneo (2018). Econometric Methods for Program Evaluation. *Annual Review of Economics 10*, 465–503.

Abate, G. T., T. Bernard, A. de Brauw, and N. Minot (2018). The impact of the use of new technologies on farmers' wheat yield in Ethiopia: evidence from a randomized control trial. *Agricultural Economics (United Kingdom) 49*(4), 409–421.

Abdulai, A. and W. Huffman (2014, feb). The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. *Land Economics 90*(1), 26–43.

Abdulai, A. N. (2016, nov). Impact of Conservation Agriculture Technology on Household Welfare in Zambia. *Agricultural Economics 47*(6), 729–741.

Abdulai, A. N. and A. Abdulai (2017). Examining the impact of conservation agriculture on environmental efficiency among maize farmers in Zambia. *Environment and Development Economics 22*(2), 177–201.

Acemoglu, D., S. Johnson, and J. A. Robinson (2001). The colonial origins of comparative development: An empirical investigation: Reply. *American Economic Review 95*(5), 1369–1401.

Acemoglu, D., T. Reed, and J. A. Robinson (2014). Chiefs: Economic development and elite control of civil society in sierra leone. *Journal of Political Economy 122*(2), 319–368.

Alexandratos, N. and J. Bruinsma (2012). World agriculture towards 2030/2050: the 2012 revision. Technical report, Rome, Italy.

Alix-Garcia, J. M., K. R. E. Sims, and P. Yañez-Pagans (2015). Only one tree from each seed? Environmental effectiveness and poverty alleviation in Mexico's Payments for Ecosystem Services Programme. *American Economic Journal: Economic Policy 7*(4), 1–40.

Alpízar, F. and P. J. Ferraro (2020). The environmental effects of poverty programs and the poverty effects of environmental programs: The missing RCTs. *World Development 127*, 2019–2021.

Angelsen, A. (2008). Moving Ahead with REDD: Issues, Options and Implications. Technical report, Center for International Forestry Research, Bogor, Indonesia.

Angelsen, A., C. Martius, V. De Sy, A. E. Duchelle, A. M. Larson, and P. T. Thuy (2018). *Transforming REDD+: Lessons and new directions*. Bogor, Indonesia: CIFOR.

Anti, S. (2021). Land grabs and labor in Cambodia. *Journal of Development Economics 149*(December 2020), 102616.

Arezki, R., C. Bogmans, and H. Selod (2018). The Globalization of Farmland: Theory and Empirical Evidence. *IMF Working Papers 18*(145), 1.

Arezki, R., K. Deininger, and H. Selod (2015). What drives the global "land rush"? *World Bank Economic Review 29*(2), 207–233.

Arslan, A., F. Belotti, and L. Lipper (2017, may). Smallholder Productivity and Weather Shocks: Adoption and Impact of Widely Promoted Agricultural Practices in Tanzania. *Food Policy 69*, 68–81.

Asfaw, S., N. McCarthy, L. Lipper, A. Arslan, A. Cattaneo, and M. Kachulu (2015). Climate variability, adaptation strategies and food security in Malawi. Technical report, Milan, Italy.

Barbier, E. B. and J. P. Hochard (2018). Land degradation and poverty. *Nature Sustainability 1*(11), 623–631.

Bardhan, P. and D. Mookherjee (2011, oct). Subsidized Farm Input Programs and Agricultural Performance: A Farm-Level Analysis of West Bengal's Green

Revolution, 1982-1995. *American Economic Journal: Applied Economics 3*(4), 186–214.

Barrett, C. B. and L. E. Bevis (2015). The self-reinforcing feedback between low soil fertility and chronic poverty. *Nature Geoscience 8*(12), 907–912.

Barrett, C. B. and M. R. Carter (2010). The power and pitfalls of experiments in development economics: Some non-random reflections. *Applied Economic Perspectives and Policy 32*(4), 515–548.

Beltramo, T., G. Blalock, D. I. Levine, and A. M. Simons (2015). The effect of marketing messages and payment over time on willingness to pay for fuel-efficient cookstoves. *Journal of Economic Behavior and Organization 118*, 333–345.

Bender, R. and S. Lange (2001). Adjusting for multiple testing - When and how? *Journal of Clinical Epidemiology 54*(4), 343–349.

Bensch, G., M. Grimm, and J. Peters (2015). Why do households forego high returns from technology adoption? Evidence from improved cooking stoves in Burkina Faso. *Journal of Economic Behavior and Organization 116*, 187–205.

Bensch, G. and J. Peters (2015). The intensive margin of technology adoption - Experimental evidence on improved cooking stoves in rural Senegal. *Journal of Health Economics 42*, 44–63.

Bensch, G. and J. Peters (2020). One-Off Subsidies and Long-Run Adoption—Experimental Evidence on Improved Cooking Stoves in Senegal. *American Journal of Agricultural Economics 102*(1), 72–90.

Berkhout, E. D., M. Malan, and T. Kram (2017). Micronutrients for agricultural intensification - Is Sub-Saharan Africa at risk? Technical report, PBL The Netherlands Environmental Assessment Agency, The Hague.

Berkouwer, S. B., J. D. T. D. Manuscript, U. Of, and U. 2021 (2021). *Credit, attention, and externalities in the adoption of energy efficient technologies by low-income households.*

Bevis, L. E. M. (2015a). Soil-to-Human Mineral Transmission with an Emphasis on Zinc, Selenium, and Iodine. *Springer Science Reviews 3*(1), 77–96.

Bevis, L. E. M. (2015b). Who supplies nutrients? The puzzle of crop zinc heterogeneity and low-zinc market crops in rural Uganda. *Working paper, Publications Dyson Cornell Edu*, 1–44.

Bhutta, Z. A., J. K. Das, A. Rizvi, M. F. Gaffey, N. Walker, S. Horton, P. Webb, A. Lartey, and R. E. Black (2013). Evidence-based interventions for improvement of maternal and child nutrition: What can be done and at what cost? *The Lancet 382*(9890), 452–477.

Biggeri, M., F. Burchi, F. Ciani, and R. Herrmann (2018). Linking small-scale farmers to the durum wheat value chain in Ethiopia: Assessing the effects on production and wellbeing. *Food Policy 79*(October 2017), 77–91.

Black, R. E., C. G. Victora, S. P. Walker, Z. A. Bhutta, P. Christian, M. De Onis, M. Ezzati, S. Grantham-Mcgregor, J. Katz, R. Martorell, and R. Uauy (2013). Maternal and child undernutrition and overweight in low-income and middle-income countries. *The Lancet 382*(9890), 427–451.

Blair, G., D. Christensen, and V. Wirtschafter (2022). How Does Armed Conflict Shape Investment? Evidence from the Mining Sector. *Journal of Politics 84*(1), 116–133.

Bluffstone, R., A. D. Beyene, Z. Gebreegziabher, P. Martinsson, A. Mekonnen, and M. Toman (2022). Experience and Learning with Improved Technologies: Evidence from Improved Biomass Cookstoves in Ethiopia. *Environmental and Resource Economics 81*(2), 271–285.

Bluffstone, R. A., A. D. Beyene, Z. Gebreegziabher, P. Martinsson, A. Mekonnen, and F. Vieider (2021). Does Providing Improved Biomass Cooking Stoves Free-of-Charge Reduce Regular Usage? Do Use Incentives Promote Habits? *Land Economics 97*(1), 180–195.

Börner, J., K. Baylis, E. Corbera, D. Ezzine-de Blas, J. Honey-Rosés, U. M. Persson, and S. Wunder (2017). The Effectiveness of Payments for Environmental Services. *World Development 96*, 359–374.

Bos, A. B., A. E. Duchelle, A. Angelsen, V. Avitabile, V. De Sy, M. Herold, S. Joseph, C. De Sassi, E. O. Sills, W. D. Sunderlin, and S. Wunder (2017). Comparing methods for assessing the effectiveness of subnational REDD+ initiatives. *Environmental Research Letters 12*(7).

Boserup, E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure.* London: Allen and Unwin.

Bottazzi, P., A. Goguen, and S. Rist (2016). Conflicts of customary land tenure in rural Africa: is large-scale land acquisition a driver of 'institutional innovation'? *Journal of Peasant Studies 43*(5), 971–988.

Bravo-Ureta, B. E., A. N. Almeida, D. Solís, and A. Inestroza (2011). The Economic Impact of Marena's Investments on Sustainable Agricultural Systems in Honduras. *Journal of Agricultural Economics 62*(2), 429–448.

Briggs, R. C. (2018). Poor targeting: A gridded spatial analysis of the degree to which aid reaches the poor in Africa. *World Development 103*, 133–148.

Brouder, S. M. and H. Gomez-Macpherson (2014). The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. *Agriculture, Ecosystems & Environment 187*, 11–32.

Burke, W. J., T. S. Jayne, and J. R. Black (2017, jan). Factors Explaining the Low and Variable Profitability of Fertilizer Application to Maize in Zambia. *Agricultural Economics 48*(1), 115–126.

Cakmak, I., W. H. Pfeiffer, and B. McClafferty (2010). Biofortification of durum wheat with zinc and iron. *Cereal Chemistry 87*(1), 10–20.

Castle, S. E., D. C. Miller, P. J. Ordonez, K. Baylis, and K. Hughes (2021, jun). The impacts of agroforestry interventions on agricultural productivity, ecosystem services, and human well-being in low- and middle-income countries: A systematic review. *Campbell Systematic Reviews 17*(2).

Center for International Earth Science Information Network (CIESIN) Columbia University (2016). *Gridded Population of the World, Version 4 (GPWv4): Population Density.* Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC).

Chakravarty, S. (2009). *Harvesting health: Fertilizer, nutrition and AIDS treatment in Kenya.* Columbia University.

Christensen, D., A. C. Hartman, and C. Samii (2021). Legibility and External Investment: An Institutional Natural Experiment in Liberia. *International*

Organization 75(4), 1087–1108.

Christensen, G. and E. Miguel (2018). Transparency, reproducibility, and the credibility of economics research. *Journal of Economic Literature 56*(3), 920–980.

Colin Cameron, A., J. B. Gelbach, and D. L. Miller (2011). Robust inference with multiway clustering. *Journal of Business and Economic Statistics 29*(2), 238–249.

Conteh, S. and S. A. Yeshanew (2016). Non-judicial grievance mechanisms in land-related disputes in Sierra Leone. Technical Report FAO Legal Papers No.99, Food and Agricultural Organization of the United Nations, Rome, Italy.

Corbeels, M., R. K. Sakyi, R. F. Kühne, and A. Whitbread (2014). Meta-analysis of crop responses to conservation agriculture in sub-Saharan Africa.

Correa, J., E. Cisneros, J. Börner, A. Pfaff, M. Costa, and R. Rajão (2020). Evaluating REDD+ at subnational level: Amazon fund impacts in Alta Floresta, Brazil. *Forest Policy and Economics 116*(February 2019).

Correia, S. (2014). *REGHDFE: Stata module to perform linear or instrumental variable regression absorbing any number of high-dimensional fixed effects.: Statistical Software Components*. Statistical Software Components: Boston College Department of Economics.

DAN Watch (2011). Not sharing the loot: An investigation of tax payments and corporate structures in the mining industry of Sierra Leone. Technical Report October.

Deaton, A. (2013). *The Great Escape: Health, Wealth and the Origins of Inequality.* Princeton, New Jersey: Princeton University Press.

Deaton, A. and N. Cartwright (2018). Understanding and misunderstanding randomized controlled trials. *Social Science and Medicine 210*(October 2017), 2–21.

DeGraft-Johnson, M., A. Suzuki, T. Sakurai, and K. Otsuka (2014, sep). On the Transferability of the Asian Rice Green Revolution to Rainfed Areas in Sub-Saharan Africa: An Assessment of Technology Intervention in Northern

Ghana. *Agricultural Economics 45*(5), 555–570.

Deininger, K. and P. Olinto (2000). Why Liberalization Alone Has Not Improved Agricultural Productivity in Zambia: The Role of Asset Ownership and Working Capital Constraints. *World Bank Policy Research Working Paper* (2302).

Dell, M., B. F. Jones, and B. A. Olken (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics 4*(3), 66–95.

Dessy, S., G. Gohou, and D. Vencatachellum (2012). Land Acquisition in Africa: Threat or Opportunity for Local Populations? *Working paper*, 1–34.

DeVellis, R. (2003). *Scale development. Theory and applications.* United States: Sage Publications.

Diao, X., P. A. Dorosh, and S. M. Rahman (2007). *Market opportunities for African agriculture: a general equilibrium examination of demand-side constraints on agricultural growth in East and Southern Africa.* Washington D.C.: International Food Policy Research Institute.

Dimkpa, C. O. and P. S. Bindraban (2016). Fortification of micronutrients for efficient agronomic production: a review. *Agronomy for Sustainable Development 36*(1), 1–26.

Dresen, E., B. DeVries, M. Herold, L. Verchot, and R. Müller (2014). Fuelwood savings and carbon emission reductions by the use of improved cooking stoves in an afromontane forest, Ethiopia. *Land 3*(3), 1137–1157.

Droppelmann, K. J., S. S. Snapp, and S. R. Waddington (2017). Sustainable intensification options for smallholder maize-based farming systems in sub-Saharan Africa. *Food Security 9*(1), 133–150.

Duchelle, A. E., C. de Sassi, P. Jagger, M. Cromberg, A. M. Larson, W. D. Sunderlin, S. S. Atmadja, I. A. P. Resosudarmo, and C. D. Pratama (2017). Balancing carrots and sticks in REDD+: Implications for social safeguards. *Ecology and Society 22*(3).

Duchelle, A. E., C. de Sassi, E. O. Sills, and S. Wunder (2018). People and communities: Well-being impacts of REDD+ on the ground. Technical report, Bogor, Indonesia.

Duflo, E., M. Kremer, and J. Robinson (2011, oct). Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya. *American Economic Review 101*(6), 2350–2390.

Dupuy, K. E. (2017). Corruption and elite capture of mining community development funds in Ghana and Sierra Leone. In *Corruption, Natural Resources and Development*, pp. 69–79. Edward Elgar Publishing.

El-Shater, T., Y. A. Yigezu, A. Mugera, C. Piggin, A. Haddad, and Y. Khalil (2016, feb). Does Zero Tillage Improve the Livelihoods of Smallholder Cropping Farmers? *Journal of Agricultural Economics 67*(1), 154–172.

Ellis, E. A., S. A. Montero, I. U. Hernández Gómez, J. A. Romero Montero, P. W. Ellis, D. Rodríguez-Ward, P. Blanco Reyes, and F. E. Putz (2019). Reduced-impact logging practices reduce forest disturbance and carbon emissions in community managed forests on the Yucatán Peninsula, Mexico. *Forest Ecology and Management 437*(November 2018), 396–410.

Engel, S. (2016). The devil in the detail: A practical guide on designing payments for environmental services. *International Review of Environmental and Resource Economics 9*(1-2), 131–177.

Engwicht, N. (2018). The local translation of global norms: the Sierra Leonean diamond market. *Conflict, Security and Development 18*(6), 463–492.

Ezzine-De-Blas, D., S. Wunder, M. Ruiz-Pérez, and R. Del Pilar Moreno-Sanchez (2016). Global patterns in the implementation of payments for environmental services. *PLoS ONE 11*(3), 1–16.

Faltermeier, L. and A. Abdulai (2009, may). The Impact of Water Conservation and Intensification Technologies: Empirical Evidence for Rice Farmers in Ghana. *Agricultural Economics 40*(3), 365–379.

FAO (2020). State of knowledge of soil biodiversity. Status, challenges and potentialities. Technical report, Rome, Italy.

Farooq, M. and K. H. M. Siddique (2014). *Conservation agriculture.* Springer.

Ferraro, P. J. (2009). Counterfactual thinking and impact evaluation in environmental policy. In M. Birnbaum and P. Mickwitz (Eds.), *Environmental program and policy evaluation: Addressing methodological challenges. New Directions for Evaluation*, pp. 75–84.

Ferraro, P. J. and A. Kiss (2002). Direct Payments to Conserve Biodiversity. *Science 289*(5599).

Ferraro, P. J. and R. Simorangkir (2020). Conditional cash transfers to alleviate poverty also reduced deforestation in Indonesia. *Science Advances 6*(24).

Fiedler, J. L., K. Lividini, R. Zulu, G. Kabaghe, J. Tehinse, and O. I. Bermudez (2013). Identifying Zambia's industrial fortification options: Toward overcoming the food and nutrition information gap-induced impasse. *Food and Nutrition Bulletin 34*(4), 480–500.

Fink, G. and J. Heitner (2014). Evaluating the cost-effectiveness of preventive zinc supplementation. *BMC Public Health 14*(1), 1–10.

Forest Trends' Ecosystem Marketplace (2021). 'Market in Motion', State of Voluntary Carbon Markets 2021, Installment 1. Technical report, Forest Trends Association, Washington D.C.

Franco, A., N. Malhotra, and G. Simonovits (2014). Publication bias in the social sciences: Unlocking the file drawer. *Science 345*(6203), 1502–1505.

Gaia Association (2014). The holistic feasibility study of national scale-up program for ethanol cookstoves and Ethanol Micro Distilleries (EMDs) in Ethiopia marketing strategy for ethanol to household cooking fuel. Technical report.

Gallup, J. L., J. D. Sachs, and A. D. Mellinger (1999). Geography and Economic Development. *International Regional Science Review 22*(2), 179–232.

Gebreegziabher, Z., A. D. Beyene, R. Bluffstone, P. Martinsson, A. Mekonnen, and M. A. Toman (2018). Fuel savings, cooking time and user satisfaction with improved biomass cookstoves: Evidence from controlled cooking tests in Ethiopia. *Resource and Energy Economics 52*, 173–185.

Gilmore, E., N. P. Gleditsch, P. Lujala, and J. K. Rød (2005). Conflict diamonds: A new dataset. *Conflict Management and Peace Science 22*(3), 257–272.

GIZ (2011). Stove Testing Results: A Report on Controlled Cooking Test Results

Performed on 'Mirt with integrated chimney' and 'Institutional Mirt' Stoves. Technical report.

GIZ (2013). Clean and Efficient Cooking Energy for 100 Million Homes. Technical Report June, GIZ, Eschborn, Germany.

Goheen, M. M., R. Wegmüller, A. Bah, B. Darboe, E. Danso, M. Affara, D. Gardner, J. C. Patel, A. M. Prentice, and C. Cerami (2016). Anemia Offers Stronger Protection Than Sickle Cell Trait Against the Erythrocytic Stage of Falciparum Malaria and This Protection Is Reversed by Iron Supplementation. *EBioMedicine 14*, 123–130.

Government of Sierra Leone (2015). Final National Land Policy of Sierra Leone, Version 6. Technical report.

Gregory, P. J., A. Wahbi, J. Adu-Gyamfi, M. Heiling, R. Gruber, E. J. Joy, and M. R. Broadley (2017). Approaches to reduce zinc and iron deficits in food systems. *Global Food Security 15*(December 2016), 1–10.

Grossman, G. M. and A. B. Krueger (1991). Environmental Impacts of a North American Free Trade Agreement. *NBER Working Paper* (3914).

Grossman, G. M. and A. B. Krueger (1995). Economic Growth and the Environment. *The Quarterly Journal of Economics 110*(2), 353–377.

Hanna, R., E. Duflo, and M. Greenstone (2016). Up in smoke: The influence of household behavior on the long-run impact of improved cooking stoves. *American Economic Journal: Economic Policy 8*(1), 80–114.

Hansen, M., P. Potapov, R. Moore, M. Hancher, S. Turubanova, A. Tyukavina, D. Thau, S. Stehman, S. Goetz, T. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. Justice, and J. Towsnhendd (2013). High-Resolution Global Maps of 21st-Century Gorest Cover Change. *Science 342*(6160), 850–853.

Harou, A. P. (2018). Unraveling the effect of targeted input subsidies on dietary diversity in household consumption and child nutrition: The case of Malawi. *World Development 106*, 124–135.

Hemming, D. J., E. W. Chirwa, A. Dorward, H. J. Ruffhead, R. Hill, J. Osborn, L. Langer, L. Harman, H. Asaoka, C. Coffey, and D. Phillips (2018). Agricultural input subsidies for improving productivity, farm income, consumer welfare and wider growth in low- and lower-middle-income countries: a systematic review. *Campbell Systematic Reviews 14*(1), 1–153.

Hengl, T., J. G. Leenaars, K. D. Shepherd, M. G. Walsh, G. B. Heuvelink, T. Mamo, H. Tilahun, E. Berkhout, M. Cooper, E. Fegraus, I. Wheeler, and N. A. Kwabena (2017). Soil nutrient maps of Sub-Saharan Africa: assessment of soil nutrient content at 250 m spatial resolution using machine learning. *Nutrient Cycling in Agroecosystems 109*(1), 77–102.

Herr, D., J. Blum, A. Himes-Cornell, and A. Sutton-Grier (2019). An analysis of the potential positive and negative livelihood impacts of coastal carbon offset projects. *Journal of Environmental Management 235*(August 2018), 463–479.

Higgins, D., T. Balint, H. Liversage, and P. Winters (2018). Investigating the impacts of increased rural land tenure security: A systematic review of the evidence. *Journal of Rural Studies 61*, 34–62.

Hofman, P., E. Mokuwa, P. Richards, and M. Voors (2019). Local Economy effects of Large-Scale Agricultural Investments. *Working paper*.

Honey-Rosés, J., J. López-García, E. Rendón-Salinas, A. Peralta-Higuera, and C. Galindo-Leal (2009). To pay or not to pay? Monitoring performance and enforcing conditionality when paying for forest conservation in Mexico. *Environmental Conservation 36*(2), 120–128.

Horton, S., F. Begin, A. Greig, and A. Lakshman (2009). Best Practice Paper: Micronutrient Supplements for Child Survival (Vitamin A and Zinc). *Copenhagen Consensus Center*.

Horton, S. and J. Hoddinott (2014). Benefits and Costs of the Food and Nutrition Targets for the Post-2015 Development Agenda. *Copenhagen Consensus Center*.

IEA (2019). Africa Energy Outlook Report. pp. 20.

IPBES (2018). The IPBES assessment report on land degradation and restoration. Technical report, Bonn, Germany.

IZA (2018). International Zinc Association. *www.zinc.org*.

Jack, B. K. (2017). Environmental economics in developing countries: An introduction to the special issue. *Journal of Environmental Economics and Management 86*, 1–7.

Jagger, P. and P. Rana (2017). Using publicly available social and spatial data to evaluate progress on REDD+ social safeguards in Indonesia. *Environmental Science and Policy 76*(June), 59–69.

Jayachandran, S. (2022). How Economic Development Influences the Environment. *Annual Review of Economics 14*, 1–30.

Jayachandran, S., J. D. Laat, E. F. Lambin, C. Y. Stanton, R. Audy, and N. E. Thomas (2017). Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation. *Science 357*(6348), 267–273.

Jayne, T. S. and P. A. Sanchez (2021). Agricultural productivity must improve in sub-Saharan Africa. *Science 372*(6546), 1045–1048.

Jeuland, M. A. and S. K. Pattanayak (2012). Benefits and costs of improved cookstoves: Assessing the implications of variability in health, forest and climate impacts. *PLoS ONE 7*(2).

Johnston, C. C., J. Z. Miller, C. W. Slemenda, T. L. Reister, M. Siu Hiu, J. C. Christian, and M. Peacock (1992). Calcium supplementation and increases in bone mineral density in children. *The New England Journal of Medicine 327*(2), 82–87.

Joy, E. J., W. Ahmad, M. H. Zia, D. B. Kumssa, S. D. Young, E. L. Ander, M. J. Watts, A. J. Stein, and M. R. Broadley (2017). Valuing increased zinc (Zn) fertiliser-use in Pakistan. *Plant and Soil 411*(1-2), 139–150.

Joy, E. J., A. J. Stein, S. D. Young, E. L. Ander, M. J. Watts, and M. R. Broadley (2015). Zinc-enriched fertilisers as a potential public health intervention in Africa. *Plant and Soil 389*(1-2), 1–24.

Kassie, M., J. Pender, M. Yesuf, G. Kohlin, R. Bluffstone, and E. Mulugeta (2008). Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agricultural Economics 38*(2), 213–232.

Kassie, M., H. Teklewold, P. Marenya, M. Jaleta, and O. Erenstein (2015, sep). Production Risks and Food Security under Alternative Technology Choices in

Malawi: Application of a Multinomial Endogenous Switching Regression. *Journal of Agricultural Economics 66*(3), 640–659.

Kato, E., C. Ringler, M. Yesuf, and E. Bryan (2011, sep). Soil and Water Conservation Technologies: A Buffer against Production Risk in the Face of Climate Change? Insights from the Nile Basin in Ethiopia. *Agricultural Economics 42*(5), 593–604.

Katona, P. and J. Katona-Apte (2008). The interaction between nutrition and infection. *Clinical Infectious Diseases 46*(10), 1582–1588.

Kihara, J., G. W. Sileshi, G. Nziguheba, M. Kinyua, S. Zingore, and R. Sommer (2017). Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. *Agronomy for Sustainable Development 37*(4).

Kim, K. and L. Bevis (2019). Soil Fertility and Poverty in Developing Countries. *Choices 34*(2), 1–8.

Kindornay, S. and F. Reilly-King (2013). Promotion and partnership: Bilateral donor approaches to the private sector. *Canadian Journal of Development Studies 34*(4), 533–552.

Kiszewski, A., A. Mellinger, A. Spielman, P. Malaney, S. E. Sachs, and J. Sachs (2004). A global index representing the stability of malaria transmission. *American Journal of Tropical Medicine and Hygiene 70*(5), 486–498.

Kleemann, L. and R. Thiele (2015). Rural welfare implications of large-scale land acquisitions in Africa: A theoretical framework. *Economic Modelling 51*, 269–279.

Kling, J. R., J. B. Liebman, and L. F. Katz (2007, jan). Experimental Analysis of Neighborhood Effects. *Econometrica 75*(1), 83–119.

Knutsen, C. H., A. Kotsadam, E. H. Olsen, and T. Wig (2017). Mining and Local Corruption in Africa. *American Journal of Political Science 61*(2), 320–334.

LaFave, D., A. D. Beyene, R. Bluffstone, S. T. Dissanayake, Z. Gebreegziabher, A. Mekonnen, and M. Toman (2021). Impacts of improved biomass cookstoves on child and adult health: Experimental evidence from rural Ethiopia. *World Development 140*, 105332.

Lawry, S., C. Samii, R. Hall, A. Leopold, D. Hornby, and F. Mtero (2016). The impact of land property rights interventions on investment and agricultural productivity in developing countries: a systematic review. *Journal of development effectiveness*, 1–21.

Lay, J. and K. Nolte (2018). Determinants of foreign land acquisitions in low-and middle-income countries. *Journal of Economic Geography 18*(1), 59–86.

Levine, D. I., T. Beltramo, G. Blalock, C. Cotterman, and A. M. Simons (2018). What impedes efficient adoption of products? Evidence from randomized sales offers for fuel-efficient cookstoves in Uganda. *Journal of the European Economic Association 16*(6), 1850–1880.

Levitt, S. D. and J. A. List (2009). Field experiments in economics: The past, the present, and the future. *European Economic Review 53*(1), 1–18.

Li, Q., E. Owen, and A. Mitchell (2018). Why do democracies attract more or less foreign direct investment? A metaregression analysis. *International Studies Quarterly 62*(3), 494–504.

Lim, S. S., T. Vos, A. D. Flaxman, G. Danaei, K. Shibuya, H. Adair-Rohani, (...), and M. Ezzati (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet 380*(9859), 2224–2260.

Liverpool-Tasie, L. S. O. (2017, feb). Is Fertiliser Use Inconsistent with Expected Profit Maximization in Sub-Saharan Africa? Evidence from Nigeria. *Journal of Agricultural Economics 68*(1), 22–44.

Liverpool-Tasie, L. S. O., S. Adjognon, and O. Kuku-Shittu (2014). Productivity effects of sustainable intensification: The case of Urea deep placement for rice production in Niger State, Nigeria. Technical report, Minneapolis, United States.

Lomborg, B. (2014). *How to spend $75 billion to make the world a better place.* Copenhagen: Copenhagen Consensus Center.

London Metal Exchange (2017). London Metal Exchange. *https://www.lme.com/en/*.

Lujala, P., J. K. Röd, and N. Thieme (2007). Fighting over oil: Introducing a new dataset. *Conflict Management and Peace Science 24*(3), 239–256.

Lyons, G. and I. Cakmak (2012). Agronomic biofortification of food crops with micronutrients. In T. Bruulsema, P. Heffer, R. Welch, I. Cakmak, and K. Moran (Eds.), *Fertilizing crops to improve scientific health: a scientific review*. United States: International Plant Nutrition Institute.

MAFFS (2011). Agricultural Household Tracking Survey (AHTS) Final Report. Technical report, Ministry of Agriculture, Forestry and Food Security, Freetown.

Martin, W. J., R. I. Glass, J. M. Balbus, and F. S. Collins (2011). A major environmental cause of death. *Science 334*(6053), 180.

Maru, V. (2006). Between Law and Society: Paralegals and the Provision of Primary Justice Services in Sierra Leone. Technical report, Open Society Institute, New York, USA.

Meenakshi, J. V., N. L. Johnson, V. M. Manyong, H. De Groote, J. Javelosa, D. R. Yanggen, F. Naher, C. Gonzalez, J. García, and E. Meng (2010). How Cost-Effective is Biofortification in Combating Micronutrient Malnutrition? An Ex ante Assessment. *World Development 38*(1), 64–75.

Michalopoulos, S. and E. Papaioannou (2013). Pre-Colonial Ethnic Institutions and Contemporary African Development. *Econometrica 81*(1), 113–152.

Michler, J. D., E. Tjernström, S. Verkaart, and K. Mausch (2019). Money matters: The role of yields and profits in agricultural technology adoption. *American Journal of Agricultural Economics 101*(3), 710–731.

Millar, G. (2017). For whom do local peace processes function? Maintaining control through conflict management. *Cooperation and Conflict 52*(3), 293–308.

Miller, G. and A. M. Mobarak (2013). Gender diferences in preferences intra-household externalities. *NBER Working Paper 18964*.

Mobarak, A. M., P. Dwivedi, R. Bailis, L. Hildemann, and G. Miller (2012). Low demand for nontraditional cookstove technologies. *Proceedings of the National Academy of Sciences of the United States of America 109*(27), 10815–10820.

Müller, O. and M. Krawinkel (2005). Malnutrition and health in developing countries. *CMAJ 173*(3).

Munyehirwe, A., J. Peters, M. Sievert, E. H. Bulte, and N. Fiala (2022). Energy efficiency and local rebound effects: Theory and experimental evidence from Rwanda. *Ruhr Economic Papers* (No. 934).

Murdoch, G. (1967). *Ethnographic Atlas.* Pittsburgh , PA, United States: University of Pittsburgh Press.

Nair, P. K. R., B. M. Kumar, and V. D. Nair (2021). *An Introduction to Agroforestry-Four Decades of Scientific Developments.* Springer.

Navarro, L. M., A. Marques, V. Proença, S. Ceauşu, B. Gonçalves, C. Capinha, M. Fernandez, J. Geldmann, and H. M. Pereira (2017). Restoring degraded land: contributing to Aichi Targets 14, 15, and beyond. *Current Opinion in Environmental Sustainability 29*, 207–214.

Nkonya, E., W. Anderson, E. Kato, K. Jawoo, A. Mirzabaev, J. Von Braun, and S. Meyer (2016). Chapter 6: Global costs of land degradation. In E. Nkonya, A. Mirzabaev, and J. von Braun (Eds.), *Economics of land degradation and improvement - a global assessment for sustainable development.* Heidelberg: Springer.

NOAA (2017). Nighttime Lights. Boulder, Colorado.

Ochiai, T. (2017). Customary land tenure, large-scale land acquisitions and land reform in Sierra Leone. *Faculty of Discussion papers, University of Kyoto*, 1–25.

OECD (2002). Foreign direct investment for development. Technical report.

OECD (2021). OECD-DAC Aid activities database (CRS).

Olken, B. A. and R. Pande (2012). Corruption in developing countries. *Annual Review of Economics 4*, 479–509.

Osgood-Zimmerman, A., A. I. Millear, R. W. Stubbs, C. Shields, B. V. Pickering, L. Earl, N. Graetz, D. K. Kinyoki, S. E. Ray, S. Bhatt, A. J. Browne, R. Burstein, E. Cameron, D. C. Casey, A. Deshpande, N. Fullman, P. W. Gething, H. S. Gibson, N. J. Henry, M. Herrero, L. K. Krause, I. D. Letourneau, A. J. Levine, P. Y. Liu, J. Longbottom, B. K. Mayala, J. F. Mosser, A. M. Noor, D. M. Pigott, E. G. Piwoz, P. Rao, R. Rawat, R. C. Reiner, D. L. Smith, D. J. Weiss, K. E.

Wiens, A. H. Mokdad, S. S. Lim, C. J. Murray, N. J. Kassebaum, and S. I. Hay (2018). Mapping child growth failure in Africa between 2000 and 2015. *Nature 555*(7694), 41–47.

Padam, G., D. Rysankova, E. Portale, B. Bonsuk Koo, and G. Fleurantin (2018). Ethopia Beyond Connections. Energy Access Diagnostic Report Based on the Multi-Tier Framework. Technical report, World Bank, Washington D.C.

Pandit, R., J. Parrota, Y. Anker, E. Coudel, C. F. Diaz Morejón, J. Harris, D. L. Karlen, Á. Kertész, M. D. P. J. L, P. Ntshotsho Simelane, N. M. Tamin, and D. L. M. Vieira (2018). Chapter 6: Responses to halt land degradation and to restore degraded land. In L. Montanarella, R. Scholes, and A. Brainich (Eds.), *The IPBES assessment report on land degradation and restoration.* Bonn, Germany: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Pandya, S. S. (2016). Political Economy of Foreign Direct Investment: Globalized Production in the Twenty-First Century. *Annual Review of Political Science 19*, 455–475.

Parker, T., H. Fraser, and S. Nakagawa (2019). Making conservation science more reliable with preregistration and registered reports. *Conservation Biology 33*(4), 747–750.

Pattanayak, S. K., M. Jeuland, J. J. Lewis, F. Usmani, N. Brooks, V. Bhojvaid, A. Kar, L. Lipinski, L. Morrison, O. Patange, N. Ramanathan, I. H. Rehman, R. Thadani, M. Vora, and V. Ramanathan (2019). Experimental evidence on promotion of electric and improved biomass cookstoves. *Proceedings of the National Academy of Sciences of the United States of America 116*(27), 13282–13287.

Pender, J. and B. Gebremedhin (2007). Determinants of Agricultural and Land Management Practices and Impacts on Crop Production and Household Income in the Highlands of Tigray, Ethiopia. *Journal of African Economies 17*(3), 395–450.

Peters, J., J. Langbein, and G. Roberts (2018). Generalization in the tropics-development policy, randomized controlled trials, and external validity. *World*

Bank Research Observer 33(1), 34–64.

Piñeiro, V., J. Arias, J. Dürr, P. Elverdin, A. M. Ibáñez, A. Kinengyere, C. M. Opazo, N. Owoo, J. R. Page, S. D. Prager, and M. Torero (2020). A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. *Nature Sustainability 3*(10), 809–820.

Poulton, C., J. Kydd, and A. Dorward (2006, may). Overcoming Market Constraints on Pro-Poor Agricultural Growth in Sub-Saharan Africa. *Development Policy Review 24*(3), 243–277.

Pretty, J. (2018). Intensification for redesigned and sustainable agricultural systems. *Science 362*(6417), eaav0294.

Pretty, J., T. G. Benton, Z. P. Bharucha, L. V. Dicks, C. B. Flora, H. C. J. Godfray, D. Goulson, S. Hartley, N. Lampkin, C. Morris, G. Pierzynski, P. V. V. Prasad, J. Reganold, J. Rockström, P. Smith, P. Thorne, and S. Wratten (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability 1*(8), 441–446.

Prince, S., G. Von Maltitz, F. Zhang, K. Byrne, C. Driscoll, G. Eshel, G. Kust, C. Martínez-Garza, J. P. Metzger, G. Midgley, D. Moreno-Mateos, M. Sghaier, and S. Thwin (2018). Chapter 4: Status and trends of land degradation and restoration and associated changes in biodiversity and ecosystem functions. In L. Montanarella, R. Scholes, and A. Brainich (Eds.), *The IPBES assessment report on land degradation and restoration.* Bonn, Germany: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Prüss-üstün, A., C. Mathers, C. Corvalan, and A. Woodward (2003). Introduction and methods: Assessing the environmental burden of disease at national and local levels. (No. 1).

Ragasa, C. and J. Mazunda (2018). The impact of agricultural extension services in the context of a heavily subsidized input system: the case of Malawi. *World Development (Oxford) 105*, 25–47.

Redding, S. and A. J. Venables (2004). Economic geography and international inequality. *Journal of International Economics 62*(1), 53–82.

Renner-Thomas, A. (2010). *Land tenure in Sierra Leone: The law, dualism and* *the making of a land policy.*

Roe, S., C. Streck, M. Obersteiner, S. Frank, B. Griscom, L. Drouet, O. Fricko, M. Gusti, N. Harris, T. Hasegawa, Z. Hausfather, P. Havlík, J. House, G.-J. Nabuurs, A. Popp, M. J. S. Sánchez, J. Sanderman, P. Smith, E. Stehfest, and D. Lawrence (2019). Contribution of the land sector to a 1.5 °C world. *Nature Climate Change 9*(11), 817–828.

Ros, G. H., A. M. van Rotterdam, D. W. Bussink, and P. S. Bindraban (2016). Selenium fertilization strategies for bio-fortification of food: an agro-ecosystem approach. *Plant and Soil 404*(1-2), 99–112.

Ryan, C. (2018a). Large-scale land deals in Sierra Leone at the intersection of gender and lineage. *Third World Quarterly 39*(1), 189–206.

Ryan, C. (2018b). Negotiating and implementing large scale land deals in Sierra Leone Improving transparency and consent. pp. 1–6.

Sachs, J. and P. Malaney (2002). The economic and social burden of malaria. *Nature 415*(6872), 680–685.

Salzman, J., G. Bennett, N. Carroll, A. Goldstein, and M. Jenkins (2018). The global status and trends of Payments for Ecosystem Services. *Nature Sustainability 1*(3), 136–144.

Schmidt, E. and F. Tadesse (2017). *The sustainable land management program in the Ethiopian highlands: An evaluation of its impact on crop production.*, Volume 103. IFPRI.

Schoneveld, G. C. (2017). Host country governance and the African land rush: 7 reasons why large-scale farmland investments fail to contribute to sustainable development. *Geoforum 83*, 119–132.

Sewell, A., S. van der Esch, and H. Löwenhardt (2020). Goals and commitments for the restoration decades. Technical report, PBL Netherlands Environmental Assessment Agency, The Hague.

Sills, E. O., C. de Sassi, P. Jagger, K. Lawlor, D. A. Miteva, S. K. Pattanayak, and W. D. Sunderlin (2017). Building the evidence base for REDD+: Study design and methods for evaluating the impacts of conservation interventions on local well-being. *Global Environmental Change 43*, 148–160.

Simonet, G., A. Agrawal, F. Bénédet, M. Cromberg, C. de Perthuis, D. Haggard, N. Jansen, A. Karsenty, W. Liang, A. Morel, P. Newton, A.-M. Sales, A. Satwika, B. Schaap, C. Seyller, V. Silvania, and G. Vaillant (2021). ID-RECCO, International Database on REDD+ projects and programs, linking Economic, Carbon and Communities data. version 3.0. *http://www.reddprojectsdatabase.org* (Accessed: 2021-09-17).

Simonet, G., A. B. Bos, A. E. Duchelle, I. A. P. Resosudarmo, J. Subervie, and S. Wunder (2018). Forests and Carbon: The impact of local REDD+ initiatives. Technical report, Bogor, Indonesia.

Simonet, G., J. Subervie, D. Ezzine-De-Blas, M. Cromberg, and A. E. Duchelle (2019). Effectiveness of a REDD project in reducing deforestation in the Brazilian Amazon. *American Journal of Agricultural Economics 101*(1), 211–229.

SNV (2018). Review of Policies and Strategies Related to the Clean Cooking Sector in Ethiopia. Technical Report May.

Stein, A. J. (2014). Rethinking the measurement of undernutrition in a broader health context: Should we look at possible causes or actual effects? *Global Food Security 3*(3-4), 193–199.

Stern, D. I. (2017). The Environmental Kuznets Curve After 25 Years. *Journal of Bioeconomics 19*(1), 7–28.

Takahashi, K. and C. B. Barrett (2013). The System of Rice Intensification and its Impacts on Household Income and Child Schooling: Evidence from Rural Indonesia. *American Journal of Agricultural Economics 96*(1), 269–289.

Takahashi, K., R. Muraoka, and K. Otsuka (2020). Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. *Agricultural Economics 51*, 31–45.

Tambo, J. A. and J. Mockshell (2018). Differential Impacts of Conservation Agriculture Technology Options on Household Income in Sub-Saharan Africa. *Ecological Economics 151*(April), 95–105.

Taskforce on Scaling Voluntary Credit Markets (2021). Phase 1 Final Report.

Technical report, Institute of International Finance, Washington D.C.

Teal, F., A. Zeitlin, and S. Caria (2010). Heterogeneous returns and the persistence of agricultural technology adoption. Accession Number: 1367200; Publication Type: Working Paper; Update Code: 20130501.

Teklić, T., Z. Lončarić, V. Kovačević, and B. R. Singh (2013). Metallic trace elements in cereal grain - A review: How much metal do we eat? *Food and Energy Security 2*(2), 81–95.

Thaler, R. (2015). *Misbehaving: The Making of Behavioural Economics.* Norton & Company.

Thaler, R. and C. Sunstein (2008). *Nudge.* Yale University Press.

The DHS Program (2018). Demographic and Health Surveys, Spatial Data Repository. *https://spatialdata.dhsprogram.com/home/*.

The Land Matrix (2022). Global Map. *https://landmatrix.org/map* (Accessed: 2022-02-11).

The Oakland Institute (2011). Understanding Land Investment Deals in Africa - Country Report: Sierra Leone. *Understanding Land Investment Deals in Africa*, 1–53.

Thomas, D. (2007). The mineral depletion of foods available to us as a nation (1940-2002) - A review of the 6th Edition of McCance and Widdowson. *Nutrition and Health 19*(1-2), 21–55.

Tilman, D., C. Balzer, J. Hill, and B. L. Befort (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences 108*(50), 20260–20264.

Tittonell, P. and K. E. Giller (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research 143*, 76–90.

UNCCD (2017). *Global land outlook.* Secretariat of the United Nations Convention to Combat Desertification Bonn ....

UNEP and FAO (2020). Preventing Halting and reversing the degradation of ecosystems worldwide. *https://www.decadeonrestoration.org/*.

United Nations (2018). Population Division.

United Nations (2021). The Sustainable Development Goals Report 2021. Technical report.

Unruh, J. (2008). Land Policy Reform, Customary Rule of Law and the Peace Process in Sierra Leone. *African Journal of Legal Studies 2*(2), 94–117.

Van der Esch, S., A. Sewell, M. Bakkenes, E. Berkhout, J. C. Doelman, E. Stehfest, C. Langhans, L. Fleskens, A. Bouwman, and B. Ten Brink (2022). The global potential for land restoration: Scenarios for the Global Land Outlook 2. Technical report, The Hague, The Netherlands.

van Noordwijk, M., L. A. Duguma, S. Dewi, B. Leimona, D. C. Catacutan, B. Lusiana, I. Öborn, K. Hairiah, and P. A. Minang (2018). SDG synergy between agriculture and forestry in the food, energy, water and income nexus: reinventing agroforestry? *Current Opinion in Environmental Sustainability 34*, 33–42.

Vanlauwe, B., A. Bationo, J. Chianu, K. E. Giller, R. Merckx, U. Mokwunye, O. Ohiokpehai, P. Pypers, R. Tabo, K. D. Shepherd, E. M. A. Smaling, P. L. Woomer, and N. Sanginga (2010). Integrated Soil Fertility Management:Operational Definition and Consequences for Implementation and Dissemination. *Outlook on Agriculture 39*(1), 17–24.

Verhoeven, D., A. Sewell, E. D. Berkhout, and S. van der Esch (2022). The global costs of international commitments on land restoration. *Forthcoming*.

Waddington, H., B. Snilstveit, J. Hombrados, M. Vojtkova, D. Phillips, P. Davies, and H. White (2014). Farmer Field Schools for Improving Farming Practices and Farmer Outcomes: A Systematic Review. *Campbell Systematic Reviews 10*(1), i–335.

Waddington, H., H. White, B. Snilstveit, J. G. Hombrados, M. Vojtkova, P. Davies, A. Bhavsar, J. Eyers, T. P. Koehlmoos, and M. Petticrew (2012). How to do a good systematic review of effects in international development: a tool kit. *Journal of development effectiveness 4*(3), 359–387.

Wainaina, P., S. Tongruksawattana, and M. Qaim (2018). Synergies between Different Types of Agricultural Technologies in the Kenyan Small Farm Sector.

Journal of Development Studies 54(11), 1974–1990.

Waldron, A., D. Garrity, Y. Malhi, C. Girardin, D. C. Miller, and N. Seddon (2017, jan). Agroforestry Can Enhance Food Security While Meeting Other Sustainable Development Goals. *Tropical Conservation Science 10*, 194008291772066.

Wang, Y. H., C. Q. Zou, Z. Mirza, H. Li, Z. Z. Zhang, D. P. Li, C. L. Xu, X. B. Zhou, X. J. Shi, D. T. Xie, X. H. He, and Y. Q. Zhang (2016). Cost of agronomic biofortification of wheat with zinc in China. *Agronomy for Sustainable Development 36*(3).

West, T. A., J. Börner, E. O. Sills, and A. Kontoleon (2020). Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon. *Proceedings of the National Academy of Sciences of the United States of America 117*(39), 24188–24194.

WHO (2018). Life Expectancy, data by WHO region Geneva, Switzerland. *http://apps.who.int/gho/data/view.main.SDG2016LEXREGv?lang=en.*

WHO (2021). Household air pollution and health. *https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health* (Accessed: 2022-06-21).

Wiik, E., R. D'Annunzio, E. Pynegar, D. Crespo, N. Asquith, and J. P. G. Jones (2019). Experimental evaluation of the impact of a payment for environmental services program on deforestation. *Conservation Science and Practice 1*(2), 1–11.

Wilebore, B. and D. Coomes (2016, dec). Combining spatial data with survey data improves predictions of boundaries between settlements. *Applied Geography 77*, 1–7.

Wilebore, B., M. Voors, E. H. Bulte, D. Coomes, and A. Kontoleon (2019). Unconditional Transfers and Tropical Forest Conservation: Evidence from a Randomized Control Trial in Sierra Leone. *American Journal of Agricultural Economics 101*(3), 894–918.

Wilson, S. A. (2019). Mining-induced displacement and resettlement: The case of rutile mining communities in Sierra Leone. *Journal of Sustainable Mining 18*(2), 67–76.

World Bank (1992). World Development Report: Development and the Environment. *The World Bank*.

World Bank (2015). *World Development Report: Mind, Society, and Behavior.*

World Bank (2021). World Development Report: Data for Better Lives. *The World Bank*.

World Bank (2022). World Bank Database. *data.worldbank.org* (Accessed: 2022-01-17).

World Health Organization (2018). COP24 Special Report: Health and Climate Change. *World Health Organization*.

World Integrated Trade Solution (2022). World Integrated Trade Solution Database. *wits.worldbank.org* (Accessed: 2022-01-18).

World Trade Organization (2022). Word Trade Organization Statistics. *stats.wto.org* (Accessed: 2022-01-17).

Wunder, S. (2007). The efficiency of payments for environmental services in tropical conservation: Essays. *Conservation Biology 21*(1), 48–58.

Wunder, S., A. E. Duchelle, C. de Sassi, E. O. Sills, G. Simonet, and W. D. Sunderlin (2020). REDD+ in Theory and Practice: How Lessons From Local Projects Can Inform Jurisdictional Approaches. *Frontiers in Forests and Global Change 3*(February), 1–17.

Summary

This thesis aims to provide insights into how development aid and private sector investments can contribute to improving the environment and economic development simultaneously. There is still little known about whether and under what circumstances economic development and environmental protection go hand in hand. Moreover, the private sector is playing a larger role in reaching the Sustainable Development Goals (SDGs), but research on how such interventions operate is scarce. To help bridge these knowledge gaps, this thesis studies a range of private sector and aid interventions that aim to improve environmental and economic outcomes.

Chapter 2 examines the socioeconomic impact of widely promoted strategies for land restoration using a systematic review. Focusing on rigorous impact assessments of agroforestry, conservation agriculture, integrated soil fertility management and soil and water conservation interventions across the globe, three key knowledge gaps emerge. First, no studies on agroforestry were retained, suggesting a need for impact evaluations in this domain. Second, most studies focus solely on farm-level outcomes instead of socioeconomic outcomes. Third, two-thirds of studies report positive on farm- or socioeconomic outcomes, but impact does not appear ubiquitous and may emerge under certain circumstances only.

Chapter 3 is a study on the impact of a voluntary REDD+ programme in Sierra Leone. Using a difference-in-difference analysis and a panel of satellite and household survey data, it provides causal evidence of the impact on local deforestation rates, livelihoods, and conservation attitudes over the first five years of its implementation. The project helped reduce deforestation by 30% relative to control

communities whilst bringing about no-net harm to communities' livelihoods. The study provides suggestive evidence of the mechanism, finding changes in the opportunity cost of labour and income from sustainable sources. This chapter adds to the pressing need to build the evidence base for voluntary REDD+ projects and shows how an independent and rigorous assessment can be put in place.

Chapter 4 describes a unique census of large-scale agricultural and mining investments in Sierra Leone. Through working with national and local governments, firms and host communities, the survey yielded the location and characteristics of 232 land investments, far more than documented in other databases. There are large differences in how agricultural and mining investors operate. The latter require less land, are less likely to negotiate a lease agreement with host communities, and are less transparent about payments to communities. Disagreements between communities and investors are more likely for mining than for agricultural deals. The study also examines whether institutions can explain within-country variation in the occurrence of investments. Mining deals are more likely to occur in chiefdoms where chiefs have more political power, suggesting that mining investors are attracted to more autocratic environments.

Chapter 5 assesses whether economic incentives and information can improve uptake of low-cost energy-efficient biomass cookstoves. Using a randomised controlled trial in 292 Ethiopian villages, this study shows that subsidisation and information on the health and economic benefits increase stove uptake substantially. For households who received a 70% or a 100% subsidy, uptake increases fourfold and tenfold, respectively. Households are twice as likely to buy a stove when they receive additional information on the economic benefits, compared to information on health benefits alone. Uptake remains low when information is not accompanied by high subsidies.

Chapter 6 examines whether there is a relationship between soil nutrient availability and health outcomes in Sub-Saharan Africa. Using newly estimated soil nutrient maps for the region and an econometric approach, this study finds statistically significant relations between soil nutrients and child mortality, stunting, wasting and underweight. The effects of soil nutrients on health dissipate when malaria pressure increases. Given these estimates, a simple cost-effectiveness analysis shows that agronomic fortification is a relatively cost-ineffective strategy to combat malnutrition compared to other policy options.

Chapter 7 draws lessons from the five core chapters of this thesis for research and policy. Three findings emerge. First, the chapters commonly suggest that if environmental interventions directed at changing household behaviour are to succeed, they should provide households with the right incentives, alternative income strategies, or even compensation for any potential loss of income. Second, there is potential for the private sector to contribute to conservation and economic development. However, to reap the benefits of such private sector initiatives, this thesis suggests that effort should be directed towards improving transparency, accountability, and regulation. Finally, this thesis is an illustration of how combining data from various sources, collected at different scales, can be used to uncover relationships and evaluate policies. It emphasises the value of re-using and combining data for learning about sustainable development.

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> *"Ik heb tot dusver ondervonden dat op deze tocht niets voortdurend erger wordt dan het al is. Na klimmen volgt afdalen, regen houdt ook wel weer eens op, moeras wordt opgevolgd door droog terrein en zelfs de stenen waarop ik mijn enkels verzwik, zijn soms over lange afstanden afwezig. Kortom: net als altijd in het leven, een soort specifiek gemiddelde van ellende."*

- W.F. Hermans, *Nooit meer slapen*

Over the years, I keep finding myself in conversations in which I defend that doing a PhD is not necessarily an excruciating journey. I would not say it was a walk in the park, but overall, I had a pretty good time. What I realise now, is that I say this from a privileged position. As a PhD-student at DEC, I was lucky to be granted just the right amount of freedom and support, and to receive countless opportunities to develop myself academically, as well as personally.

Instrumental in this, has been my daily supervisor Maarten Voors. Maarten managed to strike a balance between guidance and stimulating independence, all the while being a fun and inspiring person to work with. By occasionally throwing me in the deep end and by offering his unvarnished and candid opinion - though always delivered with humour and in good spirits, Maarten helped me become a more confident researcher, teacher, and perhaps even a better person. As such, Maarten took on a role that is, regretfully so, not assumed by every supervisor, and a role for which I am very grateful.

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Throughout my PhD, I have attempted to keep boring others with work details to a bare minimum. Nevertheless, my friends and family deserve a special thanks for enduring my ever-changing moods and endless complaints, which may or may not have been a direct result of working on this thesis. Either way, without having such lovely people around me to climb, enjoy music, eat and more generally, blow off steam with, I would have undoubtedly gone mad.

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Mandy Malan

Wageningen School of Social Sciences (WASS)

Completed Training and Supervision plan

Wageningen School of Social Sciences

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences (managing your own research project)			
WASS introduction	WASS	2017	1
Writing research proposal	WASS	2017	3
Organised bi-weekly DEC PhD Club	WUR	2018-2020	2
DEC PhD representative	WUR	2019-2021	1
'Conservation impacts of REDD+: evidence from Sierra Leone'	21st International BIOECON Conference, Wageningen	2019	1
'Conservation and livelihoods impacts of a REDD+ programme in Sierra Leone'	DEC Seminar, WUR, Virtual	2020	0.5
'Land investments and chief political power: Evidence from a census in Sierra Leone'	ISDC Seminar Series, Virtual	2022	0.5
B) General research related competences (becoming a broad academic)			
Advanced Microeconomics (ECH-51806)	WUR	2017	6
Food Value Chain research: understanding Inter-organisational relationships	WASS	2017	1.5
Impact Assessment of Policies and Programmes (DEC-32806)	WUR	2018	6
Institutions and Societal Transformations	WASS	2018	2
'Unconditional REDD+ programme slows deforestation: Evidence from a biodiversity hotspot in West Africa'	19th EUDN PhD Workshop, University of Passau, Virtual	2020	0.5
'Demand elasticity of improved cookstoves: Evidence from a randomized controlled trial in Ethiopia'	SETI Workshop, Virtual	2022	1
'Land investments and chief political power: Evidence from a census in Sierra Leone'	7th DENeB PhD Workshop, DIW Berlin, Germany	2022	1
'Building the evidence base for voluntary carbon offsets: the case of the Gola REDD+ project in Sierra Leone'	KuE/MuL workshop, RWI, Virtual	2022	0.5
C) Career related competences (personal development and your own future)			
Teaching assistant (DEC-32806)	WUR	2019-2021	2
Teaching assistant (DEC-20806)	WUR	2020	1
Organised Master Class Causal Inference	Nanjing Agricultural University, China	2020	1
Start to teach	ESC, WUR	2020-2021	1
Supervising BSc and MSc thesis students	ESC, WUR	2020-2021	0.6
Total			**33.1**

*One credit according to ECTS is on average equivalent to 28 hours of study load

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