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Agrofuels, large-scale agricultural production, and rural development – The case of Jatropha in Madagascar

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Executive Summary

Agrofuel production in marginal areas can contribute directly to creating employment and improving local livelihoods. Indirectly, through increasing household purchasing power and relaxing financial constraints of smallholder farmers, it can contribute to greater food production and/or food consumption and rural development. These benefits depend, however, largely on the feedstock crop and its processing, land and labour requirements, the business model, value chains and institutional frameworks. Jatropha, a feedstock crop with more benefits than first-generation energy crops like maize, experienced a spike in popularity in the early 2000s due to its value in the biofuel markets of industrialized countries. The majority of plantations and outgrower schemes could not survive what followed: disappointing yields, pests and disease, low oil prices, the 2007/2008 food price crisis, negative narratives, and inadequate funding for further research activities. Despite these challenges, large-scale land investments and new Jatropha projects continue to be undertaken.

Madagascar is a country characterized by severely eroded and degraded pasturelands, low agricultural productivity, high vulnerability to climatic shocks, and overwhelming poverty and food insecurity rates. It is hypothesized that the use of marginal lands for labour-intensive agrofuel feedstock cultivation, in otherwise neglected areas, through both public and private investment, will have positive impacts through the provision of wage work in large-scale plantation schemes. Although a number of studies have investigated the rural livelihood impacts of participation in Jatropha cultivation, there is little evidence that quantifies the long-term and indirect effects on smallholder food production and household food security.

Against this background, large-scale Jatropha cultivation lends itself well to studying the complex interplay between feedstock and food production, as well as the potential for agricultural and rural development. Such analysis would provide useful insights and implications for cost-effective rural development policies to target poor farmers in remote areas. Drawing on a conceptual framework that highlights the role of smallholder farmers' livelihood strategies like off-farm employment and agricultural intensification, and livelihood outcomes like food security, this thesis explores the contribution of large-scale agrofuel feedstock cultivation on marginal land. Three important outcomes, namely household food security, information and innovation spillover effects, and agricultural input use, are studied empirically in three articles, using a comprehensive household panel data set. The data was collected in six survey rounds between 2008 and 2014, in three villages near a large-scale Jatropha project in the Haute Matsiatra region, located in Madagascar's Southern Highlands.

The first article examines the relationship between wage work for a Jatropha project and household food security. Jatropha cultivation on marginal land is labour intensive and does not compete with

food production. Therefore, incomes earned can contribute to increased food security directly as well as indirectly through increased or diversified food production. Using five rounds of household panel data, results show that labour demand from the plantation declined substantially after the build-up phase and Jatropha incomes were mostly used for food and other necessities. Fixed effects models show that Jatropha work contributed significantly to an improved dietary diversity. Despite the possibility to earn income during the lean season, Jatropha work did not lead to a reduction in the more subjective lack of food and led to reduced rice stocks. Both food production and consumption were highly influenced by drought shocks and locust plagues, indicating that complementing income creation strategies with agricultural development strategies might have further positive effects on food security.

To shed light on the impact pathway from Jatropha work to agricultural production, the second article explores information dissemination through social networks and through Jatropha workers who are more exposed to modern technologies than control households. In addition to institutional factors, a lack of knowledge and limited extension services for improved agricultural technologies are considered barriers to information dissemination. Using two rounds of the dataset, which contains rich information on social capital and networks as well as knowledge and innovations, determinants of production-relevant knowledge like extension services, credit and marketing opportunities are estimated. Accounting for potential endogeneity with lagged and instrumental variables, the relevance of this knowledge to the adoption of innovations and the cultivation of a formerly taboo legume, as an example of diversification, is tested. The results indicate limited access to information, little knowledge on investment and marketing opportunities, and low adoption of innovations. Knowledge is relevant for both innovation performance and the cultivation of the Bambara groundnut, highlighting the need to increase and improve public extension services and information dissemination in rural Madagascar. Adoption is not only encouraged by knowledge, but also directly motivated through informal social networks. Bambara groundnut spillovers from the biofuel project can be observed, relaxing some of the constraints farmers face concerning access to information, social learning, and cultural norms.

The third article explores one specific hypothesized spillover: access to and use of agricultural inputs. Given the very low use of improved inputs in rural areas in Madagascar, this study explores whether improved seed and seed information distributed to farmers encourages farmers to cultivate the seed. The analysis is based on household data gathered between 2012 and 2014 from 390 households in three villages. To investigate the adoption of improved seed, as well as the diffusion of information regarding improved seed, a randomized control trial was applied in 2013. Half of the 390 households were randomly assigned to receive the improved lima bean seed (Phaseolus lunatus), which is specifically bred for dry regions. Of the seed-receiving households, half were randomly assigned to receive information on how to store, plant, and cultivate the improved seed, as the variety was

unfamiliar in the region. The control group and the two treatment groups are compared with respect to baseline characteristics, bean cultivation, information exchange with other farmers, legume consumption, and willingness to pay (WTP) for improved bean seed. To account for non-compliance, contamination, and spillover effects, local average treatment effects (LATE) are estimated. Of the seed-receiving households, 54% cultivated the seed, reaping an average yield of 6.3 kg for each kilogram of seed obtained. Seed information did not lead to higher yields. A small significant positive impact of seed distribution on legume consumption is found. WTP is 171% of the local market price for bean seed; provision of free seeds and information did not result in a higher WTP.

Based on these findings, this thesis contributes empirical evidence that large-scale agrofuel feedstock production on marginal land can enhance rural livelihoods by offering alternative livelihood strategies especially for poorer households and contributing to improved livelihood outcomes. Accounting for the indirect effects shows important impact pathways on the livelihood strategies of farmers in a remote area. The provision of incentives for private investors, complemented by more public intervention in rural areas, as well as more investment in agricultural research and extension to reduce agricultural production risks, might enhance these spillovers.

Zusammenfassung

Agrar-Kraftstoffproduktion auf marginalen Flächen kann zur Schaffung von Arbeitsplätzen und zur Verbesserung lokaler Lebensgrundlagen beitragen. Durch steigende Haushaltseinkommen oder einer Milderung finanzieller Engpässe von Kleinbauern kann Agrar-Kraftstoffproduktion auch indirekt durch Investitionen die Nahrungsmittelproduktion und den -konsum sowie ländliche Entwicklung fördern. Der Gesamtnutzen hängt jedoch maßgeblich von der eingesetzten Energiepflanze und ihrer Verarbeitung, vom Flächen- und Arbeitskräftebedarf, Arbeitsaufwand, vom Geschäftsmodell, Wertschöpfungsketten sowie den institutionellen Rahmenbedingungen ab. Jatropha als mögliche Energiepflanze mit einer Vielzahl von Vorteilen im Vergleich zu Energiepflanzen der ersten Generation wie Mais, erfreute sich Anfang 2000 aufgrund seiner Wertschöpfung in Biokraftstoffmärkten von Industrieländern wachsender Popularität. Die Mehrzahl dieser Plantagen und Vetragsanbausysteme überlebten jedoch nicht aufgrund von enttäuschenden Erträgen, Schädlingen und Krankheiten, niedrigen Ölpreisen, der Nahrungsmittelpreiskrise von 2007/2008 und den damit zusammenhängenden Negativschlagzeilen sowie unzureichende Finanzierung weiterer Forschungsaktivitäten. Trotz dieser Herausforderungen werden weiterhin neue Jatropha-Projekte initiiert und großflächige Investitionen in Anbauflächen getätigt.

Hochgradig erodierte und degradierte Weideflächen, niedrige landwirtschaftliche Produktivität Madagaskar ist ein Land mit stark erodierten, eine hohe Anfälligkeit für klimatische Schocks, sowie überwältigende Armuts- und Ernährungsunsicherheitsraten kennzeichnen Madagaskar. Es wird angenommen, dass durch die Nutzung von marginalen Flächen in ländlichen Regionen, die andernfalls von öffentlichen und privaten Investitionen vernachlässigt würden, im Rahmen großflächiger arbeitsintensiver Plantagenwirtschaft positive Effekte durch die damit entstehenden Lohnarbeitsmöglichkeiten erzielt werden. Obwohl einige Studien die Auswirkungen einer Beteiligung an Jatropha-Anbau auf die Lebensgrundlagen ländlicher Haushalte untersucht haben, gibt es kaum quantitative Daten, die langfristige und indirekte Effekte auf kleinbäuerliche Nahrungsmittelproduktion und Ernährungssicherheit der Haushalte belegen.

Vor diesem Hintergrund eignet sich der großflächiger Anbau von Jatropha als interessante Fallstudie, um das komplexe Zusammenspiel zwischen Rohstoff- und Nahrungsmittelproduktion, sowie die Potenziale für landwirtschaftliche und ländliche Entwicklung zu untersuchen. Eine solche Analyse könnte wertvolle Erkenntnisse und Implikationen zu kosteneffizienten politischen Entwicklungsmaßnahmen zugunsten armer Haushalte in entlegenen Regionen liefern und damit zur Verbesserung ihrer Lebensgrundlage beitragen. Die vorliegende Arbeit untersucht den Beitrag von großflächigem Jatropha-Anbau auf marginalen Flächen auf der Basis eines konzeptionellen Rahmens, welcher die Rolle von kleinbäuerlichen Lebensstrategien, wie landwirtschaftliche Intensivierung und Beschäftigung außerhalb der Landwirtschaft, sowie deren Auswirkung auf

Lebensbedingungen wie zum Beispiel Ernährungssicherheit, hervorhebt. Sie fokussiert sich dabei auf die drei folgenden relevanten Themen: Ernährungssicherheit der Haushalte, indirekte Effekte auf den Zugang zu Informationen und die Nutzung von innovativen landwirtschaftlichen Technologien sowie landwirtschaftliche Betriebsmittel wie verbessertes Saatgut für die Nahrungsmittelproduktion. Jedes dieser drei Themen wird empirisch in einem Artikel untersucht. Die Datengrundlage ist ein umfangreiches Haushaltspanel mit insgesamt sechs Befragungsrunden im Zeitraum von 2008 bis 2014. Die Daten wurden in drei Dörfern erhoben, welche im nahen Umkreis eines Jatropha-Projektes in der Region Haute Matsiatra im südlichen Hochland von Madagaskar liegen.

Der erste Artikel untersucht den Zusammenhang zwischen Lohnarbeit auf der Jatropha-Plantage und der Ernährungssicherheit von Haushalten. Jatropha-Anbau auf marginalen Flächen ist arbeitsintensiv und die genutzten Flächen stehen nicht im Wettbewerb zur Nahrungsmittelproduktion. Erzielte Einkommen können somit sowohl direkt zu einer verbesserten Ernährungssicherheit als auch indirekt durch Investitionen zu einer höheren oder diversifizierteren Nahrungsmittelproduktion beitragen. Die Ergebnisse auf Basis der Paneldaten zeigen, dass der Arbeitskräftebedarf der Plantage nach der Aufbauphase deutlich zurückging und das erzielte Einkommen vorwiegend für Nahrungsmittel und andere Bedarfsgüter ausgegeben wurde. Mittels *Fixed-Effects*-Modellen kann gezeigt werden, dass die Arbeit auf der Jatropha-Plantage signifikant zu einer verbesserten Ernährungsvielfalt beiträgt. Trotz der Möglichkeit, über das ganze Jahr hinweg Einkommen zu verdienen, hat die Plantagenarbeit nicht zu einer Kürzung der Hungerperiode beigetragen. Sowohl die Nahrungsmittelproduktion als auch der Konsum wurden stark durch Dürreperioden und Heuschreckenplagen beeinflusst. Dies impliziert, dass Ansätze zur Einkommensschaffung, die mit landwirtschaftlichen Entwicklungsstrategien kombiniert werden, weitere positive Wirkungen auf die Ernährungssicherheit der Haushalte haben können.

Um den Wirkungspfad von Jatropha-Plantagenarbeit auf die landwirtschaftliche Produktion zu beleuchten, untersucht der zweite Artikel die Verbreitung von produktionsrelevanten Informationen durch soziale Netzwerke. Vor allem Jatropha-Plantagenarbeiter haben auf der Plantage besseren Zugang zu Informationen bezüglich landwirtschaftlicher Technologien, Beratungsdienstleistungen, Kredit und Absatzmärkten. Neben institutionellen Faktoren gelten mangelndes Wissen und fehlender Zugang zu landwirtschaftlichen Beratungsdienstleistungen als Hindernis für die Verbreitung verbesserter landwirtschaftlicher Technologien in Madagaskar. Auf Basis von Paneldaten aus zwei der sechs Erhebungsrunden, die umfangreiche Daten zu Sozialkapital, sozialen Netzwerken, produktionsrelevantem Wissen und landwirtschaftlichen Innovationen enthalten, werden mit Hilfe von verschiedenen Regressionsmodellen die Determinanten dieses Wissens wie geschätzt. Um potentieller Endogenität Rechnung zu tragen, werden Variablen aus zurückliegenden Jahren und Instrumentenvariablen eingesetzt, um die Relevanz dieses Wissens für die Übernahme von Innovationen und den Anbau der Bambara-Erdnuss als Beispiel für eine Diversifizierungsstrategie zu bewerten. Die Ergebnisse zeigen einen begrenzten Zugang zu Informationen, wenig Wissen zu Investitions- und Vermarktungsmöglichkeiten und wenig Innovationen. Wissen ist relevant sowohl für die Übernahme von Innovationen als auch den Anbau der Bambara-Erdnuss. Dies unterstreicht die Notwendigkeit, öffentliche Beratungsdienstleistungen und Informationsverbreitung im ländlichen Madagaskar auszuweiten und zu verbessern. Für den Anbau der Bambara-Erdnuss war das Jatropha-Projekt entscheidend: Plantagenarbeiter beobachteten den Anbau dieser Leguminose auf der Jatropha-Plantage und verbreiteten diese Information in ihren sozialen Netzwerken.

Der dritte Artikel untersucht den Zugang zu und die Nutzung von landwirtschaftlichen Betriebsmitteln. Angesichts des überaus niedrigen Einsatzes von Betriebsmitteln in den ländlichen Gebieten Madagaskars, analysiert diese Studie, ob an Bäuerinnen und Bauern verteiltes verbessertes Saatgut und wichtige Anbauinformationen diese dazu ermutigt, das Saatgut anzubauen. Die Analyse basiert auf Haushaltsdaten, die zwischen 2012 und 2014 bei 390 Haushalten in drei Dörfern erhoben wurden. Um sowohl die Verwendung von verbessertem Saatgut als auch die Verbreitung von Informationen zu verbessertem Saatgut zu untersuchen, wurde 2013 eine randomisierte kontrollierte Studie durchgeführt. Die Hälfte der 390 Haushalte wurde zufällig einer Versuchsgruppe zugeteilt und erhielt verbessertes Saatgut der Limabohne, einer speziell für trockene Gebiete gezüchteten Leguminose. Fünfzig Prozent der Haushalte, die das Saatgut erhielten, bekamen zusätzlich Informationen bezüglich Lagerung, Aussaat und Anbau, da diese Bohnensorte in der Region noch weitgehend unbekannt war. Die Kontrollgruppe und die beiden Versuchsgruppen wurden hinsichtlich der Ausgangscharakteristika, des Bohnenanbaus, des Informationsaustausches mit anderen Bäuerinnen und Bauern, des Konsums von Hülsenfrüchten und der Zahlungsbereitschaft für verbessertes Bohnensaatgut verglichen. Um Nichteinhaltung, Kontrollgruppenkontamination und indirekte Effekte zu kontrollieren, wurde ein sogenannter lokaler durchschnittlicher Behandlungseffekt geschätzt. 54% der Haushalte, die verbessertes Saatgut erhielten, bauten das Saatgut an und erzielten einen Ertrag von 6.3 kg pro kg erhaltenem Saatgut. Die Anbauinformationen führten nicht zu höheren Erträgen. Eine geringe signifikante positive Wirkung der Saatgutverteilung auf den Konsum von Hülsenfrüchten konnte festgestellt werden. Die Zahlungsbereitschaft beträgt 171% des lokalen Marktpreises für Bohnensaatgut. Freier Zugang zu Saatgut und entsprechende Informationen resultierten nicht in einer höheren Zahlungsbereitschaft.

Die vorliegende Arbeit liefert somit einen empirischen Beleg dafür, dass sich großflächige arbeitsintensive Agrarkraftstoffproduktion auf marginalen Flächen positiv auf ländliche Lebensgrundlagen auswirken kann, indem alternative Einkommensquellen vor allem für ärmere Haushalte geschaffen werden und zu verbesserten Lebensgrundlagen beigetragen wird. Indem indirekte Effekte berücksichtig werden, zeigt diese Arbeit wichtige Wirkungspfade von großflächiger arbeitsintensiver Plantagenwirtschaft auf die Lebensgrundlagen von Bäuerinnen und Bauern in entlegenen Gegenden auf. Mithilfe von Anreizmaßnahmen für private Investoren, ergänzt durch mehr staatliche Intervention in ländlichen Gegenden unter Einbeziehung von Kleinbauern sowie mehr Investitionen in Agrarforschung, besonders in Bezug auf Produktionsrisiken und Klimaschocks, könnten diese positiven indirekten Effekte ausgebaut werden.

List of Abbreviations

ATT	Average treatment effect on the treated
CER	Certified emission reduction
CDM	Clean Development mechanism
CSA	Centre for Agricultural Services
CO_2	Carbon Dioxide
DID	Difference in difference
E.g.	for example
FCS	Food Consumption Score
FDI	Foreign Direct Investment
FAO	Food and Agricultural Organization of the United Nations
FOFIFA	National Research Centre for Rural Development
FRAM	Association of pupils' parents
GHG	Greenhouse gas
Ha	Hectare
HDDS	Household Dietary Diversity Score
HFIAS	Household Food Insecurity Access Score
I.e.	id est
IFAD	International Fund for Agricultural Development
INSTAT	National Statistics Institute Madagascar
ITT	Intention to treat
IV	Instrument variable
Km	Kilometre
OLS	Ordinary least squares
ONE	National Office of the Environment Madagascar

LATE	Local average treatment effect
LSLA	Large-scale land acquisitions
LSLI	Large-scale land investment
MAEP	Ministry of Agriculture, Livestock and Fishing of Madagascar (until 2013)
MPAE	Ministry of Agriculture and Livestock of Madagascar (as of 2013)
NEAP	National Environmental Action Plan
PSM	Propensity Score Matching
PCA	Principal Component Analysis
PPP	Purchasing Power Parity
RCT	Randomized control / controlled trial
RSB	Roundtable for Sustainable Biomaterials (Roundtable for Sustainable Biofuels until 2013)
SRI	System of Rice Intensification
UNDP	United Nations Development Programme
UNFCC	United Nations Framework Convention on Climate Change
WFP	World Food Programme of the United Nations

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1 Introduction

1.1 General introduction

Reasons to produce agrofuels/feedstock for bioenergy in developing countries are manifold, reaching from economic over environmental to social aspects. Biofuel has been promoted in view of the declining fossil fuel availability and the negative impacts of fossil fuel use on the climate. Blending quotas for transport fuel in industrialized countries, which could not be achieved with local production and global carbon trading schemes, have triggered feedstock production in developing countries. Labour-intensive agrofuel production was expected to generate positive employment and rural development effects within appropriate institutional contexts (e.g. Von Braun & Pachauri, 2006), to restore degraded land and contribute to energy security in both importing countries as well as rural regions in the producing countries.

Energy from renewable biological sources can be distinguished according to the feedstock it is derived from, the technology and the type of application. So-called first-generation biofuels were mostly derived from food crops like maize, sugarcane and oil plants. Second-generation biofuels originate from crops such as oil palm, Jatropha curcas, Ricinus communis, Miscanthus fuscus and others, but also from manure and crop residues, waste oil and solid waste, or other biological resources like algae. Most common technologies include diesel, ethanol, gas, and electricity and their uses vary from traditional ones like cooking to modern ones like transport and industry (see e.g. Mirzabaev et al., 2015). The term agrofuels specifically refers to biofuel generated from energy crops and/or agricultural (including animal) and agro-industrial by-products (FAO, 2004). The competition between biomass feedstock production and land with potential negative impacts on food security, environment and biodiversity through higher food prices and indirect land use changes, is seen as a major obstacle to the further expansion of sustainably produced bioenergy (Lewandowski, 2015).

These impacts however vary largely with different feedstock crops, land and labour requirements, business models, institutional frameworks, feedstock processing and value chains.

Since the food price crisis in 2007/08, which was partly attributed to increasing biofuel production from maize, soybeans and oilseed (e.g. Headey & Fan, 2008), numerous initiatives have been launched to promote sustainable bioenergy systems and to avoid negative impacts of biofuel production. FAO (2011a) provides an overview over regulatory frameworks, voluntary standards/certification schemes, and scorecards, that address different aspects, synergies and trade-offs of environmental, socio-economic, governance and food security aspects that are associated with the production of feedstock for biofuels. One possibility to make sure social and environmental concerns are considered in biofuel production are private certification standards. One of the most significant private initiatives for the sustainability of agrofuels has been the Roundtable of Sustainable Biomaterials (RSB, extended from the Roundtable of Sustainable Biofuels implemented in 2007). Its contribution includes a detailed sustainability standard, distinguishing between large-scale and smallholder production, and a certification system for import into the European Union.

Certification standards cannot account for indirect land use changes, unless all food production is also certified. Consequently, their contribution to energy security, climate change and rural poverty is small. Vogelpohl (2014) furthermore criticizes that in the EU discourse, biofuels were conceptually linked to environmental protection, agricultural and socio-economic development, and energy security, leading to an unconditional win-win narrative. Moreover, producers also face high costs of certification, high demand for monitoring, whereas capacity is often lacking. Vogelpohl & Hirschl (2013) point out that the European Renewable Energy Directive (RED), internationally being one of the most significant standards, does not take into account social aspects. Rather than through certification schemes, which face problems like the complexity of a market-based certification system and the fact that more ambitious standards like the RSB cannot compete against more commercial certification bodies, they recommend to directly and locally address issues like land rights and working conditions (for a detailed analysis see Ponte, 2014). Schut & Florin (2015) argue that global sustainability criteria are useful but have to be operationalized at and adapted to the local level, since smallholder production and local oil marketing systems are less monitored. As a solution, strengthening local capacity to assess rules and standards and for smallholders to assert their rights, has been proposed (Florin et al., 2014).

Jatropha curcas[1] (Jatropha hereafter) as a biofuel feedstock was introduced due to its low requirements for soil quality and water, and therefore reduces the competition with food crop cultivation. Because of this potential, Jatropha production lends itself well to study the complex interplay of feedstock and food production, as well as potentials for agricultural and rural development. Moreover, Jatropha plantations have been proposed as climate change mitigation strategy, e.g. as a cost-efficient instrument of CO_2 storage in hot and dry coastal areas (Becker et al., 2013). A meta study on lifecycle assessments of global Jatropha production found considerable benefits in GHG reductions compared to fossil fuels (Van Eijck et al., 2014), in particular with low input use and cultivation on marginal or wasteland with low carbon stocks. Knowledge gaps

[1] The species *Jatropha curcas* L., a drought-tolerant shrub or small tree, produces oil-containing seeds (Jongschaap et al., 2007)

regarding its full GHG reduction potential still exist for case-specific characteristics, like the use of by-products, and the type of value chain (Van Eijck et al., 2014). Trade-offs exist between economic and environmental objectives, i.e. yield expectations on marginal and wasteland as well as fertilizer and pesticide use (e.g. Van Eijck et al., 2014).

These specific characteristics of Jatropha led to a very particular development of promotion and production. The first adopters and promoters of the energy crop were non-governmental organisations. Supported by international donors for start-up costs, but also pressured by the same, they became the most important actors, venturing into local processing, and local electricity and energy production. Since many hopes for sustainable development were put into Jatropha, basic and adaptive research was funded without strings attached, however making the projects highly vulnerable to shifts in donor funding priorities. Given that Jatropha takes several years until bearing fruits, research was slow in providing evidence from field trials (Hunsberger, 2010). Private companies were attracted more by high oil prices, export markets and carbon offsets and focused more on large-scale plantations. Next to a disappointing yield performance, pest and disease pressure and the decline of oil prices, negative narratives on Jatropha led among others to a shorter time frame for learning from experimentation (Slingerland & Schut, 2014).

Even if Jatropha production has not proven to be economically viable on a global scale, it offers development options for remote rural areas (Achten et al., 2010). Comparative and meta-evaluations (De Jongh & Nielsen, 2011; Nielsen et al., 2013) conclude that due to its high labour requirements for cultivation the plant is especially suitable for areas with low-input extensive farming systems, low land and labour costs, high fossil fuel prices and poor infrastructure.

Next to outgrower production schemes, Jatropha has been cultivated on large-scale plantations, mostly because of economic risks and uncertainties concerning markets and value chains. In general, large-scale investment in land and large-scale agricultural production[2] has often been found to lead to positive employment, growth and poverty reduction effects, however depending on the institutional context and the type of investment (Herrmann, 2017; Herrmann et al., 2017; Nolte & Ostermeier, 2017; Nolte et al., 2016; Van den Broeck et al., 2017). With the help of Land Matrix data, Nolte & Ostermeier (2017) estimate employment effects of large-scale agricultural investments in developing countries. Distinguishing between former land use, crop and production model the authors conclude that employment created by these investments cannot absorb all labour released from smallholder agriculture, especially since most of the investments focus on capital-intensive

[2] The following terms are most commonly found in the literature: Large-scale land acquisitions (LSLA) which includes land lease, large-scale land investment (LSLI) as a subset of LSLA (Baumgartner et al., 2015), large-scale plantations, or large-scale farming / agricultural production, which includes outgrower schemes.

annual crops with a highly mechanized type of production. For Jatropha, available figures estimate labour intensity (number of workers required to cultivate one hectare) at 0.9 workers per hectare, which is less than assumed for smallholder agriculture (1.77). According to Land Matrix data it is the third most labour-intensive crop, after banana and tea (Nolte & Ostermeier, 2017). Since opportunity costs for land are often assumed to be zero for Jatropha when cultivated on otherwise unproductive land (Grass & Zeller, 2011), it might offer opportunities for additional employment. The pivotal role of employment generation in poverty reduction is widely accepted (e.g. Von Braun, 1995). Employment generation for poverty alleviation is one of the main arguments, be it in publicly financed employment programs, in the promotion of private enterprises or in attracting foreign direct investment.

Knowledge gaps exist for the long-term socio-economic impacts of large-scale Jatropha production on marginal lands in developing countries. This is partly due to the rather recent widespread cultivation of second-generation energy crops in developing countries, the long time of tree crops until yielding fruits and the lack of existing value chains. Furthermore, this is also due to the highly overestimated potential of Jatropha yield on marginal lands, and the consequent abandonment of most of the early commercial Jatropha operations. This thesis therefore adds to addressing these knowledge gaps with a comprehensive panel data set, providing evidence on the relationship between employment for a large-scale Jatropha project and household food security, as well as spillover effects to food and agricultural production, e.g. adoption of innovations and input use.

1.2 Jatropha in Madagascar

Madagascar was a prioritized target for investment in land and feedstock production, given high poverty rates and high vulnerability to climatic variability, low access to energy and a low percentage of cultivated land compared to potential arable land (Deininger & Byerlee, 2011; FAO, 2015). In Madagascar, potential arable land of 15 to 20 million hectares was reported by FAO in 2009 (Uellenberg, 2009), yet without further details than being degraded grasslands used extensively for cattle grazing. Foreign direct investment in land in Madagascar was hypothesized to have direct positive impacts on tax incomes, food production and productivity, and technology spillovers like fertilizer use or mechanization (Uellenberg, 2009). Madagascar is not only a net-food importer, but food production is also highly vulnerable to climate change, especially due to changing rainfall patterns and extreme weather events, and adaptation is costly (Ministère de l'Environnement des Eaux et des Forêts, 2006; Porter et al., 2014; Tadross et al., 2008). Furthermore, Madagascar is benefiting from investments by industrialized countries supporting both the creation of carbon sinks and the reduction of sources of greenhouse gas emissions (Stavins et al., 2014).

An early overview about the state of Jatropha projects, their potentials for rural development but also the risks involved, such as large-scale land lease or acquisition by international investors and the lack of publicly available data and knowledge on all stages of oil production is provided by Uellenberg (2007). According to the land matrix, in 2017 only few projects were still in place, and some have shifted to large-scale food production, castor bean production or other renewable energies (The Land Matrix Global Observatory, 2017). To mitigate the negative effects of land acquisition and possible trade-offs for land and water, national energy and rural development regulations and institutional frameworks have been recommended (Grass & Zeller, 2011). These were however not realized in the wake of the political crisis in 2009, when government institutions were not functioning, development objectives have been put to a halt and financial assistance from abroad was shut off, and investors therefore welcomed with low conditionalities (Neimark, 2016).

Since most of the Jatropha plantations were not economically viable in Madagascar, inclusion of projects into the Clean Development Mechanism (CDM) have been suggested. Yet, especially the social sustainability of such projects has been put into question, due to large-scale land acquisition of so-called marginal[3] or unused lands, conflicts over resource and land use, lack of transparency and participation, consistent control and evaluation of projects' claimed benefits, as well as the lack of addressing local energy needs (Millock, 2013; Newell et al., 2009; Sutter & Parreño, 2007).

In Madagascar, the majority of households rely on fuel wood or charcoal for cooking, less than 1% use modern cooking fuel (Nussbaumer et al., 2012). In 2011, more than 90% of the total energy was from wood products (Praene et al., 2017). To increase access to energy for households and reduce dependency from fossil fuel imports, other renewable energy sources, like hydropower or solar energy are considered in national strategies. These energy sources however are characterized by high initial investment and operation costs, face economic, geographic and political constraints (Praene et al., 2017). Therefore, Jatropha can be an alternative for less developed and less accessible areas, e.g. for transport and generators.

1.3 Agricultural and rural development in Madagascar

Agriculture, fishery, and livestock production are key contributors to Madagascar’s economy. In the period between 2010 and 2014, 75.3 % of the employment took place in the agricultural sector.

[3] Problems with the vague term “marginal land” are discussed by Shortall (2013). Definitions range from land where food production is not feasible to land where biofuel production is more productive than food production. Current land uses are often underestimated, leading to a risk for smallholders loosing access to land. The use of term “marginal land” also entails several assumptions, like the sufficient availability of marginal land, the possibility of biofuel production on only that land, and less negative impacts on environmental and social aspects (ibid).

Official unemployment rates are very low, however 90% are classified as working poor, with incomes less than PPP$ 3.10 a day (UNDP, 2016). Poverty is mostly concentrated in rural areas, in 2012 77.3% versus 48.5% in urban areas. (INSTAT, 2013 :137). Since 2001, poverty had increased after both political crises in 2001/2002 and 2008/2009 and is still at a higher level than 2001.

Apart from cash crops, which are grown primarily in the east and northwest of the country, rice (42% of total agricultural revenues), cassava, sweet potato, maize and beans are the most grown crops. Average and median farm sizes are 1.4 and 1.0 ha, respectively (INSTAT, 2013). Average cereal yields increased from 1.9 t/ha in 2000 to 3.7 t/ha in 2014 (The World Bank Group, 2017). The percentage of arable land has increased from 5% in 2000 to 6% in 2014 and that of agricultural land from 70% to 71%, while that of forest area[4] has decreased from 22% to 21% (The World Bank Group, 2017), suggesting that both extensification and intensification took place. In rural regions, 72% of income is spent on food, whereof 42% is home-produced (INSTAT, 2013).

Randrianarisoa & Minten (2001) give an overview of agricultural development policies, focusing heavily on rice and cash crops. After independence in 1960, the main rice production regions like Lac Aloatra, Marovoay, and the Delta of Mangoky were extensively targeted with irrigation schemes, extension on the use of fertilizer, pesticides and equipment. The related productivity increases combined with an expansion of arable land led to production increases of 50% between 1960 and 1968 in the targeted regions. In 2013, these regions, adding Sofia and Vakinankaratra, were still mentioned as grain baskets by INSTAT (2013). The productivity increases after independence were followed by a period of export taxing and local price subsidies, which next to other factors led to a decline in agricultural production, and while having been a net exporter of rice, from the 1970s on Madagascar had to import rice to sustain its population. From the 1980 and 90s on, the government gradually disengaged from price and agricultural support policies, leading to declining agricultural productivity, deteriorating infrastructure and an increase in rural poverty rates (Randrianarisoa & Minten, 2001; Zeller et al., 1999). Due to the expansion of the agricultural frontier, the country was heavily targeted by environmental conservation programs. Some studies have shown that the role of traditional farming in resource degradation is condemned and exaggerated, and livelihood strategies based on agriculture, fishery and forestry were of secondary importance compared to environmental conservation (Pollini, 2011; Scales, 2011). The Madagascar Action Plan started in 2007, and included ambitious goals like poverty reduction, rural development and the modernization of the agricultural sector. An important component was the inflow of money and technologies from abroad, achieved with incentives in the form of subsidies, land acquisition and lease, and tax cuts. Yet, next to other

[4] According to a recent study by Vieilledent G., et al., (2018), 44% of Madagascar's natural forests have been lost since 1950. Moreover, deforestation has gained speed since 2005, and the remaining forests are highly fragmented.

drivers like the spike in global food prices and the international financial crisis these policies attracted among others the South Korean and Indian companies Daewoo and Varun, which eventually led to the fall of the Ravalomanana government in 2009 (Ratsialonana et al., 2011).

Although including a socio-economic assessment, it is the National Office of the Environment, which has the mandate to deliver licences for large-scale land investments. The design as well as the impacts of large-scale agricultural production on agricultural and rural development might therefore depend on this institutional framework. After the 2005 land reform non-titled land was no longer state-owned, i.e. local land rights were recognized and land management was decentralized to municipalities, handing over negotiation rights to mayors (Burnod et al., 2013). Case studies show that local populations have some negotiation power, although they lack information on investors, impacts and their rights. Opponents in these case studies were mostly richer cattle owners worried about pasture areas, yet in the dilemma of not wanting to forego employment and rural development possibilities (Evers et al., 2011; Gingembre, 2015; Ratsialonana et al., 2011).

In 2012/13, 35.7% of the population were involved in non-agricultural businesses, where a trend from mostly trading activities to the processing of agricultural products and crafts was observed. The mining sector, with 25% of businesses, has doubled its importance from 2010 to 2013 (INSTAT, 2013), yet according to Minten & Barrett (2008) had not yet contributed to improved welfare.

Exemplary for agricultural development in Madagascar, Minten & Ralison (2005) show for the period from 2001 to 2004, that although adoption of improved agricultural technologies increased slightly, production did not increase. This was attributed to natural shocks and price shocks. Moreover, the exceptionally high rice prices did not benefit smaller and poorer farmers since they occurred at a time of the year when those farmers had already sold their surpluses. Lack of capital (irrigation, equipment, cattle) was perceived to be the biggest constraint to improve agricultural productivity (Minten & Ralison, 2005). Similarly, intensification in the highlands of Madagascar has shown to be hindered by financial constraints. Despite of being aware of the loss of soil fertility and erosion, farmers do not have the technologies or the means to invest in existing measures to maintain soil fertility and take measures against erosion (Radison et al., 2008).

Access to extension services, improved seed and fertilizer is limited in Madagascar, especially in more remote areas with limited agricultural potential. Minten, Randrianarisoa, et al. (2007) blame difficult topography, poor transport infrastructure and high transaction costs. The low uptake of chemical fertilizer to increase rice productivity has been attributed to high and volatile prices within the fertilizer supply chain (Minten, Randrianarisoa, et al., 2007), research and interventions to reduce those costs have been suggested. However, the Malagasy agricultural research system has been characterized by an ongoing lack of research funds and lacking incentives for developing and improving agricultural technology options, as well as by a lack of involving stakeholders and extension (Springer-Heinze et al., 2003).

With regard to extension services, a national household survey found only 7% of farmers had contact with an extension officer in 2004 (Minten, Randrianarisoa, et al., 2007), with distances from farmers to the next officer of more than 50 km for the majority of the country (Randrianarisoa, 2003). The distance to the next extension services has been shown to be a significant determinant of the adoption of SRI (system of rice intensification[5]) techniques (Minten & Barrett, 2008; Moser & Barrett, 2003b). Although this method was praised as low external-input technology, high rates of disadoption were reported after funding for NGO extension projects was disrupted (Moser & Barrett, 2003b). These latter authors argue that for the adoption of complex innovations, which radically change traditional methods, extension presence is not only necessary for learning but also in terms of conforming to authorities. This would make the diffusion and scaling up of such technologies prohibitively high (Moser & Barrett, 2003b). Improving the access to off-farm income was suggested as a means to increase seasonal labour input and therefore adoption (Moser & Barrett, 2003a).

Against the background of market and political failures, Reardon et al. (2009) argue that new agents in development, such as producer organisations and private actors in integrated value chains, for example via resource-provision contracts, can help overcome smallholders constraints, like the access to inputs, credit, extension or non-land assets (irrigation, greenhouses, roads, vehicles, associations). Since most of those arrangements favour larger or better-connected farmers, they also point to the role of the government in providing these for a successful participation of smallholders in those arrangements.

This suggests that especially in marginal areas, foreign direct investment (FDI) in the agricultural sector could provide technological spillovers to smallholder agriculture. In Madagascar, spillovers from private extension services have been studied in the framework of cash crop production in the central highlands (Bellemare, 2010; Minten, Randrianarison, et al., 2007). These contract production arrangements have been found to lead to intensification (through higher input use) of agricultural production and therefore potentially less pressure on forests (Minten, Randrianarison, et al., 2007). Yet for more remote areas with low access to input and output markets there is no evidence on impacts and impact pathways.

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[5] According to the SRI International Network and Resources Center, SRI is a climate-smart, agroecological methodology for increasing the productivity of rice and more recently other crops by changing the management of plants, soil, water and nutrients. SRI originated in Madagascar in the 80s and has been heavily promoted there (sri.ciifad.cornell.edu).

Rural areas are especially disadvantaged. Barrett (1996) shows that in rural areas in Madagascar, where infrastructure is poor and grain storage concentrated in urban areas, rice price risk and adverse welfare effects disproportionately affect rural smallholders that depending on the season are net food sellers or buyers. The placement of development projects in the country is similarly skewed towards less remote communities with existing communication infrastructure (Moser, 2010).

Biofuel policies and investments could break with these patterns since oil plants like Jatropha are more likely to be placed on marginal land in neglected areas with few alternatives. Moreover, there is a lack of knowledge on farmers' constraints, knowledge and objectives, as well as livelihood strategies and social and equity aspects.

1.4 Conceptual framework

This chapter introduces the conceptual framework used to address the research questions and hypotheses of this thesis. Being the most comprehensive conceptual framework in terms of smallholder famers' livelihoods, I use the sustainable livelihoods framework (Scoones, 1998). In the following, I link the framework to important impact pathways through which large-scale bioenergy projects could affect adjacent smallholder agriculture and rural development. The first article explores the linkages between livelihood strategies and livelihood outcomes, by analysing the effects of a newly introduced livelihood strategy, namely off-farm wage work on a Jatropha plantation, on food security. The second article explores the linkages between institutional and organizational processes and structures, livelihood assets, and livelihood strategies. It does so by analysing how the implementation of a Jatropha plantation affects adoption of agricultural innovations, mediated by information dissemination through social networks and Jatropha workers. The third paper picks one of these innovations, which is crop diversification and intensification through improved seed and explores the linkages between this livelihood strategy and an important livelihood outcome, namely the consumption of more nutritious food.

When assessing the (socio-economic) impacts of biofuel production, different lenses have been applied, e.g. the fuel-versus-food discussion (Ewing & Msangi, 2009), which has been widened into the food-water-energy nexus (Mirzabaev et al., 2015), the food-energy-environment nexus (Popp et al., 2014), or the food–feed–fibre–fuel competition (Lewandowski, 2015). These nexus-perspectives have been criticized for not sufficiently taking into account the role of sustainable livelihoods (Biggs et al., 2015). Based on a metastudy of impact assessments concerning a large-scale land acquisition for sugarcane production in Sierra Leone, Mann and Buergi Bonanomi (2017) find that depending on the approach the impacts varied significantly: Utilitarian approaches looking at wages and incomes found mostly positive effects, deontological/normative approaches focusing on human rights and peoples' options found mostly negative ones.

Against this background, this thesis draws on a conceptual framework that highlights the role of smallholder farmers' livelihood strategies and options, like off-farm employment and agricultural intensification, and livelihood outcomes like food security. By adding external pressures as main drivers of biofuel production and consumption, this thesis explores the contribution of large-scale agrofuel cultivation on marginal land in regards to livelihood outcomes.

The two following subchapters define the concepts of food security as an important livelihood outcome and spillover effects, which are hypothesized indirect effects from the Jatropha project on all aspects of sustainable livelihoods. Given the significance of a large-scale agrofuel project in a remote rural area and the political instability in Madagascar at the same time, these effects can be manifold, ranging from decreased vulnerability to food insecurity of rural farm households and increased investment into education to less tangible ones like better ties to governmental organisations. A study on the local benefits of a national park in the southern highlands of Madagascar for instance found improved watershed and microclimate protection as well as electricity provision from a hydropower plant (Ferraro, 2002). Yet these effects were diffusely distributed and only long-term and were not taken into account of the peoples' overall perceptions of the project's benefits (ibid). This thesis therefore focuses on spillovers to agricultural and food production, through the pathway of a better access to information, a higher capacity to adopt innovations in the agricultural value chain and a higher agricultural input use. Access to information, the type of innovations considered as well as the concepts of social capital and social networks are explained in detail in chapter 4. Figure 1.1 shows the conceptual framework, topics and linkages explored in the three chapters are shown with respective figures.

1.4.1 Food production, employment and food security

Next to agricultural production as the main source of income, small businesses, employment in the public and private sector are means to ensure livelihoods in rural areas. Bioenergy or agrofuel production may generate wage work and therefore increase available income, but could also compete for labour with agriculture. When food production is affected, and areas are not well integrated into markets, (seasonal) food availability and food prices might be affected. Especially in the lean season or after climatic shocks, off-farm income might be used to smooth consumption, but could also be used for more leisure time, durables, or invested in alcohol.

Off-farm (all activities outside the own farm) and non-farm (wage or self-employment outside of the agricultural sector) employment have been shown to decrease income and consumption variability

(Barrett et al., 2001; Randrianarisoa & Minten, 2001). Public employment programs have been shown to shorten the lean season, increase livestock holding and productive assets (Berhane et al., 2011). Newer studies also provide evidence on the impact of off-farm earnings on food security, e.g., Nigerian households with off-farm income cultivated larger areas and had higher total and farm incomes, leading to higher energy and nutrient consumption and better nutritional status of children (Babatunde & Qaim, 2010). Because of the multidimensional nature of food security, Ecker & Qaim (2011) could show that increases in income have positive but small effects on nutrition outcomes. According to these authors, in Malawi, this effect was less pronounced for households in urban areas than for rural households, who increased consumption for all food groups except food from animal sources.

The relationship between off-farm income (employment on the Jatropha plantation) and food security is explained in more detail in chapter 3.

Food security is a multidimensional concept, encompassing the physical availability of food, economic and social access to food and metabolic utilization of dietary energy and nutrients (World Food Summit, 1996). As conceptualized by UNICEF (1990) food availability is determined by natural resources, as well as the economic, institutional and political environment. Underlying factors are household food security, which is determined by agricultural production, income or food aid, by the care and feeding practices of children and the health environment and access to health services. These three factors influence dietary intake and health, which determine nutritional outcomes. This framework has been empirically tested by Smith & Haddad (2015), in a cross-country analysis from 1990 to 2015. They found that most of the reduction in under- and malnutrition can be attributed to increases in female education and access to safe water and sanitation, but also to national food availabilities and dietary quality, which was measured as the share of non-staple crops in total calorie consumption. Dostie et al. (2002) provide evidence of seasonal poverty and undernutrition in the lean season in rural areas in Madagascar, leading to increased malnutrition and child mortality rates.

Since a majority of the poor in African countries live in rural areas, and depend on agriculture as a source of food, employment and income, the agricultural sector is an important entry point for poverty reducing, and food and nutrition security enhancing policies. There is a growing number of studies looking at food security outcomes of adoption of agricultural innovations, diversification and commercialization at the household level (Kabunga, Dubois, et al., 2014; Kabunga, Ghosh, et al., 2014; Loos & Zeller, 2014).

1.4.2 Spillover effects

In this thesis, one of the main impact pathways from the implementation of the Jatropha project to smallholder farmers' livelihood to be explored is the investment in agriculture and small-scale businesses, mediated by income earned on the plantation and the dissemination of information about marketing options and technologies. I hypothesize that Jatropha workers are more exposed to information than other farmers are, since the plantation uses modern inputs, like fertilizer and agrochemicals. Especially in a region where the access to extension service is very low, these channels might prove important. The dissemination of this information to villages and farmer-to-farmer learning is analysed, as well as investment in land or cattle, adoption of innovations like diversification or processing and selling of agricultural products.

Off-farm and non-farm employment have been shown to overcome credit and liquidity constraints at the beginning of the planting season and therefore increase the use of inputs and food production (Barrett et al., 2001; Randrianarisoa & Minten, 2001). For biofuels, Ewing & Msangi (2009) hypothesize spillover effects to productivity of smallholder agriculture, through the pathway of lower transport and input costs, as well as technological investments in rural areas. Yet, the nature and size of spillover effects are highly specific to the business model, the institutional context and other site-specific characteristics. Technological spillover effects to agriculture are generally assumed to happen in outgrower systems (van Eijck et al., 2012). For example, Minten et al. (2007) used changes in soil fertility due to inputs provided through vegetable production contracts as well as training on compost use to provide evidence on how and which spillovers occur. Similarly, Riera & Swinnen (2016) looked at the pathway of higher input use in castor outgrower contracts with free input provision. Govereh & Jayne (2003) analysed the same pathway in the framework of cash crop cultivation. Herrmann et al. (2017) used the changes in land holding, expenditures on agricultural inputs as well as purchases of agricultural assets as possible channels on how sugarcane outgrower schemes can contribute to higher food production. Contrary to these studies, a case study on Jatropha production in northern Ghana, argues that agricultural intensification is in fact a coping strategy due to loss of land. The study found a reduction of shifting farming, an increased use of agrochemicals and unsafe use of fertilizers (Hamenoo et al., 2017). Similarly, studies on the pathway from environmental conservation incentive schemes or payments for environmental services have mainly looked at the pathway of agricultural intensification in response to the loss of agricultural area, e.g. SRI techniques to replace slash-and-burn agriculture in forest areas (e.g. Moser & Barrett, 2003b).

As large-scale agricultural projects, such as the set-up of a Jatropha plantation, demand a lot of wage labour, especially during early phases of land clearing and planting, the evidence with public works and cash-for-work programs is equally relevant. In addition, many rural jobs are correlated with seasonality and weather events in agricultural production, e.g. in drought years. Dry season purchasing power is low and many businesses are closed, and grain trade is usually concentrated after harvest. Therefore year-round off-farm income has the potential to have spillover effects to businesses and grain trade.

The Jatropha project led both to a high employment offer and to a significant amount of cash input in a rather subsistence-oriented and non-monetized rural economy, therefore similarities of Jatropha work with cash-for-work and cash transfer programs are hypothesized and impact pathways compared. Cash- or food-for-work programs, which are implemented in disaster contexts, have the aim to smooth consumption and avoid negative impacts of reduced food intake. Nonetheless, for cash transfers and other social protection programs, impacts to agricultural production through the pathway of loosening liquidity constraints have been tested (Sadoulet et al., 2001; Thome et al., 2013; Tirivayi et al., 2016). Public works programs aim to improve (e.g. road, irrigation) infrastructure and by design should include spillover effects to agricultural production and commercialization, this has however not always proven to be the case (Beegle et al., 2017). Spillovers in public work programs can be substantial but can bias impact assessments, e.g. if they indirectly increase wages in the private labour market for non-participants (Ravallion, 2008). Universality of access to employment can provide an effective insurance against risk, which in turn can lead to higher investment in productive activities. Intermediate impacts like savings or investment can provide insights in the impact-determining processes and in how long-term impacts of the program might occur (Ravallion, 2008).

Several other spillovers were hypothesized but during fieldwork either could not be observed or were not seen as relevant during focus group discussions. One aspect is the provision of biodiesel for local uses in generators or vehicles, and the establishment of an electricity grid from a hydropower plant to the villages. This was envisioned in cooperation with JIRAMA, the national electricity provider company, but both did not occur until the end of data collection. Other aspects are environmental benefits, which are hypothesized to happen through the replacement of fossil fuel imports with renewable energy on a global level and through the restoration of eroded and degraded soils on a local level. A former research project in the area found that intercropping cassava with Jatropha reduces soil erosion significantly, but due to the high pest pressure pesticides had become necessary and Jatropha hedges were therefore not recommended and promoted for farmers' plots (Becker et al., 2011).

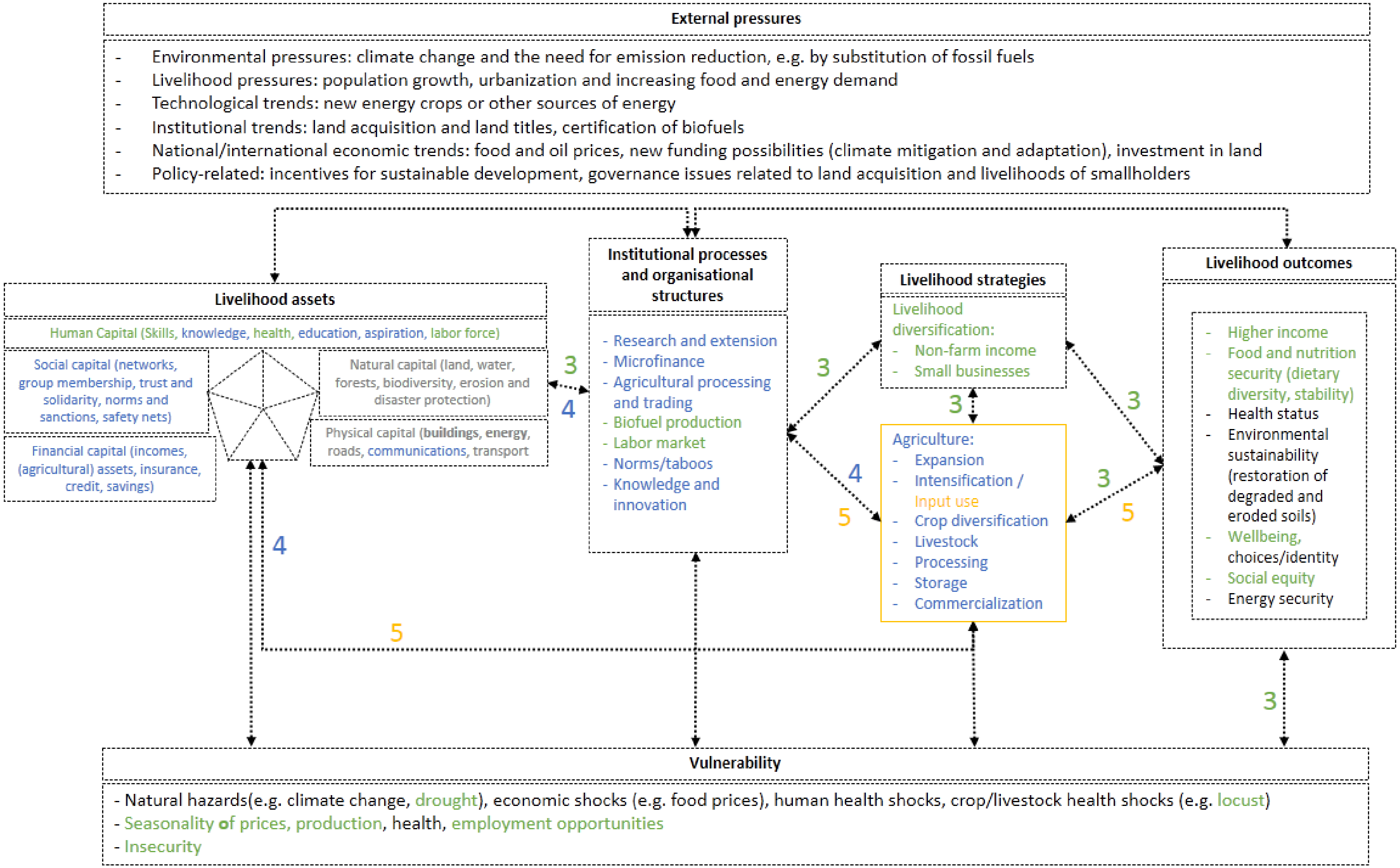

Figure 1.1: Conceptual framework

1.5 Research questions and hypotheses

As seen above, foreign direct investment into land and agriculture in Madagascar has long been attracted by the government as a means to finance necessary investments in agricultural and rural development. Madagascar is characterized by high poverty and food insecurity rates, low adoption of improved agricultural technologies, poor infrastructure and a high vulnerability to climatic variability and change. Mostly due to political crises, almost no improvement in national food security has been achieved in the last decades. Jatropha production, with its specific characteristic features as plant and feedstock and the resulting institutional setting provides an interesting case study in exploring policy options for sustainable rural development in Madagascar. Based on the conceptual framework above, this thesis examines the contribution of one exemplary large-scale biofuel project to food security, agricultural production and rural development, offering insights in adoption of innovations and use of improved inputs.

Research question 1: Does employment for biofuel production offer sustainable livelihood possibilities and therefore contribute to an improved household food security?

Research hypothesis 1: Following the conceptual framework in chapter 1.4, employment for the labour-intensive production of Jatropha, by providing an additional income source to mostly poor households, is expected to contribute positively to livelihoods and food security.

Research question 2: Does the installation of the plantation increase the awareness and diffusion of knowledge on market opportunities for farmers?

Research hypothesis 2: Following the conceptual framework in chapter 1.4, it is expected that plantation workers are more aware of market opportunities and improved technologies used on the Jatropha plantation and also diffuse this knowledge in their networks in the villages.

Research question 3: Does the additional income and higher awareness of market opportunities and improved technologies contribute to investment and the adoption of innovations in agriculture?

Research hypothesis 3: Following the conceptual framework in chapter 1.4, it is expected that incomes generated from plantation work are invested partly in improved agricultural techniques.

Research question 4: Does the provision of inputs combined with agronomic information lead to technology adoption?

Research hypothesis 4: Following the conceptual framework in chapter 1.4, it is expected that the seed and information distribution relaxes information, financial, and supply-side constraints in terms of access to input for farmers.

1.6 Outline of the thesis

This thesis includes six chapters. After the introduction and the conceptual framework, chapter 2 presents the study area and the quantitative and qualitative data collection. Chapters 3-5 are papers destined for publication in scientific journals. Chapter 3 addresses the impacts on food security, chapter 4 the spillovers to knowledge and innovations in agriculture, and chapter 5 investigates the impacts of a seed distribution. In chapter 6, the results are discussed and policy recommendations are given. Chapter 7 concludes with limitations and recommendations for future research.

2 Study area and data collection

The research conducted for this thesis took place in the Haute Matsiatra region in Madagascar, located about 500km south of the capital city Antananarivo in the central highlands (altitude of 757 m). A map of the study region is provided in chapter 5, figure 5.1. Climate conditions are semi-arid, with an average annual temperature of 26° C and an average annual precipitation between 600 and 1000 mm. During the dry season from April to September, rainfall is below 50mm, and more than 80% of the rainfall occurs between November and February. According to the latest nationally representative household survey on living conditions in Madagascar in 2012/13 (INSTAT, 2013), 76.1% of the households in the Haute Matsiatra region have incomes below the national poverty line (535 603 *ariary*[6]/person/year), which is slightly above the national average of 75.6%. More than 73% do not consume the caloric requirements of 2133 kcal/day, which is slightly below the national average of 76%. The region is the one with the national highest prevalence of child malnutrition in the country (stunting, wasting, and underweight) of 65.2%.

The commune of Fenoarivo (see figure A1) comprises 1.200 km2, with an estimated number of 13.000 habitants in 2011 and therefore a population density of 10.8 people/km2. The prevailing vegetation type is grassland savannah used as pasture for zebu cattle, the predominant crops grown are rice, cassava, maize and legumes under rainfed agricultural systems and characterized by low productivity and high yield gaps for major crops. The soil in the study area is characterized by an extremely low carbon content, a strong deficiency in phosphorous, a low available water storage capacity and a low effective cation exchange capacity. According to local information and as expected by the soil carbon content there was no forest cover since at least the middle of 1990s (Poetsch, 2008).

JatroGreen S.A.R.L, a joint venture between a German and a Malagasy firm founded in 2007, acquired 3000 ha of land through a 99-year lease. Jatropha plants are cultivated in tree nurseries, the expected yield was 4 t/ha with 1250 plants/ha, irrigation and fertilization was applied, a press from Germany, a tractor and it was planned to mechanize harvest (Grass & Zeller, 2011; Uellenberg, 2007). Buenner (2009) estimated opportunity costs for land in comparison to rice production and argues that for most of the land acquired these are zero. Employment was hypothesized to occur mainly in the initial establishment of the plantation. In 2010, the planting of an initial 1000 ha had been achieved (see figure A2) but only 400 ha were intensively used in 2014. JatroSolutions GmbH also seeked financing through a CDM project and proposed a new methodology to evaluate small-

[6] The official yearly exchange rate from Malagasy Ariary (MGA) to Euro (EUR) in 2012 was one EUR = 2828 MGA and in 2013 one EUR = 2,945 MGA.

scale projects substituting fossil fuel in combustion engines through biofuel from degraded land. This had however not been approved by the UNFCC board (JatroSolutions, 2009), instead another methodology “Plant oil production and use for transport applications” had been suggested by UNFCC (2014). In 2012, the CDM approval had been abolished, due to the price collapse of CER (Certified emission reduction) credits and at the same time high transaction costs for certification as well as high monitoring costs of activities and end use of oil.

The data used in this thesis originates from five household survey rounds and additional qualitative data collection between 2008 and 2014. Three villages in the commune of Fenoarivo had been purposefully selected as they represent villages that provide the majority of the labour force working for the Jatropha project[7], (Grass 2010). In these three villages, household lists were compiled with the help of the mayor and the village heads. From the complete list, 50% of households were randomly chosen. The first three household survey rounds (2008, 2009 and 2010) were carried out in the framework of a multidisciplinary research project on Jatropha cultivation at the University of Hohenheim. The survey rounds in 2012, 2013 and 2014 were part of a follow-up research project investigating direct and indirect socio-economic impact of the Jatropha project. The majority of the households could be revisited and therefore a comprehensive panel data set could be compiled.

In this thesis, a mixed methods approach i.e. combining quantitative with qualitative methods, is used. Focus group discussions and in-depth interviews were used to elicit the most perceived changes and discourses on the Jatropha project, and to understand the underlying processes of how impacts work, and the size and nature of the expected impacts. Furthermore, flexibility to adjust to changes in treated households, to changes in treatment, for the inclusion of contextual factors and heterogeneity is allowed. To capture complex and multidimensional concepts like poverty or community organizations, in-depth interviews can help in understanding and aggregating the information to suitable quantitative indicators. With additional qualitative data, it is possible to distinguish between design and implementation failure of projects. Moreover, outcomes can be compared to what according to evidence or theory the project could achieve, and not only to the counterfactual (Bamberger et al., 2010; Wilkinson, 1998). The panel sample is explained in detail in chapter 3, where household data collected from 2008 to 2013 is used to perform panel analysis. Fixed effects model have several advantages over cross-section data, e.g. to control for omitted variable bias (Wooldridge, 2002).

[7] A first household survey had been carried out already in 2008. This survey was planned as baseline survey, however since the Jatropha project started offering wage work already in late 2007, the impacts in terms of income earned were already apparent (Buenner, 2009) Moreover, one of the villages included in this survey could not be revisited due to security reasons (Grass & Zeller, 2011). Therefore, this household survey data is not used in this thesis but provides valuable insights in relevant questions.

The last two survey included additional questions on adoption of innovations, selling of agricultural produce and social networks. Therefore, the analysis of spillover effects in chapter four relies on cross-section data, and lagged variables for agricultural production and plantation wage work. Due to the very low adoption rates of improved technologies, a rather general definition of innovation is used, considering all the changes farmers had made since the installation of the plantation in the area. Social network analysis is then combined with regression models explaining households' knowledge and adoption of innovations. Depending on the nature of the dependent variables, OLS, probit, and tobit regression models are used to estimate the determinants of knowledge and adoption of innovations. To account for potential endogeneity problems with social networks and the outcome variables an instrumental variable approach is tested.

Randomizing treatment and control group eliminates a number of biases occurring in observational studies (Angrist & Pischke, 2014). Randomized controlled trials can especially be helpful in drawing policy recommendations and scaling up policies when only limited funds are available (Banerjee & Duflo, 2008; De Janvry, Sadoulet, et al., 2017; Duflo et al., 2008). Since many private seed initiatives do not report their results or monitor seed use, evidence on the determinants of success or failure is missing. After distributing improved bean seed in the framework of the household survey in 2013, a follow-up survey on the outcomes was organized in 2014. This data is used in chapter 5, where next to treatment effects on yield and consumption, the willingness to pay for improved seed is estimated. Additionally, net-maps, a tool based on a social constructivist approach (Douthwaite et al., 2003), were used as a subjective and participatory tool to elicit actors and their objectives in development processes (Schiffer & Hauck, 2010).

Moreover, document analysis added insights into the design phase, the drivers and motivation of the project, the actors involved and the monitoring approach (The Project Design Document compiled for the Economic Impact Assessment and the CDM application, the CDM application document (proposed methodology, feedback from UNFCC, changed proposal), and reports for both the technical project implementation and the accompanying research projects).

3 Large-scale biofuel production and food security of smallholders: Evidence from Jatropha in Madagascar[8]

Abstract

Large-scale agricultural investments in land and biofuel feedstock production have been found to lead to positive employment, growth and poverty reduction effects. However, these outcomes depend on the institutional context and the type of investment. This article aims to provide insights into the relationship between wage work for a large-scale Jatropha project and household food security, measured as dietary diversity and food provision during the lean season. After the initial hype and the subsequent downfall of Jatropha, new projects are still being undertaken. Yet there is little evidence quantifying the long-term impacts of large-scale Jatropha production on smallholders' livelihoods. This article addresses the gap by using five rounds of panel data collected between 2008 and 2013 from 390 randomly selected households in the vicinity of a Jatropha project in Madagascar. Labour demand by the plantation declined substantially after the build-up phase, and incomes from wage work were mostly used for food and other necessities. Impacts were estimated with the help of fixed effects models. Jatropha wage work contributed significantly to dietary diversity but did not reduce the more subjective lack of food during the lean season. One reason might be that households stored significantly less rice over time. Moreover, food production and consumption were highly influenced by seasonality, drought and locust shocks, which implies that complementing income creation with agricultural development strategies might have further positive effects on livelihoods and food security.

3.1. Introduction

Jatropha[9] as a source of biofuel has been used in view of the shortage and high prices of fossil fuels starting during the second world war (Foidl et al., 1996; Heller, 1996; N. Jones & Miller, 1992; Nielsen et al., 2013). Hopes were high in the early 2000s, when Jatropha was heavily promoted, that it would be a means to utilise otherwise unused or degraded land and therefore reduce the competition between fuel and food production and hence reduce environmental impacts (Francis et al., 2005; Renner, 2007). Investment in biofuel has been driven by economic incentives in industrialised countries (Achten et al., 2014). Policy assumptions, however, have often been contradicted by real practices (Achten et al., 2014;

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[9] The species *Jatropha curcas* L., a drought-tolerant shrub or small tree, produces oil-containing seeds (Jongschaap et al., 2007)

Franco et al., 2010). Despite many failed projects, Jatropha production is still being promoted and new projects are still undertaken (Nielsen et al., 2013; Wahl et al., 2013). Based on LandMatrix data in 2016, Jatropha was found to lose importance as driver, but was still the second most reported agrofuel crop in large-scale land investments after oil palm and before sugar cane (Nolte et al., 2016). Hamelinck (2013), however, found that the majority of these entries were incorrect or investments were never realised and estimated that only 0.5% of these land transactions were driven by EU biofuel policies.

Numerous authors have discussed possible benefits and trade-offs of second-generation biofuel feedstock production for poor smallholders in low-input subsistence agriculture. Bindraban et al. (2009) for example argued that large-scale biofuel production will not likely be sustainable because the additional land use will have negative effects on biodiversity, greenhouse gas emissions and food production. Accordingly, development impacts will depend primarily on the employment possibilities that are created and price effects, which could mean a deterioration of food security among the poor. That said, small-scale production and production on marginal lands might have different effects but would not contribute significantly to global production of biofuels.

Systematic reviews on the local impacts of biofuels have inconclusive evidence for effects on food security, which were highly context specific and heterogeneous regarding different affected groups (Hodbod & Tomei, 2013; Locke & Henley, 2013). Analysis based on cross-sectional data found mostly positive socio-economic benefits of Jatropha production on livelihoods, wellbeing, and food security (Peters, 2009; Schut & Florin, 2015; Thornhill et al., 2016). Some studies constructed baselines through recall questions (Portale, 2012; Timko et al., 2014). Yet, these studies do not control for selection bias and omitted variable bias. Exceptions are Negash and Swinnen (2013) who used a two-stage model to explain the food security impacts of castor production and Herrmann et al. (2017) who used propensity score matching and endogenous switching regressions to look at impacts of sugarcane outgrower schemes on food production. Moreover, the time of the impact assessment is likely to be relevant, as labour demand is significantly higher in the set-up phase and revenues from oil production occur only several years after the first planting or are heavily subsidised in the first years (see e.g. Acheampong & Campion, 2014).

We therefore contribute to filling this knowledge gap by making use of an extensive panel data set collected between 2008 and 2013 in two seasons from 390 households in three villages in the vicinity of a large-scale Jatropha project. By using panel data, unlike the majority of socio-economic studies conducted on Jatropha, we were able to control for selection bias and omitted variable bias and to test the sustainability of the previously shown positive effects on household income (Bosch & Zeller, 2013; Grass & Zeller, 2011). The main objective of this study is to provide insights into the relationship between employment for the Jatropha project and household food security, controlling for households' socio-economic characteristics, seasonality and weather shocks. Moreover, comparing our results with the suggestions of the Roundtable on Sustainable Biomaterials (RSB 2016), as the standard most adequately addressing food security (Schlamann et al., 2013), we want to inform political as well as private decision-makers about social sustainability and social feasibility of biofuel projects in marginal areas.

3.2. Material and methods

3.2.1 Conceptual framework

The socio-economic impacts of biofuel production have been widely studied. Mirzabaev et al. (2015) provide a conceptual framework for analysing synergies and trade-offs of bioenergy production, considering a food-energy-water nexus perspective. Other approaches have focused more on drivers of investment, policy processes and issues of land and social justice (e.g. Borras Jr et al., 2010; Venghaus & Selbmann, 2014). Jongschaap et al. (2007) have suggested the Sustainable Livelihoods Framework to assess the effects of biofuel production on smallholder farmers. In this framework, food security is considered one of the outcomes of livelihood strategies, next to income, wellbeing, reduced vulnerability and a more sustainable resource base. Although not specifically intended in the project design phase, income earning on the Jatropha plantation and improved access to food is the main pathway by which the project affects livelihoods. Households reported to have spent the majority of their Jatropha income on food, which might lead to increased intake of nutritious food. Next to health status, dietary intake is one of the two immediate causes for an improved nutritional status (UNICEF, 1990).

Short-term impact assessments estimated higher positive income impacts than long-term assessments, whereas direct and indirect effects on food security have been shown to occur with time delay. Therefore, we argue that the time of the impact assessment is relevant and that it is important to show long-term viability as well as possible spillovers with the help of panel data.

3.2.2 Data

The study is based on primary data collected from households living in the vicinity of a Jatropha plantation project in Madagascar. The project has been operating since 2007 on an area of 3,000 ha, with 1,000 ha planted in 2010. To assess the project's impact on surrounding communities, interviews with relevant stakeholders as well as semi-structured focus-group interviews with about 10 to 20 villagers representing former and current Jatropha workers, project management and farmers, traders, local government and 390 households were conducted in four villages each year from 2008 to 2013 (see Grass & Zeller, 2011).

The dataset contains 390 randomly selected households in three villages from 2008, representing the majority of households working for the Jatropha plantation (hereafter referred to as "Jatropha households") and the majority of people living within a 10 km radius from the original project site. Table 3.1 shows the total number of households in the sample, the number of Jatropha households and households for whom dietary diversity variables and panel data are available for each survey year. In 2008 and 2009, dietary diversity was only captured for a random subsample: the sample from 2009 included newly migrated households to the area, but not all households from 2008 were covered. Due to the high employment demand of the Jatropha plantation, substantial migration to the study area was observed up to 2010. In 2010, the sample had been reduced by 25% due to logistical constraints, and by 2012, almost all of these households had left the area. Moreover, attrition was caused by death, migration, relocation of teachers and members of the gendarmerie, and an unwillingness to respond. Such attrition can lead to attrition bias, that is, an unrepresentative sample. Therefore, in Table 3.7 (in annex), variable means for cross-sectional data and panel data available up to 2013 are compared, showing only slight differences between them (see Glewwe & Kassouf, 2012).

Table 3.1: Number of households in the household survey from 2008 to 2013

Household survey year	Total number of households	Number (%) of Jatropha households	Number of households with dietary diversity variables	Household with panel data from 2008 to current year
2008	735	391 (53.2)	362	735
2009	613	303 (49.4)	287	569
2010	473	195 (41.2)	472	397
2012	418	140 (33.5)	418	352
2013	390	76 (19.5)	390	332

Source: Household surveys (2008-2013)

3.2.3 Variable description

Next to food shortage during the lean season, the most prevalent problem in the region was low dietary diversity. We therefore used these two outcomes as indicators of a household's food security status. We used dietary diversity for seven days prior to the interview combined with the relative nutritional importance of the different food groups based on World Food Programme methodology (Wiesmann et al., 2009). Data on consumption frequency is not available for all rounds of the survey; therefore, we used a dummy for consumption in the previous seven days instead of frequency. Equation 1 below shows the model specification

$$\text{Dietary diversity } = \alpha_{staples}d_{staples} + \alpha_{pulses}d_{pulses} + \alpha_{vegetables}d_{vegetables} + \alpha_{fruits}d_{fruits} + \alpha_{meatfish}d_{meatfish} + \alpha_{sugar}d_{sugar} + \alpha_{dairy}d_{dairy} + \alpha_{oil}d_{oil} \qquad (1)$$

where α is the weight of each food group and *d* a dummy for consumption of the respective food group in the past seven days, resulting in a minimum value of 1 and a maximum value of 16. Weights of the different food groups are shown in Table 3.8 (in annex). We also estimated a dietary diversity indicator with the same eight food groups without weights and a household dietary diversity score (HDDS) with 12 food groups (distinguishing between cereals and roots/tubers for staples, and between meat and fish/seafood for animal products, and including miscellaneous). Household dietary diversity was proved to be a valid proxy of household access to food, and a promising measurement of monitoring changes and impacts (Hoddinott & Yohannes, 2002). More specifically for Madagascar, dietary diversity has been shown to be a good predictor of children's micronutrient consumption (Moursi et al., 2008). Regarding cross-sectional and intertemporal validity and nutritional relevance, dietary diversity performed best compared with food expenditures, poverty and subjective indicators (Headey & Ecker, 2013). Although the inclusion of sugar, fats and oils weakens the correlation of dietary diversity scores with micronutrients, it has been validated as an indicator for household access to food (Leroy et al., 2015).

Food shortage was measured for 30 days and 12 months prior to the interview, based on subjective questions if there were days/months in the reference period, in which the household did not have enough food to meet the family's needs (Bilinsky & Swindale, 2010). Dostie et al. (2002) described a significant reduction in household food consumption during the lean period in Madagascar. Therefore, to capture seasonal differences, the surveys were carried out during two different seasons (during the rainy season in 2008 and 2012 and during the dry season in 2009, 2010 and 2013).

Moreover, we used rice stock after harvest as a proxy for food security. Rice is the most important subsistence crop. Rice stock after harvest is significantly correlated with lack of food in the same year and, since the majority of households' rice stock does not last a full year, it is also a proxy for food stability. As the majority of households produce rice, it allows us to shed light on the linkages between Jatropha work and food production.

Additionally, we tested the Food Consumption Score with frequencies (FCS) and the Household Food Insecurity Access Scale (HFIAS), which we were able to estimate for the year 2013. The HFIAS score is a continuous measure of the degree of food access in the household in the past 30 days. It has been shown to be associated with determinants and consequences of food security (Leroy et al., 2015).

As an indicator for Jatropha plantation work, we used the number of Jatropha household members working for the Jatropha project during the reference periods. Jatropha operations started in 2007, and the first wage work was demanded at the end of 2007. Additionally, we measured changes in living standards of households. In 2013, households were asked if their living standard had changed since the Jatropha plantation had been installed in 2007. Households were asked to point out the change on a scale from -5 to 5: -5 meaning a drastic negative change in living standard, 5 representing a significant positive change and 0 standing for no change in living standard. As proxies for wealth we used farm size, number of cattle owned, possessing a storage room, and owning a business. Moreover, in 2013, subjective wealth was elicited on a scale from 1-10, where 1 is the poorest and 10 the wealthiest household in the village.

3.2.4 Econometric estimation

The first household survey captures the period from February 2008 to February 2009, that is, no baseline data is available. Furthermore, all households were aware of the possibility to work as daily labourers at the plantation and were allowed to work if coming to the site in the mornings. Therefore, this study has to deal with a selection bias consisting of the fact that households differ in socio-economic characteristics which influence their decision to work for the plantation or not. Households that decided to work might have had different outcomes from households who did not, even in the absence of the employment possibility.

Previous studies have shown that Jatropha households have less land, agricultural equipment, cattle and off-farm income sources (Bosch & Zeller, 2013; Buenner, 2009; Grass & Zeller, 2011). Given the daily wage, which is equivalent to the wage of an unskilled agricultural worker, poorer households self-selected themselves into plantation work. Those poorer households benefitted from plantation wage work by increasing their low income significantly (Grass & Zeller, 2011). No impact on food security and dietary diversity could be shown (Bosch & Zeller, 2013; Grass & Zeller, 2011). The impact on dietary diversity might have been moderated by food purchases, higher food availability at the market, or a higher crop and livestock production diversity, and therefore might have materialised only over time. This study addresses this shortcoming with a more extensive panel data set that allows the application of a fixed effects model. We use a fixed effects model since we aim to estimate the causal effect of Jatropha plantation work, a variable which varies over time, on household food security. A fixed effects model exploits variation within households, that is, households serve as their own controls. Moreover, it controls for all time-invariant household characteristics and therefore reduces omitted variable bias and the consequent potential endogeneity (Hsiao, 2003). Equation 2 shows our panel data model.

$$FS_{it} = \beta X_{it} + \alpha_i + u_{it} \tag{2}$$

where FS_{it} is the dependent variable observed for household *i* at time *t*, here different indicators for food security, X_{it} is a vector of explanatory variables for household *i* at time *t*, including the main variable of interest, the number of household members working for the Jatropha project, ß is a vector of coefficients controlling for the propensity of Jatropha work, a_i denotes unobserved household specific effects, which in a fixed effects model are assumed to be invariant over time and vary across households i, and u_{it} is the error term. To test if the outcomes are moderated by a higher own agricultural production or by food purchases, we included an interaction term of Jatropha work and production diversity. We used all observations for which at least two data points were available.

3.3 Results

3.3.1 Qualitative and descriptive results

Among the benefits most mentioned by households were the additional income source and the resulting higher living standard for workers, reforestation and overall rural development. Newly established businesses and sellers of agricultural products benefited from higher purchasing power and improved security in the region. As the plantation was established on land that was only very extensively used for cattle grazing, opportunity costs of land were assumed to be negligible. Discourses were mostly positive up to 2010. Villagers were proud of the project and considered it a unique opportunity for community development and were willing to support it.

The Jatropha project is the only important employer in the region and has support from the government and a foreign company. Villagers stated that they felt voiceless and powerless when local team leaders were replaced with family members in 2012, when employment and piecework wages were reduced, when promised investment in village infrastructure was stopped and when the payment of property and income taxes to the local government was refused until sustainable income from Jatropha oil sales were achieved. Discussions about the benefits of the Jatropha project changed over time. In 2012/13, the project was seen by some as a poverty reduction strategy and jokes were made about those who were "still in need to go working for the Jatropha project". Unrealistic expectations in the implementation phase of the project and a lack of transparency regarding the objectives and risks involved with Jatropha production and limited participation by the population might have contributed to this. One village elder stated very angrily: "I myself was a big proponent of the Jatropha project at the beginning and helped them to convince the villagers, I thought we [the commune of Fenoarivo] were saved, but now I am very disappointed, they have not kept their promises". Some farmers who set up rice fields at a riverbank in the plantation area with the approval of the project management were told in 2012 to stop cultivating these fields and were prohibited from watering their cattle at the river. The local government tried to mediate in these conflicts but had limited power towards an internationally acting company with official land titles. The mayor repeatedly stated the importance of the investment for the commune in times of political uncertainty and additionally was helped by the project management in raising concerns, such as road rehabilitation, with the national government. Close cooperation and communication with the mayor and village elders was considered very important and local government and informal laws were always adhered to. Team leaders who were recruited in the villages had a higher education level or were opinion leaders or authorities speaking in favour of the Jatropha project. Most of them still spoke in favour of the project in 2013, still viewing the project as a unique opportunity for rural development.

Table 3.2 shows the level of employment from the Jatropha project by village. During the labour-intensive planting phase from 2008 to 2010, workers were paid mostly for piecework and workers could earn up to 10,000 MGA[10] a day. Supervisors, responsible for a group of up to 50 workers, were recruited in the villages and compensated with a monthly salary. Most had at least a high school education, as their task was to train workers and control piecework and payment. For other tasks, like applying cow dung and pruning, the daily wage was 3,000 MGA. A political crisis in 2009 and a consequent economic recession led to an increase in poverty and inequality in the country; the salaries of public employees were not given in full or distributed late, as financial support from the international community, especially for the education sector, ceased. This economic uncertainty caused the Jatropha project to also attract workers from other communities. Until 2010, there was transport to the plantation site from Village 1 with trucks and tractors. In 2010, after having planted 1,000 ha, the management moved to a new site, about 12 km from Village 1, 8 km from Village 3 and 20 km from Village 2. Both transport and further plantation of Jatropha were stopped and labour demand decreased considerably. By 2012, almost all the newly migrated households had left the villages. The project management reported for the first time that they could not find enough workers for the Jatropha harvest. Daily wage was increased from 3,000 to 3,500 MGA.

Table 3.2 Employment for the Jatropha project (%), by village

	2008	2009	2010	2012	2013	Average years/HH
Village1	52	70	43	30	4	2.03
Village2	4	19	24	6	0	0.72
Village3	85	82	55	80	63	3.63
Total	45	60	41	34	20	2.00
Number of observations	735	709	474	418	390	390

Source: Household surveys (2008-2013)

Personal interviews with former supervisors showed that wage work in the region was seen as an inferior livelihood strategy. During focus group discussions, farmers reported that they prefer working in their own fields and selling part of their harvest, but that in drought years or when money for inputs was

[10] The official yearly exchange rate from Malagasy ariary (MGA) to euro (EUR) in 2013 was 1 EUR = 2,945 MGA.

needed, they appreciated the opportunity to work for the Jatropha project. In 2013, 50% of the households reported engaging in off-farm employment during the previous drought year, and 70% said they would seek an off-farm income source in the event of future droughts. According to discussions with team leaders working on the Jatropha plantation, richer households that had not previously worked for the plantation decided to do so to compensate for their harvest losses.

In 2014, Jatropha oil was still produced on a trial basis and wages were still pre-financed by the foreign investor. Due to agronomic, technical and financial problems, only 1,000 ha of the 3,000 ha acquired had been planted and only 400 ha were intensively cultivated. Villagers were aware of the financial and production problems. When the employment for Jatropha production declined, villagers were recruited for construction work, a small hydroelectric power station and for intercropping Jatropha with legumes. Cow dung applied by wageworkers on Jatropha fields was sourced from cattle owners in exchange for cash or housing material, providing another source of income. Employment was not monitored by the investor, therefore no figures on total employment and wage expenditures are available.

Table 3.3 shows mean Jatropha incomes over time. Very few households relied on the plantation for regular income which, in the farther villages, might be explained by the time-consuming transport to the plantation site, the manual labour and the wage level that does not allow big investments or a significant change in living standard. Villagers decided to work when urgent money needs arose or when the weather did not allow for sufficient agricultural production of their own.

Table 3.3 Mean Jatropha income, by village, per capita/month (Means in 1,000s of MGA and standard deviations in brackets)

	2008	2009	2010	2012	2013
Village1	10.14 (14.0)	8.45 (12.3)	8.55 (9.4)	4.86 (10.7)	9.74 (18.7)
Village2	2.57 (3.1)	1.73 (1.4)	4.8 (2.7)	0.88 (0.6)	0
Village3	17.05 (16.0)	6.87 (6.5)	8.2 (6.9)	5.17 (6.2)	4.61 (6.2)
Total	11.83 (14.8)	7.77 (10.7)	7.95 (8.1)	4.83 (8.7)	6.63 (12.9)
Number of observations	391	303	195	140	76

Source: Household surveys (2008-2013)

Table 3.4 shows explanatory variables for agricultural production and other income sources. Few households reported a reduction in their agricultural production due to the time spent on the Jatropha plantation up to 2010. Yet focus group discussions from 2010 showed that many households neglected agriculture in the first year of Jatropha work, resulting in a decline in mutual help in fieldwork, where workers were compensated with a meal or a small part of the harvest. Due to a lack of agricultural workers in the villages, larger-scale farmers started paying their workers a daily wage (2,000 MGA for cassava peeling, 3,000 MGA for field work, 10,000-15,000 MGA for preparing fields with cattle and machinery). More wage work instead of unpaid help was demanded. Farmers who were not able to afford to pay workers and therefore relied on mutual help found it hard to maintain agricultural production. Due to this, food production decreased, food demand increased and food prices rose. Agricultural production in 2010 was constrained by a severe drought, leading to major harvest losses (Bosch & Zeller, 2013). Weather data are only available from 2010 on and only for the Jatropha project site; therefore, effects from Jatropha work and weather cannot be disentangled. In 2012, production of almost all important crops increased compared with 2008. The only crop whose production fell was cassava, which is a staple crop consumed mostly by poorer households and during the lean season when rice stocks are depleted. It is also the most important cash crop in the region, before rice, legumes and maize, in both volume and sales. Before selling, it is peeled manually, a labour-intensive job mostly done by women. Agricultural production in the 2012/13 season was constrained by a locust infestation and a drought period prior to the rice harvest; more than 90% of households reported losses in their rice production. Almost 80% of the households classified the 2012/13 season as the worst agricultural season in the past five years (see also FAO, 2013). Due to lack of other pest control measures, farmers tried to fight locusts manually, keeping them away from the rice fields with fire. Therefore, agricultural wage work was particularly high and wages increased to 4,000 MGA.

According to larger-scale farmers and those who hire agricultural workers, the high demand for daily wage labourers led to an improvement of work morale and workers' motivation for agricultural wage work: workers stayed for a full working day rather than just the morning. Some farmers reported an increase in production due to that. In 2013, 87% of workers reported that they or their family members worked more hours in total or only worked for the Jatropha project when there was no work in the field.

Households also reported that the additional income allowed them to invest in agricultural equipment, seed and other inputs and therefore cultivated more land and more intensively. During the focus group discussions participants stated that before the Jatropha project, due to armed cattle rustlers, households only cultivated land near the villages and returned early from fieldwork. Once the project began they were able to work longer in their fields. Cattle thefts decreased, mostly because the plantation site cut the usual route of cattle rustlers and the project employed gendarmerie for the protection of the planted areas as well as buildings and staff members. Due to the increased security in the region, households reported cultivating more land farther away from the villages and working more hours in the fields. As households not offering labour to the plantation owned significantly more land they were better able to expand food production.

Households which increased their agricultural production or diversified into other income sources could benefit from the increased purchasing power of Jatropha households and the increased demand for food and other products and services. The supply of food products, especially vegetables and meat, at market increased in both quantity and quality. As a large number of households worked for the Jatropha project from Monday to Saturday up to 2010, an additional market day was introduced on Sundays. Attracted by the high purchasing power and additional food demand of households, traders from outside of the villages started selling food. As mostly women are responsible for vegetable production and not able to earn the same as men in piecework tasks on the Jatropha plantation, they invested in vegetable production and sales.

Asking other households for food or stealing harvested food – common strategies for poor and food-insecure households during the lean season – decreased due to the income opportunities provided by the Jatropha project. Wealthier households reported this as a benefit. Poor households reported that the willingness to give food declined, whereas more households were forced to take consumption credits from wealthier households with high interest rates. The number of years working for the Jatropha project was significantly correlated with more credit for food. Starting in 2012, reports of harvest thefts resumed.

Table 3.4 Explanatory variables – Variable means and standard deviations in brackets

	2008	2009	2010	2012	2013
HH members working for Jatropha project (number)	0.91	0.82	1.1	0.54	0.29
	(1.06)	(0.99)	(1.06)	(0.89)	(0.69)
Total land per capita (ha)	0.55	0.42	0.41	0.52	0.43
	(0.86)	(0.47)	(0.41)	(0.54)	(0.56)
Cultivated land per capita (ha)	0.40	0.32	0.30	0.43	0.35
	(0.62)	(0.29)	(0.35)	(0.45)	(0.42)
Crop diversity (number of different crops grown)	4.5	4.8	3.8	8.0	7.4
	(2.4)	(2.3)	(1.9)	(4.6)	(3.7)
Production diversity (crops and livestock diversity)	5.9	6.0	5.2	9.6	9.0
	(2.9)	(2.6)	(2.4)	(5.1)	(4.1)
Storeroom for agricultural products (dummy)	0.26	0.29	0.34	0.37	0.38
	(0.44)	(0.45)	(0.48)	(0.49)	(0.49)
Agricultural equipment (dummy)	0.47	0.45	0.53	0.63	0.64
	(0.50)	(0.50)	(0.50)	(0.48)	(0.48)
Livestock per capita (number)	1.98	1.96	2.03	2.51	2.54
	(3.45)	(3.16)	(2.86)	(4.09)	(3.82)
Livestock sales (dummy)	0.48	0.39	0.23	0.61	0.26
	(0.50)	(0.49)	(0.42)	(0.49)	(0.44)
Public employment (dummy)	0.04	0.03	0.04	0.06	0.06
	(0.20)	(0.18)	(0.19)	(0.24)	(0.24)
Own Business (dummy)	0.22	0.34	0.25	0.32	0.23
	(0.41)	(0.47)	(0.43)	(0.47)	(0.42)
Employment as agricultural labour (dummy)	0.30	0.30	0.18	0.56	0.31
	(0.46)	(0.46)	(0.38)	(0.50)	(0.46)

Dependents (number, age <10 and >65)	2.0	2.1	2.1	2.0	2.3
	(1.5)	(1.4)	(1.5)	(1.3)	(1.4)
Working age adults (number, age >=10 and <=65)	3.2	3.3	3.5	4.2	4.1
	(1.8)	(1.9)	(1.8)	(2.3)	(2.1)
Total rice production (kg)	1,331	1,430	542	1,632	944
	(1,619)	(1,522)	(944)	(1,727)	(1,211)
Total cassava production (kg)	2,267	767	642	1,666	1,991
	(8,875)	(1,166)	(933)	(2,320)	(6,298)
Total maize production (kg)	316	135	45	380	158
	(672)	(211)	(107)	(633)	(264)
Total pulses production (kg)	143	127	14	260	91
	(269)	(1,104)	(47)	(623)	(151)
Agricultural workers (dummy)	0.24	0.42	0.34	0.31	0.38
	(0.43)	(0.49)	(0.47)	(0.46)	(0.49)
Mutual help (dummy)	0.28	0.83	0.85	0.86	0.82
	(0.45)	(0.38)	(0.36)	(0.35)	(0.38)
Number of observations	735	613	473	418	390

Source: Household surveys (2008-2013)

Subjective wealth in 2013 was significantly and positively correlated with an increase in living standard after the installation of the plantation. Households that assessed themselves as wealthier in 2013 also reported a significantly higher number of innovations, more investment into equipment, housing and education and less credit for food over past years.

Table 3.5 show the means of the food security proxies over the years. Dietary diversity in 2008 and 2009 was only available for a random subsample, therefore, sample sizes are shown separately. The surveys in 2008, 2010 and 2013 were done at the beginning of the lean season, between August and October; the surveys in 2009 and 2012 were carried out between January and March. The rice harvest takes place between April and May/June.

Table 3.5 Mean food security variables, all survey years

	2008	**2009**	**2010**	**2012**	**2013**
Dietary diversity (8 groups, dummy past 7 days)	5.87	6.05	6.33	7.05	5.97
	(1.51)	(1.40)	(0.69)	(1.06)	(1.01)
Dietary diversity (8 weighted groups, dummy past 7 days)	11.28	11.39	9.99	13.60	10.07
	(3.53)	(3.34)	(2.14)	(2.78)	(2.44)
HDDS (12 food groups, past 7 days)	7.81	8.09	9.19	9.59	8.39
	(1.85)	(1.87)	(1.25)	(1.43)	(1.39)

HFIAS	n.a.	n.a.	n.a.	n.a.	3.7 (3.0)
Number of observations	362	287	472	418	390
Number of rice meals (7 days)	14.4	15.7	14.4	16.4	14.1
	(5.7)	(5.1)	(5.0)	(4.8)	(6.5)
Number of vegetable meals (7 days)	8.8	11	14.4	16.8	11.6
	(6.9)	(5.7)	(4.4)	(4.5)	(5.4)
Number of meat meals (7 days)	0.7	0.8	0.8	1.1	1.2
	(1.8)	(1.7)	(1.1)	(2.3)	(1.5)
Rice stock after harvest (in kg)	726	895	372	945	751
	(799)	(915)	(547)	(1,165)	(999)
Rice stock left at time of interview (in kg)	53	234	106	140	237
	(225)	(501)	(281)	(294)	(551)
Days without enough to eat (30 days)	7.7	5.1	3.4	3.5	2.4
	(11.5)	(9.8)	(5.9)	(6.5)	(4.4)
Months without enough to eat (12 months)	1.13	0.27	0.25	0.17	0.18
	(2.46)	(0.95)	(1.0)	(1.05)	(1.06)
Access to a well (dummy)	0.27	0.31	0.22	0.33	0.26
	(0.44)	(0.46)	(0.41)	(0.47)	(0.44)
Access to sanitation (dummy)	0.31	0.22	0.45	0.33	0.33
	(0.46)	(0.41)	(0.50)	(0.47)	(0.47)
Number of observations	735	610	472	418	390

Source: Household surveys (2008-2013), variable means and standard deviations in brackets

The three different dietary diversity indicators were all highly correlated with each other. Correlation between survey rounds was much weaker, pointing to seasonal and intra-year variation. The HFIAS score was negatively and significantly correlated with all dietary diversity measures from 2010 to 2013, but not before 2010. Jatropha households had a significantly higher HFIAS score as measured in 2013, reflecting self-selection of poorer households for Jatropha wage work.

3.3.2 Econometric results

Table 3.6 shows the estimation results from the regression models. To account for detected heteroskedasticity, robust standard errors are reported (Wooldridge, 2002). Following a Wald test, year dummies were included. Employment on the Jatropha project contributed to increased dietary diversity (Model 1), but not to a reduction of the more subjective lack of food (Models 2 and 3). Jatropha work was a significant and negative predictor of rice stocked after harvest (Model 4). Land owned by the households and access to mutual help led to significant improvements in all models. Even though livestock ownership was positively associated with a lack of food, the result was significant only at the 10% level of alpha. Production diversity increased dietary diversity and reduced the short-term lack of food. In the rainy season, which coincides with the lean season, dietary diversity was significantly higher, whereas both droughts in 2009/10 and 2012/13 led to a significant decline in rice stocks, and dietary diversity. Agricultural employment, ceteris paribus, led to a higher dietary diversity, but increased long-term food shortage and led to lower rice stocks. Year dummies (not shown) for lack of food showed an improvement in all years, which indicates higher food availability in the market, especially during the lean season. Those who engaged in businesses, which were mostly shops or trading activities at the market and who were mostly wealthier households, had higher dietary diversity, higher rice stocks and reported less lack of food. Other proxies for wealth are storage possibilities, which contribute to a reduction in the short-term lack of food, and ownership of agricultural equipment, which increases dietary diversity and rice stocks and reduces the long-term lack of food. Despite its importance as a subsistence crop, rice production was not significant in all models (not reported). Cassava contributed to a reduction of the short-term lack of food, similar to pulses, which also increased dietary diversity. Regressing rice production instead of rice stock, Jatropha work was also a significant negative predictor, albeit less strong.

Table 3.6 Estimation results of the regression models

	(1) Dietary diversity (8 food groups with weight)[1]	**(2) Lack of food (30 days)**	**(3) Lack of food (12 months)**	**(4) Rice stock (kg, after last harvest)**
Jatropha workers (number per household)	0.608***	0.150	0.103	-43.10*
	(0.206)	(0.600)	(0.107)	(22.60)
Total land cultivated (ha per capita)	0.454*	-1.399**	-0.186*	387.10***
	(0.245)	(0.570)	(0.103)	(93.24)
Livestock (number per capita)	-0.025	0.093	0.027*	10.98
	(0.034)	(0.082)	(0.015)	(10.50)
Production diversity (number of all crops/ vegetables/ fruits grown, and livestock)	0.101*** (0.029)	-0.170** (0.072)	0.008 (0.014)	
Storeroom for agricultural products (dummy)	0.867*** (0.250)	-1.270* (0.682)	0.050 (0.088)	84.70 (58.41)
Agricultural equipment (dummy)	0.255	-1.057	-0.241*	59.31
	(0.275)	(0.817)	(0.145)	(43.36)
Own Business (dummy)	0.487**	-2.439***	-0.069	88.52*
	(0.226)	(0.529)	(0.086)	(45.96)
Agricultural employment (dummy)	0.703***	-0.951*	0.185**	-88.97**
	(0.200)	(0.487)	(0.076)	(36.38)
Working age adults (number, age >=10 and <=65)	0.234*** (0.088)	0.003 (0.184)	-0.005 (0.031)	85.02*** (23.66)

Mutual help (dummy)	1.119***	-1.329**	-0.308**	149.00***
	(0.222)	(0.635)	(0.129)	(39.46)
Pulses production (tons)	0.628***	-0.263**	-0.005	
	(0.241)	(0.130)	(0.013)	
Jatropha work*Production diversity[2]	-0.053**	-0.0260	-0.014	
	(0.024)	(0.070)	(0.010)	
Rainy season (dummy, 2008 and 2012)	1.015***	0.0151		
	(0.261)	(0.618)		
Drought year (dummy, 2010 and 2013)	-1.308***	-2.756***		-186.1***
	(0.260)	(0.627)		(60.06)
Year dummies included	no	no	yes	yes
R^2 within	0.25	0.08	0.09	0.20
R^2 between	0.13	0.08	0.05	0.55
R^2 overall	0.20	0.09	0.08	0.36
Number of observations	1,668	1,781	1,777	1,813

Robust standard errors in brackets.
*, **, *** denote a significance level at the 10%, 5% and 1% significance levels, respectively.
[1]Results for HDDS and household dietary diversity (8 food groups without weights) are not reported, since coefficients do not vary considerably in direction and magnitude.
[2]Interaction term. Including the interaction term in model 4 as a proxy for investment into agriculture does not yield significant results.
Additionally, we controlled for rice and cassava production in the first three models and for public employment in all models; coefficients were not significant and therefore not reported, but can be obtained upon request from the authors.

3.4 Discussion

Our results show that Jatropha work increased dietary diversity but did not reduce the more subjective lack of food. Due to the missing baseline, the effects of the plantation work might be underestimated. However, our results also show that over the years Jatropha households invested less in their own agriculture and had smaller rice stocks.

The majority of income earned from Jatropha work was spent on food and necessities and only a small part invested in agriculture or business. This was confirmed by the significant and negative coefficient of the interaction term of Jatropha work and production diversity and suggests that time constraints between plantation and own farm work and that Jatropha households had less access to agricultural assets and inputs. Jatropha households reported that income helped to cover basic needs, especially during drought years and in responding to idiosyncratic shocks. Whereas before households had to reduce consumption considerably in the lean season, with the new work they had cash available to buy food, medicine and other necessities. However, Jatropha households also took significantly more credit for food consumption, which is usually taken and repaid in rice. Jatropha households might have relied more on purchased food, leading to a more varied and micronutrient-rich diet than home-grown food, but not to an increase in quantities consumed. Better-educated households, owning more land, mostly expanded their agricultural activities, or invested in other income possibilities, such as trade of agricultural products or small enterprises.

This compares with other studies, where participation in plantation wage work has been shown to be an income strategy for asset-poor households, whereas in outgrower systems better endowed households participated (Lansing et al., 2008; Mogaka et al., 2014; Schut & Florin, 2015). The same applies for large-scale production systems, as in the horticultural sector, where land-poor households benefit more, whereas better endowed households have higher benefits from outgrower systems (e.g., Herrmann, 2017; Van den Broeck et al., 2017). For Jatropha, Schut and Florin (2015) found both positive and negative effects for both production systems, yet large-scale production is more closely monitored. Given above-average wages and monthly contracts, Peters (2009) found an increase in income, expenditures, and working time, but a decrease in food production and in other cash generating activities one year after the establishment of a Jatropha plantation in Mozambique. Portale (2012) found that participation in Jatropha fuel supply chains improved the subjective wellbeing of outgrower farmers in Tanzania. Grass and Zeller (2011) argue that this depends to a great extent on wage levels, if wages are similar to those offered for local agricultural wage work and if there is at least seasonal unemployment. Minten and Barrett (2008) found that mean agricultural wages do not increase demand during the harvest/peak season in Madagascar. Due to gaps in the agricultural calendar and the high number of children and elderly people supported by working age adults, even wage workers fully employed throughout the growing season have incomes significantly below the poverty line (ibid).

Regarding food security outcomes, Negash and Swinnen (2013) found that participation in a castor bean outgrower scheme increased farmers' food consumption and narrowed their food gap. Schut and Florin (2015) found ambiguous effects on food security, depending on the Jatropha production scheme and the dimension of food security analysed. In the province of Antananarivo, Minten et al. (2009) estimated a reduced lean period of 1.7 months for a group of farmers participating in contract farming, compared with 3.7 months before the contract and 4.3 months for similar farmers without contract, based on farmers own estimation.

RSB (2016) suggests that piecework wages should at least be equivalent to the prevailing minimum wage. However, for Jatropha harvest, where yield was highly variable between fields, daily wage was often not equivalent to local agricultural wage work, which represents the minimum wage. Yet, as seasonal unemployment exists, opportunity costs of workers in the agricultural lean season might be below this minimum wage.

The low explanatory power of the variables for lack of food might hint at measurement problems, due to the perception-based nature of this variable. Poorer households rely much more on cassava consumption, richer households more on rice consumption. Richer households might therefore report a higher subjective lack of food. It might also hint at the importance of unobserved factors such as food utilisation and health status. Participants of focus group discussions reported that in the lean season when food shortage and high labour requirements coincide, people are more often sick and food utilisation by the body might be reduced. Moreover, the region is affected by a high rate of water-borne diseases which might further constrain food utilisation (in 2013, only 26% had regular access to a well, and only 33% reported using latrines). Jatropha workers are especially vulnerable to water-borne diseases as the only water source available during work times is the river. In one of the villages, the project management donated a public well; Jatropha households are significantly more likely to have access to a well, and to use a latrine. The RSB (2016) suggests providing access to safe drinking water to workers during work time and contributing to awareness of water quality, which might increase both worker wellbeing and productivity.

Production diversity led to a significantly higher dietary diversity in our study. This compares with the results of Kabunga et al. (2014), who found that a higher crop diversity, especially vegetables and fruits, contributed to a more diversified diet with higher nutritional quality. Other studies found that types of food, context and location matter, and that effects varied greatly in size. However most studies support the hypothesis that household agricultural production has direct and important linkages with household dietary patterns and the nutrition of individual members (Carletto et al., 2015). Sibhatu et al. (2015) argue that the effect of crop diversity on dietary diversity diminishes probably because foregone benefits from specialisation become more relevant for farms that are already highly diversified. Dietary diversity in the rainy season is higher, although it coincides with the lean season, when food consumption was significantly reduced in Madagascar (Dostie et al., 2002). One explanation for this could be that due to a lack of irrigation, crop diversity has increased especially in the rainy season. Another explanation is the increasing consumption of rice, which is traditionally complemented more with vegetables, meat or legumes than cassava, which is often prepared without complements. However, knowledge that cassava consumption leads to malnutrition exists, and consumption of cassava leaves is widespread.

To enhance the socio-economic and food security status of the local population, RSB (2016) suggests setting aside land for food production, increasing yields, sponsoring agricultural support programmes and activities, making value-added food by-products available to local markets as well as providing opportunities for workers to carry out household-level food production and providing energy services to smallholder farmers. In our case, Jatropha households were encouraged not to come to work during the agricultural season or share tasks among household members and helped to create awareness about bush fires and climate change, such as droughts and soil erosion partly caused by deforestation.

The participation in mutual help arrangements for farming activities increased dietary diversity and reduced lack of food, therefore it might be a risky strategy for households to drop out of those arrangements for the preference of plantation wage work. A reason for this is also that agricultural labourers receive a meal during work and receive part of the harvest.

Numerous studies analyse positive impacts of off-farm income or income diversification on household food and nutrition security and argue that not only investment into agricultural growth, but also into households' access to off-farm employment should be considered as a development strategy (Babatunde & Qaim, 2010; Reardon, 1997; Ruben & Van den Berg, 2001). For rural Madagascar, Minten and Barrett (2008) found a strong inverse relationship between wage rates and the average length of the lean period. Sitienei et al. (2014) found that participation in low-income casual work on others' farms increased off-farm income but decreased own farm productivity, suggesting a possible poverty trap, due to the need for more off-farm income from year to year. RSB (2016) suggests the preference for local workers and the creation of permanent employment possibilities. We argue that the latter is not a feasible suggestion for Jatropha plantations because of seasonality of demand for unskilled workers and would only be possible if they were to also engage in other activities, such as intercropping with food or other cash crops, or process and market by-products.

During focus group discussions, the low bargaining power of workers for better working conditions or worker welfare against the project was mentioned. Concerning working conditions, RSB (2016) suggests monthly meetings with workers and encouraging workers to associate. Farmer and worker associations could help in negotiating working conditions and mitigating negative social impacts such as land disputes. Minten et al. (2009) suggest that even in situations where farmers are very poor, institutions and infrastructure barely exist and with monopsonistic companies farmers can benefit substantially with the right incentives and management systems. An ethnographic study not far from the project under study showed that smallholders could oppose the additional acquisition of land by a biofuel company. Noteworthy, however, is that in this case major actors were rich cattle owners and local elites, who had previous experience with international investors and the help of transnational activists (Gingembre, 2015). Several studies suggest that (international) development agencies could assist in the negotiating and managing of contracts and therefore overcome power asymmetries in agricultural investments and give farmers a better negotiating position (Burnod et al., 2013; Vermeulen & Cotula, 2010). In the case of Jatropha, negotiations were based on largely overestimated yields, land and labour profitability and non-existing value chains. In Madagascar, agricultural projects of more than 1,000 ha need an environmental license from the National Agency for Environment (ONE) given against the delivery of an environmental impact assessment that includes socio-economic criteria. This Project Design Document (PDD) is required by the Malagasy government only once after the contract is signed, but does not include a mechanism to monitor projects over time. For our case study the PDD stated that the created jobs were only temporary, yet communities might have overestimated the labour demand and the economic potential of Jatropha when negotiating during the implementation phase.

Achten et al. (2014) point to the risks involved for smallholders, who should only be involved when genetic material is chosen and monitoring systems are in place. Investments in new and emerging species can have negative social effects for involved communities if those investments are stopped, such as income losses and negative attitudes towards new projects (Achten et al., 2014; Van Eijck et al., 2014).

Although not intended by the Jatropha project, an important impact pathway is through higher security, less cattle theft, more working hours in the field and an increase in agricultural land in the study area. This is remarkable as national data suggests an increase in cattle raids since 2009 (Jütersonke & Kartas, 2011), but could not be verified with the police station, as farmers do not report cattle theft there. Insecurity, manifested in the fear of crop theft and encounters with cattle thieves, was found to hinder the expansion of cultivated acreage, and more so in land-abundant, remote and insecure locations in Madagascar (Fafchamps & Minten, 2009). Harvest theft was reported to have first declined and then increased again, which is consistent with Fafchamps and Minten (2006) who showed that crop theft is used by rural poor as a risk-coping strategy and increased significantly with an increase in poverty in central Madagascar.

Livestock ownership did not contribute to higher food security in our study. Cattle are an important status symbol in the region and are not usually sold to smooth consumption. Another explanation can be that livestock owners are richer households who report a higher subjective lack of food. Cattle could also increase agricultural production through the pathway of higher crop productivity. The Jatropha project also helped to question some of the taboos farmers have, such as not using cow dung or planting several legume species. These and other spillovers could not be addressed in this study, but would merit further investigation.

3.5 Conclusion and recommendations

The Jatropha project became an important source of employment in the study region, especially for poorer households and during the off-season and drought years. Nevertheless, as labour demand decreased significantly after the labour-intensive establishment phase, very few regular jobs were created and households mostly used wage work if urgent money needs arose. As shown with the help of a fixed-effects model, wage work contributes to higher dietary diversity, but not to a reduction of the more subjective lack of food and shortening of the lean season. The Jatropha project promotes flexible wage work and recommends that farmers prioritise their own farm work. Yet, results show that Jatropha households decreased their rice stock significantly over time, while at the same time demand for labour declined.

To increase spillovers to agriculture, the extension service could cooperate with the Jatropha project using its scale and central position for the promotion of crop diversification and the demonstration of improved inputs and technologies. Furthermore, the project could use its storage possibilities and access to markets to offer collective marketing of crops or livestock. Jatropha oil could be tested for local use, for example for generators, and tractors could be rented out to for mechanised soil preparation. Moreover, the majority of households rely on firewood as their main energy source for cooking and spend a considerable amount of time collecting it. The use of Jatropha oil for rice dehusking or cooking might reduce females' work burden. Putting in place a monitoring system that covers work incidence and employment could improve communication with workers and farmers and lead to more realistic expectations. The current government is now promoting foreign investments again; more control over investments could therefore channel these investments into fulfilling socio-economic objectives, such as the supply of decent work. Land rights could be granted for shorter periods and prolongation only given against proof of compliance with the contract.

Large-scale production of Jatropha oil in Madagascar for the global market is not commercially viable with the planting material that is currently used, but improved cultivars have been developed (see Senger et al., 2016) and local marketing options are available. Furthermore, since biofuel production has positive effects on poverty reduction, food security, and land restoration, (different) energy crops could be incorporated into rural energy projects, agroforestry systems and public works programmes, for example as wind and erosion control or plants for fencing in cattle (see e.g. Mogaka et al., 2014), and afforestation or climate mitigation projects (Venghaus & Selbmann, 2014).

Since this article focuses on access to food, further research could look at indirect effects on agriculture and food availability, for instance through the pathway of higher crop productivity. Additionally, food utilisation and health status as important determinants of nutritional status merit further attention.

Annex

Table 3.7: Selected variable means for cross-sectional and panel data, 2008-2013

	2008	2009		2010		2012		2013	
	Cross-section[1]	Cross-section	Panel[2]	Cross-section	Panel	Cross-section	Panel	Cross-section	Panel
Dietary diversity (8 groups with weights)	11.28 (3.53)	11.39 (3.34)	11.37 (3.34)	9.99 (2.14)	10.01 (2.18)	13.60 (2.78)	13.62 (2.83)	10.07 (2.44)	10.12 (2.41)
JG (number of HH members)	0.91 (1.06)	0.82 (0.99)	0.82 (1.00)	1.10 (1.06)	1.09 (1.05)	0.54 (0.89)	0.56 (0.91)	0.29 (0.69)	0.31 (0.71)
Land cultivated (ha, p/c)	0.40 (0.62)	0.32 (0.29)	0.32 (0.29)	0.30 (0.35)	0.30 (0.37)	0.43 (0.45)	0.43 (0.44)	0.35 (0.42)	0.35 (0.43)
Working age adults	3.18 (1.76)	3.27 (1.86)	3.34 (1.88)	3.45 (1.75)	3.44 (1.71)	4.19 (2.30)	4.13 (2.21)	4.13 (2.15)	4.07 (2.01)
HH head education	3.19 (1.75)	3.12 (1.70)	3.12 (1.70)	3.28 (1.57)	3.25 (1.51)	3.36 (1.56)	3.35 (1.51)	3.42 (1.56)	3.40 (1.51)
HH max. education	3.83 (1.65)	3.85 (1.56)	3.87 (1.55)	3.95 (1.56)	3.93 (1.52)	4.17 (1.72)	4.13 (1.67)	4.25 (1.70)	4.21 (1.66)
HH head age	41.37 (14.3)	41.91 (14.5)	42.30 (14.4)	43.42 (13.9)	43.85 (14.0)	45.59 (14.2)	45.95 (14.0)	46.03 (13.9)	46.21 (13.6)

Source: Household surveys (2008-2013), [1]Mean of all households surveyed in the respective year, [2]Mean of all households with panel data from 2008 to respective year. Standard deviations are shown in brackets.

Table 3.8: Food groups and respective weights used for dietary diversity

Food group	Weight	Justification
Main staples	2	Energy dense, protein content lower and poorer quality (PER* less) than legumes, micronutrients (bound by phytates).
Pulses	3	Energy dense, high amounts of protein but of lower quality (PER* less) than meats, micronutrients (inhibited by phytates), low fat.
Vegetables	1	Low energy, low protein, no fat, micronutrients.
Fruit	1	Low energy, low protein, no fat, micronutrients.
Meat + fish	4	Highest quality protein, easily absorbable micronutrients (no phytates), energy dense, fat. Even when consumed in small quantities, improvements to diet quality are large.
Milk	4	Highest quality protein, micronutrients, vitamin A, energy. However, milk could be consumed only in very small amounts and should then be treated as condiment and therefore reclassification in such cases is needed.
Sugar	0.5	Empty calories. Usually consumed in small quantities.
Oil	0.5	Energy dense but usually no other micronutrients. Usually consumed in small quantities.

*PER: Protein Efficiency Ratio, a measure of protein quality of food proteins. Source: WFP (2008)

4 Measuring the effect of informal social networks on knowledge and innovation performance of rural farm households in Madagascar

Abstract

Next to institutional factors and lack of capital, lack of knowledge and extension services for improved agricultural technologies is considered a barrier to their dissemination in Madagascar. There is a growing literature on the role of knowledge and social learning for the adoption of innovations. This study contributes to this literature by investigating the influence of informal social networks on knowledge and adoption of innovations of households in a remote area in the southern highlands of Madagascar. Using data collected in the vicinity of a large-scale biofuel project, we estimate determinants of knowledge and test its relevance for the adoption of innovations of households and for the cultivation of a former taboo legume with the help of regression models. Results show limited access to information, little knowledge on investment and marketing possibilities, and low adoption of innovations. Knowledge is relevant for both the adoption of innovations and the cultivation of Bambara groundnut, which strengthens the need for extending and improving public extension service and information dissemination in rural Madagascar. Adoption is not only mediated by knowledge, but also directly motivated through informal social networks. For Bambara groundnut spillover effects from the biofuel project can be observed, relaxing some of the constraints farmers face concerning access to information, social learning and cultural norms.

4.1 Introduction

Numerous studies point out the effects of the lack of access to information in rural areas. Among other factors, lack of information or imperfect knowledge are constraints to the adoption of innovations (Feder et al., 1985; Foster & Rosenzweig, 1995). and can limit agricultural output and profits (Fletschner & Mesbah, 2011). Increased access to and adoption of new technologies can address the challenges of poverty and food insecurity through the pathways of higher crop yields, better job opportunities and higher non-farm income. Prices can signal opportunities to producers, consumers, and traders - such as when excess demand is creating more profitable opportunities to sell or when excess supply leads to cheaper deals (Torero, 2014). In Madagascar rural communities with higher rates of adoption of improved agricultural technologies and higher crop yields show lower food prices, higher real wages for unskilled workers and better welfare indicators (Minten & Barrett, 2008). The authors therefore strongly favour support for improved agricultural production as a strategy to poverty and food insecurity reduction. Yet, adoption rates of improved agricultural technologies have been disappointedly low (e.g. Moser & Barrett, 2003b).

In rural regions, where access to information is low, informal social networks might be the most important source of information. Social networks can influence a households' decision for any activity through the flow of information, ideas, skills, or services. Farmers learn from and share information on technologies with peer farmers or friends. Relations with others also represent access to credit, regular trade flows and risk sharing (Fafchamps & Minten, 1999). These kind of links or connections can be formed through various interactions and relationships (Maertens & Barrett, 2013). According to Collier (2002), social learning occurs through two channels: copying and pooling. Copying occurs when farmers have similar characteristics and are observable, and some of them have a knowledge advantage. Copying only requires unidirectional interaction, and therefore might have a positive effect on innovation (Grootaert & Van Bastelaer, 2002). Yet as copying can also lead to knowledge free-riding, it can inhibit innovation in agriculture and therefore the impetus for research might have to come from outside of the village (Collier, 2002). When knowledge differs among agents and networks are diverse, pooling occurs through reciprocal interactions, exchange of information and through decision-making by farmers, instead of just copying from others (Collier, 2002). Poor households might be excluded from important networks if they have less knowledge to pool (Grootaert & Van Bastelaer, 2002). A third channel can be social pressure, through which farmers deliberately adopt or not adopt a technology without observing the outcomes of other farmers (Maertens, 2017; Moser & Barrett, 2006).

This article estimates a knowledge score for smallholder farmers in rural Madagascar, which includes awareness and knowledge about market prices, input traders, buyers of agricultural products and extension and microfinance services. It investigates how informal social networks and social capital influence this knowledge and its role for the adoption of innovation. We make use of a household survey designed for a representative sample of rural households living in the vicinity of a large-scale *Jatropha* plantation in the Haute Matsiatra region in the southern highlands of Madagascar. In 2011, on the land not used for *Jatropha*, the project management started to engage in the cultivation of food crops. We hypothesize that Jatropha workers are more exposed to information than other farmers are, since the project uses modern inputs and targets national output markets. Jatropha households are mostly poorer farmers with less land and cattle, with more workforce and less access to other income sources. One of the crops grown on the plantation area, *Bambara groundnut*, was taboo (*fady* in Malagasy) to grow in the village fields due to traditional beliefs that it prevents rainfall. Villagers observed that rainfall did not hold off and started planting it themselves. The remoteness of the region, the low access to information (through extension service, input dealers, traders or NGOs) and the implementation of the biofuel project provide an interesting context to investigate the low adoption of improved agricultural technologies in Madagascar, the mostly neglected roles of knowledge and the different aspects of social capital in innovation adoption studies.

4.2 Methodology

4.2.1 Estimation strategy

Numerous studies point out the effects of the lack of access to information in rural areas. Among other factors, lack of information or imperfect knowledge are constraints to the adoption of innovations (Feder et al., 1985; Foster & Rosenzweig, 1995). and can limit agricultural output and profits (Fletschner & Mesbah, 2011). Increased access to and adoption of new technologies can address the challenges of poverty and food insecurity through the pathways of higher crop yields, better job opportunities and higher non-farm income. Prices can signal opportunities to producers, consumers, and traders - such as when excess demand is creating more profitable opportunities to sell or when excess supply leads to cheaper deals (Torero, 2014). In Madagascar rural communities with higher rates of adoption of improved agricultural technologies and higher crop yields show lower food prices, higher real wages for unskilled workers and better welfare indicators (Minten & Barrett, 2008). The authors therefore strongly favour support for improved agricultural production as a strategy to poverty and food insecurity reduction. Yet, adoption rates of improved agricultural technologies have been disappointedly low (e.g. Moser & Barrett, 2003b).

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This article estimates a knowledge score for smallholder farmers in rural Madagascar, which includes awareness and knowledge about market prices, input traders, buyers of agricultural products and extension and microfinance services. It investigates how informal social networks and social capital influence this knowledge and its role for the adoption of innovation. We make use of a household survey designed for a representative sample of rural households living in the vicinity of a large-scale *Jatropha* plantation in the Haute Matsiatra region in the southern highlands of Madagascar. In 2011, on the land not used for *Jatropha*, the project management started to engage in the cultivation of food crops. We hypothesize that Jatropha workers are more exposed to information than other farmers are, since the project uses modern inputs and targets national output markets. Jatropha households are mostly poorer farmers with less land and cattle, with more workforce and less access to other income sources. One of the crops grown on the plantation area, *Bambara groundnut*, was taboo (*fady* in Malagasy) to grow in the village fields due to traditional beliefs that it prevents rainfall. Villagers observed that rainfall did not hold off and started planting it themselves. The remoteness of the region, the low access to information (through extension service, input dealers, traders or NGOs) and the implementation of the biofuel project provide an interesting context to investigate the low adoption of improved agricultural technologies in Madagascar, the mostly neglected roles of knowledge and the different aspects of social capital in innovation adoption studies.

4.2.2 Measuring social networks

Social networks can be described as one aspect of social capital. Through social interactions, trust, knowledge and norms can be generated, which in turn reduce transactions costs. Grootaert and Van Bastelaer (2002) similarly argue that social capital can facilitate access to and sharing of information In locations with high transaction costs and weak law enforcement concerning market contracts and property rights, coordination is mainly happening through social interaction or personal exchange, not through formal organizations (Collier, 2002; Grootaert & Van Bastelaer, 2002; Kherallah & Kirsten, 2002).

We are interested if and how the nearby large-scale *Jatropha* project have influenced social networks. During plantation work, *Jatropha* households get in contact and interact with management and workers from other villages and are therefore expected having more producer-relevant knowledge, which they are expected to share in their traditional village networks.

When measuring social networks, we therefore focus on networks as access to and acquiring of information. Maertens and Barrett (2013) compared existing measurements of informal networks, considering also cost and time efficiency of integrating the methods within existing samples. 'Random matching within sample' yielded better results than 'network within sample' methods (Conley & Udry, 2010; Maertens & Barrett, 2013; Santos & Barrett, 2010). Following Maertens and Barrett (2013) we let each interviewed household randomly draw 6 households from the same village in the sample and asked them about their relation and knowledge about the match's farming activities and outcomes. To control for important network actors that are not part of the sample, we asked households to report the three most important information sources concerning agriculture in the village, with whom they exchange information and with whom they cooperate in agricultural production. As the most mentioned information sources in the villages are included in our sample, we consider omitted variable bias as not problematic.

Due to multicollinearity among the different components of social networks and in order to include these as explanatory variable in regression analysis, principal component analysis (PCA) is applied to aggregate the variables into a social networks index (SNI, hereafter, see table 4.2). PCA constructs a new variable, which is a linear combination of the original indicators, while their total variance is preserved. Standardised components, with a mean of zero and a standard deviation of one are extracted. We follow Zeller et al. (2006) in their methodology of aggregating different aspects of poverty into a poverty indicator. Keil et al. (2008) applied PCA to construct a drought resilience index and use this index as dependent variable in a regression model to identify influencing factors of drought resilience. Below et al. (2012) constructed an activity-based adaptation index to climate change and concluded that its construction is a simple but promising way to capture complexity and local variation of adaption activities. To improve the interpretability of the index, we follow Keil et al. (2008) and rescale it by adding the absolute value of the minimum household score to each score, to achieve a minimum value of 0 and then dividing each value by the maximum score to achieve a value between 0 and 1.

In addition to the social network index, as different aspects of social capital are hypothesised having different effects on innovation, we control for the following aspects of social capital and networks: Participation in groups and networks, proxied by the membership in farmer and village associations and churches (dummy), collective action and cooperation, proxied by the participation in village collective action (dummy) and mutual help in agriculture (dummy), and trust and solidarity, proxied by the agreement to seven statements11. To control for the information flow from *Jatropha* workers

[11]'Most people in the village are honest and can be trusted'; 'People are only interested in their own situation'; 'If I need a helping hand, there is always someone helping me'; 'If I need to borrow cattle, there is always someone who lends it to me'; 'If I need help with the construction of a house, there is always someone helping me'; 'If I lose an animal, someone from the village will help me searching'; 'If I need food or money in the lean season, there is always someone who lends it to me'.

to non-workers, we use the percentage of *Jatropha* households known in the households' network. A *Jatropha* household is a household in which at least one member worked for the *Jatropha* project in the respective period. We use a dummy for *Jatropha* work in 2012/2013 to test the influence on knowledge, and a for Jatropha work from 2008 to 2013, to test the influence on innovation.

4.2.3 Measuring knowledge

To elicit households' knowledge, we ask respondents to estimate the consumer end price of rice in the district capital, and if they know the next microfinance institution, the agricultural extension service, private input sellers, and a newly established cassava-processing firm. Households were first asked if they know about it or not, and then some follow-up questions to test their knowledge. Average consumer end prices in the district capital were investigated for April 2013, September 2013 and April 2014, and included in the household survey taking place from September to October 2013. The agricultural extension service provides improved seed varieties, training and in cooperation with the microfinance institution subsidised agricultural material on credit. One farmer in the village is being trained as a representative by the agricultural extension service in the district capital since 2012. Farmer groups have the possibility to organise a paid training by an extension officer. Focus group discussions revealed lacking willingness to pay for these services and illiteracy of the farmers are the biggest barriers. The cassava factory has been established with funds of the agricultural ministry about 35 km from Fenoarivo. The region is a major cassava producer, in the villages 92% of households are producing cassava. As fresh cassava has to be processed within 24 hours, it was considered setting up a first processing facility in one of the study villages. As farmers have only limited access to traders, access to the processing firm could mean higher prices.

For the analysis, we use a dummy for at least one price estimation, the accuracy of the price estimations given, and a knowledge score, which is the sum of the three price estimations, and knowledge of microfinance institution, agricultural extension service, private input sellers and cassava-processing firm.

4.2.4 Measuring innovation

To elicit households' knowledge, we ask respondents to estimate the consumer end price of rice in the district capital, and if they know the next microfinance institution, the agricultural extension service, private input sellers, and a newly established cassava-processing firm. Households were first

All answers are measured on a 1-5 Likert scale, where 1 represents no agreement at all and 5 full agreement. Since the second statement is negatively phrased, it was recoded. The mean of the seven answers is our proxy for trust and solidarity.

asked if they know about it or not, and then some follow-up questions to test their knowledge. Average consumer end prices in the district capital were investigated for April 2013, September 2013 and April 2014, and included in the household survey taking place from September to October 2013. The agricultural extension service provides improved seed varieties, training and in cooperation with the microfinance institution subsidised agricultural material on credit. One farmer in the village is being trained as a representative by the agricultural extension service in the district capital since 2012. Farmer groups have the possibility to organise a paid training by an extension officer. Focus group discussions revealed lacking willingness to pay for these services and illiteracy of the farmers are the biggest barriers. The cassava factory has been established with funds of the agricultural ministry about 35 km from Fenoarivo. The region is a major cassava producer, in the villages 92% of households are producing cassava. As fresh cassava has to be processed within 24 hours, it was considered setting up a first processing facility in one of the study villages. As farmers have only limited access to traders, access to the processing firm could mean higher prices.

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4.3 Data and descriptive analysis

We use data collected from 390 households in three villages in a remote rural community in Madagascar. In 2008, three villages have been purposely selected to represent the population in the catchment area of a large-scale Jatropha plantation. In these three villages, 50% of households were randomly selected (Grass & Zeller, 2011). Household surveys were carried out during five survey rounds from 2008 to 2013, and focus group discussions in 2010 and 2012/2013. Questions on social networks, knowledge and innovations were included in 2012/2013. We therefore do not have panel data for the main variables of interest, but are able to use lagged variables, as described in section 2.1

In table 4.1, an overview of households' knowledge given. The social network index is shown in table 4.2. Other social network and social capital characteristics are shown in table 4.4.

In the study villages, 98% of households cultivated rice in 2013, and 99% consumed rice in September 2013. After the season 2012/13, 37% of households sold rice to traders. Farmers are predominantly price takers, only 23% said they bargained successfully with traders for the five most important crops (rice, cassava, maize, beans and peanuts) with an average negotiation gain of 52 *ariary*12/kg. Rice for consumption was bought by 49% on the local market, with significant price differences to the district capital. The average price in September 2013 for white rice on the local market was 420 *ariary* for one *kapoaka*13 compared to 380 *ariary* in the district capital. Average consumer end prices in the district capital amounted to 300, 380 and 225 *ariary* for one *kapoaka* (approximately 0.3 kilograms) in April 2013, September 2013 and April 2014 respectively. When asked about prices, 72% of households estimated at least one of the three prices, with a mean accuracy of 82%.

The microfinance institution was known by 32% of the farmers, 8% had contact to the agricultural extension service, and 10% bought inputs from the input seller in the district capital. The cassava-processing firm was known by 26%. On average, farmers travel two times per year to the next bigger town, and 0.65 times, they asked others to bring them inputs from the town. Public employees have to travel regularly to the district capital to collect their salary, representing an advantage in access to information like extension services, programs, and subsidies. Significantly more households in which the household head has at least secondary education know the extension service, private input sellers, and the microfinance institution, and gave more accurate price estimations.

Most of the social capital and network variables differ significantly between the three villages, reflecting distance to markets and institutions, but also village size and trust and solidarity. Village 1, with the highest population and is the seat of the local government and hosts a weekly market has a significant lower social network index (SNI) that the two smaller villages. In the two smaller villages, there are more taboos and social control seems higher, reflected in less cultivation of *Bambara groundnut*. Village 3 is the closest to the *Jatropha* project and provides the majority of workers. Knowledge is not significantly different from village 1, but innovation scores are significantly lower.

Households in which the household head completed at least secondary education have a significant lower SNI, but are more active in formal groups, and have significantly more knowledge, have less taboos and reported more innovations, including the cultivation of *Bambara groundnut*. *Jatropha* households do not differ significantly in social capital and network, but have less assets and access to other income sources (see tables 4.5).

In the household survey when asked for the three most important people who can provide new and relevant information concerning agriculture in the villages, only 38% of households named a person.

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[12] 1 EUR was equivalent to 2,945 Malagasy *ariary* (MGA) using official yearly averages for 2013.
[13] *Kapoaka* is a common expression for milk tins used to measure amounts of various items. For rice, 1 *kapoaka* is equivalent to approximately 250 g.

Focus group discussions confirm the low information sharing between villagers. When looking at the wider network of households, 33% stated having contacts outside the community with whom they share information concerning agriculture. During a travel to the district capital, 22% stated exchanging information on agriculture.

Households reported few innovations, except for planting new crops and selling crops to new traders. According to focus group discussions, farmers stick to their traditional methods. Several taboos exist in the study region, for example the use of cow dung for crop production, and cultivation of the majority of legumes, except for common beans, peanuts and voanemba (Niébé, *Vigna unguiculata L.*). Reported innovations were SRI techniques, mostly row planting or improved water management with water pumps; diversified production, for example vegetables or trees for firewood; processing of agricultural products, for example peeled and dried cassava, husked rice, pumpkin bread; new selling places, other than the local market, selling to wholesalers and hiring of agricultural workers. Significantly more households in which the household head has at least secondary education reported hiring workers or investing into land and equipment. Significantly more *Jatropha* households reported selling products at other markets than five years before.

After the first cultivation of *Bambara groundnut* by some farmers and the *Jatropha* project, 8.2% and 35.4% of households were cultivating it in 2011/2012 and 2012/2013, respectively. Innovative farmers in the villages stated they were the first to cultivate, but only the cultivation by the *Jatropha* project allowed farmers to observe that rainfall did not hold off. Since we are interested in household innovation we consider the 36.7% of those starting cultivating until 2012/2013, including 9 farmers who stopped cultivation after the first year. The motivation for *Bambara groundnut*, according to focus group discussions, is a higher market price than for other legumes and that at the same time it does not need inputs.

Households that innovated generally reported satisfaction with their innovations, e.g. 67% of those that diversified crop production said it increased sales, 88% of those implementing new technologies said it resulted in higher yields, 83% of those that processed their products themselves said it led to higher quality, and 92% and 96% of those selling products with other traders or at other markets, respectively, reported higher sales prices.

Table 4.1 What do households know?

	N	Mean	S.D.	Min	Max
Estimation of consumer price of rice in district capital					
April 2013	239	244.9	54.3	150	450
September 2013	275	404.3	28.4	250	450
April 2014	221	264.3	87.5	150	500

Number of prices estimated by a household	390	1.9	1.3	0	3
No. of prices estimated, <20% deviation of actual price	390	1.3	1.0	0	3
Dummy, at least one estimated price, <20% deviation	390	0.72	0.5	0	1
Deviations from actual price (ariary, % in brackets)					
April 2013	239	-55.1 (-18.4)	54.3 (18.1)	-150 (-50)	150 (50)
September 2013	275	24.3 (6.4)	28.4 (7.5)	-130 (-34.2)	70 (18.4)
April 2014	221	39.3 (17.5)	87.5 (38.9)	-75 (-33.3)	275 (122)
Mean deviation in % of all prices estimated (absolute value)	283	18.79	11.9	0	122
Mean accuracy of all price estimations, in % (absolute value)	283	81.21	11.9	-22.2	100
Knowledge of					
Microfinance institution?	390	0.32	0.5	0	1
Agricultural extension service?	390	0.08	0.3	0	1
Private input seller in the district capital?	390	0.10	0.3	0	1
Cassava-processing factory?	390	0.26	0.4	0	1
Knowledge score (sum of 3 prices and 4 other knowledge variables)	390	2.66	1.71	0	7

Table 4.2 Social network index

	Mean	S.D.	Min	Max	Hypothesised relationship	Component loading	K-M-O
HH know x's profit	4.31	1.6	0	6	+	0.965	0.829
HH knows x	4.31	1.6	0	6	+	0.957	0.844
HH knows x's yield	4.29	1.6	0	6	+	0.956	0.856
HH knows x's risk preference	4.35	1.6	0	6	+	0.953	0.950
HH knows x's occupation	4.36	1.6	0	6	+	0.950	0.847
HH visited fields of x	1.78	1.9	0	6	+	0.605	0.855
HH is related to x	1.17	1.5	0	6	+	0.501	0.916
X knows HH's yield	1.02	1.5	0	6	+	0.449	0.819
Social network index (rescaled)	0.6	0.2	0	1			0.863

The questionnaire module on informal social networks contained 13 questions. The questions not retained for the index were: For how many years have you known x?, Is x your neighbour?, Does x cultivate a field neighbouring your field?, How often did you talk to x in the last month?, Would you ask x for advice if you had a problem with your rice cultivation?

KMO: Kaiser-Meyer-Olkin Criterion

Table 4.3 Innovations, 2008-2013

	N	Mean	S.D.	Min	Max
Innovations in past 5 years, % of households					
New technology (for example tools, pump)	390	0.13	0.34	0	1
Transforming products	390	0.02	0.13	0	1
New varieties/crops/trees	390	0.46	0.50	0	1
Sales of products in other market	390	0.14	0.35	0	1
Sales to other traders	390	0.85	0.36	0	1
Negotiation with traders (only 2013)	390	0.23	0.42	0	1
New forms of work organization	390	0.22	0.42	0	1
Financial investment in land/equipment/cattle	390	0.31	0.46	0	1
Innovation score (sum of up to eight innovations)	390	2.46	1.31	0	7
Bambara groundnut, % of households					
Cultivating in 2011/2012	390	0.08	0.28	0	1
Cultivating in 2012/2013	390	0.35	0.48	0	1
Cultivating by 2013	390	0.37	0.48	0	1

Table 4.4 Household socio-economic characteristics determining knowledge and innovation

	N	Mean	S.D.	Min	Max
Human capital					
Age of HH head	390	46	13.9	16	92
Years schooling of HH head	390	4.26	3.15	0	15
Maximum years schooling of HH members	390	6.5	3.29	0	19
Dummy for ethnicity Betsileo	390	0.84	0.37	0	1
Dummy for ethnicity Bara	390	0.06	0.25	0	1
Dummy for ethnicity Merina	390	0.04	0.2	0	1
Sex of HH head	390	1.17	0.38	1	2
Agreement to ‘working hard improves living standard’[1]	390	3.97	0.97	1	5
Workforce (nbr of HH members >=10 and <=65)	390	4.14	2.14	0	14
Economic and financial capital					
Farm size per capita (ha, 2008)	390	0.53	0.814	0	8.25
Cultivated land per capita (ha, 2008)	390	0.41	0.54	0	4.20
Cattle ownership (dummy, 2012)	390	0.66	0.48	0	1
Subjective wealth (scale 1-10, 2013)	390	3.73	1.62	0	9
Public service (dummy, 2013)	390	0.06	0.24	0	1
Work at *Jatropha* project (dummy, 2013)	390	0.2	0.4	0	1
Hiring agricultural workers (dummy, 2013)	390	0.38	0.49	0	1

Mutual help (dummy, 2013)	390	0.82	0.38	0	1
Sales of main crops to traders (dummy, 2013)	390	0.87	0.34	0	1
Working as middlemen for trader (dummy, 2013)	390	0.1	0.3	0	1
Livestock sales (dummy, 2012)	390	0.61	0.49	0	1
Own business (dummy, 2012/2013)	390	0.23	0.42	0	1
Rice yield (in kg, 2013)	390	944	1211	0	11.700
Rice sales (in 1000 *ariary*, 2012/2013)	390	70.94	189.8	0	1.800
Expenditures for rice (in *ariary*, 7 days, 2012/2013)	390	6580	9173	0	54.600
Cassava sales (in 1000 *ariary*, 2012/2013)	390	206.62	384.5	0	3510
Social capital					
Membership in association 2008 (dummy)	390	0.23	0.42	0	1
Membership in association 2012 (dummy)	390	0.22	0.41	0	1
Participation in collective actions 2008 (dummy)	390	0.87	0.33	0	1
Participation in collective actions 2008 (sum HH)	390	2.04	1.29	0	5
Participation in collective actions 2012 (dummy)	390	0.72	0.41	0	1
Participation in collective actions 2012 (sum HH)	390	1.36	1.03	0	4
Member of a church in 2012 (dummy)	390	0.78	0.42	0	1
Exchange of rice seed in 2012 (dummy)	390	0.16	0.37	0	1
Exchange of cassava seedlings in 2012 (dummy)	390	0.06	0.24	0	1
Talk to others about cassava in 2012 (1 very often - 4 never)	390	2.46	1.39	0	4
Obligations given to others in rice in 2013 (kg)	390	39.8	63.6	0	450
Trust and solidarity, 2013 (1 lowest – 5 highest)	390	3.58	0.48	2.29	4.86
Possible credit for food, hospital, wedding, death (in 1000 *ariary*)	390	366	619	0	6.200
Use of phone (2013, dummy)	390	0.38	0.49	0	1
Phone expenditures (per month, 2013, in 1000 *ariary*)	390	2.1	4.4	0	36
Travel to the district capital (nbr, 2012, per HH)	390	2.01	3.36	0	26
Agricultural information exchange during travel (dummy, 2013)	390	0.22	0.41	0	1
Asking to bring goods from district capital (nbr, 2013, per HH)	390	0.67	3.87	0	52
Jatropha households in social network (%, 2013)[2]	390	0.22	0.27	0	1
Jatropha households in social network (%, 2008-2013)[2]	390	0.78	0.27	0	1
Villages					
Village 2 (dummy)	390	0.24	0.43	0	1
Village 3 (dummy)	390	0.19	0.39	0	1

[1]Answer to the question: Do you believe that by working hard you can improve your living standard?' (Likert scale: 1 do not agree at all, 5 totally agree). [2]Percentage of *Jatropha* households from all known households among the 6 randomly drawn households for the SNI

Table 4.5 Contingency tables

Statistical differences in the following tables were determined with the help of Wilcoxon rank-sum and Kruskal-Wallis tests, in the latter case the Wilcoxon rank-sum test served as post-hoc test. Statistical significance is shown at the 5% significance level, a denotes significant difference between groups 1 and 2, b between 1 and 3 and c between 2 and 3.

Table 4.5.1 Differences between villages

	Village 1	Village 2	Village 3
SNI[ab]	.50	.72	.78
Trust and solidarity[abc]	3.48	3.64	3.82
Membership in organizations (dummy, 2008)	.27	.16	.19
Membership in church[abc]	.96	.76	.51
Collective action (dummy, 2012)[ab]	.80	.60	.66
Work at *Jatropha* project (dummy, 2013)[abc]	.14	0	.63
Agreement to ‘working hard improves living standard’	3.85	4.13	4.12
Years of schooling of household head[ab]	5.08	3.01	3.43
Maximum years schooling of HH members[ab]	7.32	5.21	5.70
Travels to district capital[ab]	2.52	1.13	1.62
Knowledge score[ab]	3.03	1.95	2.44
Innovation score[b]	2.58	2.54	2.12
Cultivation of *Bambara groundnut* by 2013[abc]	0.53	0.26	0
Taboo for *Bambara groundnut*[ab]	.29	.61	.69

Table 4.5.2 Differences between *Jatropha* and non-*Jatropha* households

	Never worked (22.05%)	Worked at least in one survey period (77.95%)
SNI	.61	.60
Trust and solidarity	3.60	3.58
Membership in organizations (dummy, 2008)	.21	.24
Collective action (dummy, 2012)[a]	.60	.76
Agreement to ‘working hard improves living standard’	4.02	3.95
Years of schooling of household head[a]	3.87	4.38
Maximum years schooling of HH members	6.23	6.58
Knowledge score	2.56	2.68
Farm size per capita (in m2, 2008)[a]	5,725	3,769
Sales of agricultural products (dummy, 2013)[a]	.89	.78
Innovation score	2.45	2.46
Cultivation of *Bambara groundnut* by 2013	.33	.38
Taboo for *Bambara groundnut*	.48	.43

Table 4.5.3 Differences between education levels of household heads

	No schooling (10.85%)	Primary education (65.61%)	Secondary education or more (23.54)
SNI[b]	.66	.62	.56
Trust and solidarity	3.62	3.61	3.51
Membership in organizations (dummy, 2008)[bc]	.12	.20	.38
Membership in a church[abc]	.59	.83	.96
Collective action (dummy, 2012)[ab]	.51	.74	.75
Work at *Jatropha* project (number of years, 2008-2013)[c]	2.68	2.05	2.55
Agreement to 'working hard improves living standard'	4.00	4.06	3.83
Maximum years schooling of HH members[abc]	4.24	5.75	9.90
Travels to district capital[abc]	0.88	1.57	3.81
Knowledge score[bc]	2.12	2.42	3.69
Innovation score[bc]	1.98	2.42	2.84
Cultivation of *Bambara groundnut by 2013*[abc]	.10	.32	.60
Taboo for *Bambara groundnut*[abc]	.71	.46	.28

4.4 Results and discussion

4.4.1 Knowledge and determinants of households' knowledge

Covariates are shown in table 4.4, regression results in table 4.6. In the following, results are presented and the three models (price estimation, price accuracy and the knowledge score) are compared.

Table 4.6 Regression results - knowledge

	1) Price estimation (probit, marginal effects)	2) Accuracy of price estimation in % (OLS)	3) Knowledge score (tobit[1])
Human capital			
Age	-0.00253	-0.155***	-0.00116
	(0.00181)	(0.0537)	(0.00725)
Maximum years schooling of all HH members	0.0245**	0.0282	0.109***
	(0.00973)	(0.270)	(0.0364)
Agreement to 'working hard improves living standard'	0.151***	-1.124	0.555***
	(0.0253)	(0.781)	(0.0991)
Economic and financial capital			
Public service (dummy, 2013)	-0.100	-1.571	1.198***
	(0.150)	(2.988)	(0.429)

Work at *Jatropha* project (dummy, 2013)	0.194***	-2.126	0.672***
	(0.0518)	(2.059)	(0.250)
Dummy for phone use (2013)	-0.0271	-3.785**	0.356*
	(0.0582)	(1.643)	(0.188)
Social capital			
Trust and solidarity	0.0505	6.726***	0.317
	(0.0523)	(1.662)	(0.193)
Mutual help (dummy, 2013)	0.131*	1.899	0.490**
	(0.0706)	(2.081)	(0.244)
Informal social networks (SNI, 2013)	-0.0406	7.613**	0.690
	(0.134)	(3.801)	(0.462)
Memberships in organizations (dummy, 2008)	0.102**	3.551**	0.500**
	(0.0511)	(1.600)	(0.218)
Travels to district capital (number, 2012)	0.0178*	0.171	0.0376
	(0.0107)	(0.227)	(0.0249)
Village effects			
Village 2 (dummy)	-0.282***	-2.766	-1.029***
	(0.0836)	(2.290)	(0.270)
Village 3 (dummy)	-0.249**	0.230	-1.041***
Observations	390	283	390
F-Statistic (tobit/OLS) / LR chi2 (probit)	113.96***	2.64***	9.02***
Pseudo R2/Adjusted R2	0.25	0.12	0.12

*, **, *** indicate significant differences at α=0.1, α=0.05, α=0.01 respectively

[1] Robust standard errors, lower limit 0, upper limit 7. Only significant variables are reported. Additionally, we control for: sex of household head, own business, land and cattle ownership, sales to traders or working as middlemen for traders, agricultural workers, obligations given to others in rice, rice purchase past 7 days, participation in collective action, and radio ownership, and the number of *Jatropha* households in the network. In the third model, cassava cultivation is additionally controlled for.

Entry points for information are mostly public employees and a large-scale *Jatropha* project, which also helped to create new links among formerly unconnected farmers from different villages. Informal social networks, the main variable of interest does not have a significant and positive effect on the knowledge score and on price estimation.

Working as public employee, using a phone and travelling to the district capital similarly increases knowledge, but not price estimation. Households who are members in farmer and village associations and households relying on mutual help, know more. To capture location effects, village dummies were included. Village 1, left out in the models, is the seat of the municipal government and a weekly market takes place there. Households from villages two and three have a lower knowledge score. The biggest constraint to access information therefore seems to be the distance to public administration and market. Lambrecht et al. (2014) similarly found that awareness for mineral fertiliser was influenced by living in a program or neighbouring village, being educated, being member of a program or an agricultural association, participating more often in collective actions, and listening to agricultural radio programs.

Age and sex of household head do not play a significant role for knowledge. Education has a positive and significant effect on price estimation and knowledge. Education is generally very low in the villages, household heads on average went to school for 4.26 years, while the mean of the most educated household members is 6.5 years. Madagascar only recently increased its enrolment rate, therefore children are often better educated than their parents. Although education of the household head and other household members is correlated, the maximum years of schooling in a household had a higher effect than years of schooling of the household head, suggesting for knowledge sharing in the household. This result relates to Fletschner and Mesbah (2011) who argue that access to information often requires literacy and a higher education level allows for more complex information acquiring, processing and applying.

Households agreeing that by working hard they can improve their living standard, were significantly more likely to give a price estimation and to achieve a higher knowledge score. Most mentioned reasons for disagreeing households were weather shocks, diseases and pests. This result relates to Hill et al. (2013) who find that individuals agreeing they had power to make decisions that change the course of their life are significantly more likely to buy weather-index insurance.

Jatropha work has a positive effect on price estimation and the knowledge score. The project employs agronomists and agricultural technicians who could presumably disseminate information. Management members travel regularly to the district capital and are in contact with governmental organizations. In the villages, they started a discourse on the linkages between deforestation, climate change and land erosion. Progressive farmers started planting trees for firewood. Additionally, workers get in contact with farmers from other villages and exchange information with them. We also test for information dissemination through *Jatropha* workers, by including the percentage of *Jatropha* households in the informal social network. This variable is correlated with *Jatropha* work and the number of *Jatropha* households in the villages, but is significantly and positively related to the cultivation of *Bambara groundnut*, meaning that Jatropha workers are the main channel on how certain information disseminates in the villages. A majority reported that there are no farmers in the village who can provide new and relevant information concerning agriculture. Information coming from the Jatropha project might therefore be seen as relevant, and more valuable than information coming from local farmers. Based on the assumption that information about innovations spreads in the social network of farmers, several recent studies give recommendations on whom to target by extension services so that information disseminates most effectively, e.g. Maertens (2017) recommends to target information to progressive farmers and in case of social pressures, to launch large-scale information campaigns. The *Jatropha* project is socially distant and its main contribution to rural development is employment creation, but due to the possibility for on-farm experiments, and at the same time observability by farmers through wage work – contrary to innovative farmers in the villages - information about a taboo could disseminate in the villages. *Jatropha* households also had a higher knowledge score, but this information did not disseminate on non-*Jatropha* households into their informal networks. A field experiment in Kenya showed there is learning-by-doing by farmers, and learning from others who also participate in the training, but limited learning of non-participating farmers (De Janvry, Macours, et al., 2017 a). Kondylis et al. (2017) showed that training farmers directly leads to large increases in adoption, but not to the diffusion of the technology to other farmers.

Selling to traders, working as middlemen for traders and buying rice on the market does not have a significant effect on price estimation and knowledge. This confirms focus group discussions that most of the traders hire local middlemen to buy products from the farmers and the majority of farmers therefore do not have any direct contact with traders and no information exchange takes place. Those having to purchase rice on the market are the poorer households and those engaged in off-farm employment.

4.4.2 Do better informed farmers also innovate more?

Covariates are shown in table 4.4, regression results in table 4.7. In the following, results are presented and discussed and the two models (innovation and cultivation of *Bambara groundnut*) are compared.

Table 4.7 Regression results – innovation and cultivation of *Bambara groundnut*

	1) Innovation score (tobit)	2) *Bambara groundnut* (probit, marginal effects[1])
Human capital	2008-2013	2011-2013
Education (HH head)[2]	0.0580**	0.00580
	(0.0229)	(0.00417)
Sex of HH head (dummy)	-0.844***	-0.0705**
	(0.164)	(0.0302)
Knowledge score[3]	0.0792*	0.0184**
	(0.0444)	(0.00873)
Economic and financial capital		
Land cultivated (ha, per capita, 2008)	0.253**	-0.0250
	(0.108)	(0.0227)
Cattle ownership (dummy, 2008)	0.315**	-0.0313
	(0.147)	(0.0285)
Value of agricultural assets (1000 ariary, 2008)	0.000251**	1.29e-05

	(0.000120)	(2.17e-05)
Work at *Jatropha* project (nbr of years, 2008-2013)[4]	-0.0154	0.00980
	(0.0537)	(0.00943)
Legume cultivation (nbr of species, 2011/2012)		0.0380**
		(0.0185)
Social capital		
Social network index[5]	0.696*	0.150**
	(0.365)	(0.0734)
Number of *Jatropha* households in network (2008-2013)	0.0968	0.0784*
	(0.350)	(0.0603)
Membership in village groups (dummy, 2008)	0.269*	-0.0236
	(0.154)	(0.0217)
Participation in collective action (dummy, 2008)	-0.200	0.00191
	(0.202)	(0.0336)
Taboo for *Bambara groundnut* (2012)	-0.293**	-0.106***
	(0.126)	(0.0358)
Social obligations (1000 ariary, 2008)	-0.000659	1.16e-05
	(0.000860)	(0.000142)
Village effects[6]		
Village 1 (dummy)	0.408*	0.965***
	(0.220)	(0.0199)
Village 2 (dummy)	0.457	0.999***
	(0.314)	(0.0007)
Observations	390	390
F-Statistic (tobit) / LR chi2 (probit)	6.05***	169.41***
Pseudo R2 (tobit) / Adjusted R2 (probit)	0.08	0.33

*, **, *** indicate significant differences at α=0.1, α=0.05, α=0.01 respectively
[1] Robust standard errors, lower limit 0, no upper limit. Only significant variables are reported. Additionally, we control for age, workforce, agreement to 'working hard improves living standard', trust and solidarity, membership in a church, mutual help, and agricultural workers. [2] We assume that for innovation, education of the household head is more important than the maximum education. Replacing the education of the household head with the maximum education of the household only slightly changes the coefficient in both models.
[3] When instrumenting the knowledge score with the variable "agreement to 'working hard improves living standard'", the knowledge score becomes insignificant in both models, in the second model village 2 becomes insignificant. [4] Replacing the number of years with a dummy for 2012/13 makes the coefficient insignificant.
[5] Both models are robust against dropping the social networks index, only in model 1 village 1 becomes insignificant. [6] Since village dummies are highly significant and might capture various effects, we estimate the second model without these. Church membership becomes significant. This is plausible since churches are actively leading a discourse against taboos, and church membership is significantly different among villages.

Knowledge as measured in this study has a positive and significant effect on both adoption of innovations and *Bambara groundnut*. We also test price estimation instead of the knowledge score to explain innovation. In this case, price estimation as proxy for knowledge does not have a significant effect on innovation scores. Knowledge about prices might be of less importance to farmers than knowledge about access to new technologies or markets. The fact that some households might have guessed the right price or that some households are more confident than others about their knowledge might not have been properly dealt with by simply asking for the price. The lack of knowledge might also reflect that this knowledge cannot open up management options for farmers. Knowing prices might increase the success of choosing traders or bargaining, but there are other factors related to product sales, like low or only seasonal access to traders for communities with poor infrastructure and high crime rates, high entry costs into trading, limited trader competition and price transmission (Moser et al., 2009). Lack of trust in government services might also a play a role; some farmers had applied with the extension service to get access to improved seed, but did not succeed due to a lack of supply. In the season 2012/13, villagers knew about an intervention from the Ministry of Agriculture providing insecticides for the affected regions of a locust plague, which then failed to reach the more remote regions, including our study region. In the case of microfinance, travel time and costs and absenteeism were mentioned. Furthermore, knowledge as measured in our study might be necessary for farmers to decide to innovate, but insufficient in changing their practices if they lack complementary inputs like land or credit.

Wealth as proxied by land and cattle ownership, agricultural assets, and education and formal memberships significantly increased adoption of innovations, whereas for *Bambara groundnut*, those factors are not important, but experience in legume cultivation and *Jatropha* work. Households cultivating Bambara groundnut were poorer and not the usual innovators.

Households with bigger informal social networks were significantly more likely to cultivate *Bambara groundnut*. Informal social networks as elicited with the social network index (SNI) reflect learning from others and copying, and since *Bambara groundnut* has been linked to a taboo, and non-observance of taboos might lead to social and economic losses, farmers observed early-adopters and traditional opinion leaders. Most of the reviewed studies also found a positive effect of social networks on innovations. Hartmann and Arata (2011) find that more connected farmers in the wine sector in Peru reported a higher number of innovations. Gebreeyesus and Mohnen (2013) find that households in the Ethiopian Footwear Cluster with more and longer business relationships as the main channel to obtain knowledge are significantly more likely to innovate.

Trust and solidarity as measured in our study does not have a significant effect in both models. When controlling for the type and function of social capital, Van Rijn et al. (2012; 2015) and Wossen et al. (2015) found ambiguous effects on agricultural innovations. Structural social capital, proxied by households' connections beyond the village were associated with a higher level of innovations, whereas cognitive social capital, proxied by shared norms and trust within the villages are negatively associated, for example the number of relatives and memberships in funeral insurance arrangements, since they might serve other functions like insurance to shocks (van Rijn et al., 2015; Wossen et al., 2015). Barrett (2004) argues that agricultural practices of Malagasy smallholders are often chosen to conform to local behavioural norms, and that e.g. gains in rice yield are sacrificed for higher gains from maintaining identities and social networks. Because behavioural norms consist of not doing things conflicting with the "ways of the ancestors", this creates a behavioural status quo bias that can inhibit or slow down innovation processes (Barrett, 2004). This becomes clear when looking at the existence of taboos, which are a negative predictor both for innovations and *Bambara groundnut*. Taboos were shown to be both a hindering factor for development and poverty reduction (Stifel et al., 2011) but also as important for resource conservation (Ferraro, 2002; J. P. G. Jones et al., 2008) and are an important source of identity. Yet, even controlling for taboos, the agreement to 'working hard improves living standard' significantly decreases innovations. Especially in the two smaller villages, innovations in general are considered risky and risk has a very negative connotation.

Female-headed households are equally likely to have knowledge, but significantly less likely to innovate and cultivate *Bambara groundnut*, reflecting a disadvantage related to productive assets. Focus group discussions showed that especially women started cultivating vegetables and legumes, and for vegetables more inputs are used. Vasilaky (2013) showed that by randomly connecting women farmers for information exchange during a season, those women farmers achieved a higher productivity.

Sales of agricultural products leads to a significantly higher number of innovations. When asked about their motivation for innovations, the majority of farmers reported higher production and more sales. This was confirmed in focus group discussions where farmers stated they would use more inputs and innovate more if they knew about market possibilities. This confirms the findings of Stifel and Minten (2008), that remoteness from markets is a significant and negative predictor of the use of agricultural inputs and yields of major staple crops in Madagascar. Due to weather instability and frequent crop failures, farmers are reluctant to spend money on inputs, without being able to store crops over the lean season or knowing if and when they can sell their crops profitably. Minten et al. (2009) observed that contracts for producing off-season export crops in central Madagascar led to significant changes in crop production systems, namely the use of compost, fertiliser and more weeding.

Grootaert and Van Bastelaer (2002) look at how external agents like NGOs could have effects on social capital in rural communities. According to them these agents could increase social capital for example if they act as mediators between vertical (between community and other actors – bridging/linking) and horizontal (within the community – bonding) networks, or decrease by generating incomes or providing social services. External agents generally do not rely on community networks and extend normative behaviour and trust, while cultural patterns and social and economic trends might hinder the emergence of new forms of civic engagement. If new norms and incentives for interaction are introduced or mediated by the external agent, then these enhanced social interactions usually are heavily dependent on such mediations and not sustainable.

4.5 Conclusion and recommendations

We elicited knowledge of households in rural Madagascar and estimated the determinants of this knowledge, testing especially informal social networks. Given the potential endogeneity of knowledge and social networks, causal inference might be biased and results need to be interpreted carefully.

Descriptive results show that surprisingly little is known in the villages, for example the rice prices in the district capital and extension services. Information and communication as measured with our social network index is highest in the two smaller and more remote villages where significantly less is known, showing that remoteness is the biggest constraint for access to information. Access to informal social networks does not seem to be a constraint for the households, but the access to relevant and reliable information. This strengthens the importance of extension services in rural Madagascar. Yet, at least in the mid-term widespread awareness about technology and market options among farmers cannot be reached by the traditional extension service. The village responsible trained by the extension service has yet to prove to be effective to disseminate producer-relevant information and increase the access to inputs and markets.

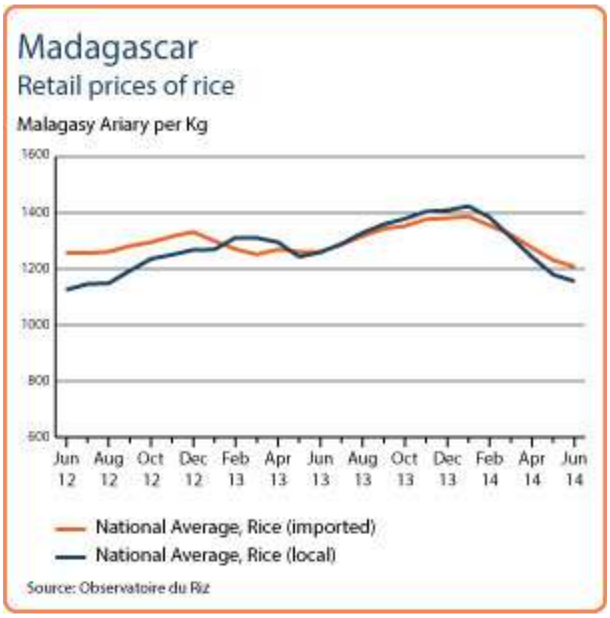
Cooperation of extension service with private input sellers, schools and microfinance institutions, and expanding extension methods, for example radio contributions or videos for remote villages and including women in trainings could be tested. Yet, as a field experiment in Uganda suggests, video messages are most effective when they touch on simple and profitable techniques for traditional crops. When new techniques or crops are introduced or beliefs have to be updated, more extensive extension methods are needed (Van Campenhout et al., 2017). Similarly, phone or internet-based extension services can potentially be more cost-effective, but for more difficult technologies only complementary (Aker, 2011), and the translation into adoption of improved agricultural technologies is still not widely understood (De Janvry, Sadoulet, et al., 2017).

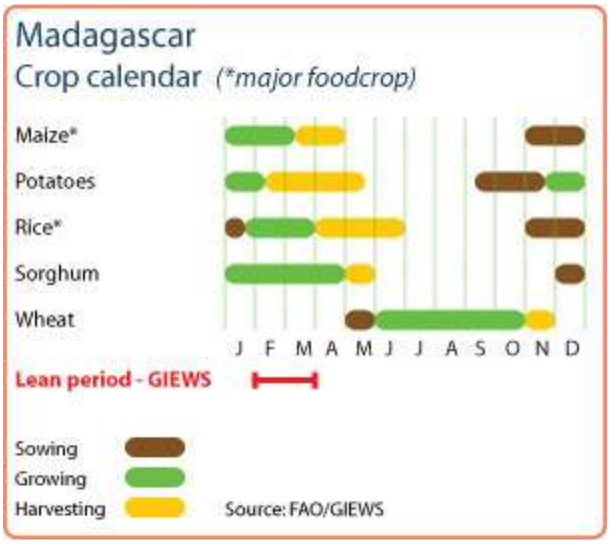
Testing the relevance of knowledge for the adoption of innovations yields some interesting insights. Knowledge as measured in our study is significantly and positively correlated with both innovations and *Bambara groundnut*. Bambara groundnut spread without extension effort and farmers were proud of innovating without help from outside. Qualitative innovation stories could therefore help to disseminate information on technologies and its costs and benefits and innovation contests could provide incentives to try out and share information on new technologies.

Yet, innovations much more than knowledge are embedded in social networks, and reflect norms within a village. The case of *Bambara groundnut* shows that due to the existence of foreigners who are not bound to local traditions, prevailing structures and beliefs are questioned and taboos can erode over time. Examples are the questioning of the practice of burning fields, and the strategy of the *Jatropha* management to exchange manure (selling manure is taboo) against housing materials. The possibility to observe others is especially important for riskier innovations, like improved seeds and other inputs, and credit subsidy programs, therefore we suggest to target these to farmers being able to experiment and demonstrate to others. As taboos play a big role in the adoption of new technologies, we recommend more participatory research, where technologies are developed together with farmers and successful adopters show the technique to other farmers on trial fields. Focus group discussions revealed farmers have difficulties in preparing land for cultivation, especially for cassava, maize and bean production, and reported to be willing to pay for tractor rental services to the *Jatropha* project. Since creating awareness without improving the access to inputs or output markets will not result in a widespread adoption, the public extension service could cooperate with the *Jatropha* project which is closer to farmers, for example in trials for new or improved varieties, or in collective storage and marketing, especially for poorer farmers without access to extension services or traders.

For future studies, different proxies for informal networks could be tested and instead of using the number of links the qualitative network structure of households could be taken into account and the process of information dissemination be described. The knowledge score was able to better explain innovations than a simple price estimation. Since production and consumption decisions are non-separable for the majority of households, we suggest to use broader knowledge and innovation scores for different crops, including livestock and other livelihood strategies. Value chain analysis could detect beneficial technologies for specific crops and its linkage to local markets, gender-disaggregated analysis and intra-household decision-making can shed light on entry points for extension services. Knowledge of perceptions and norms about the technology and its benefits could help understand innovation adoption decisions. Panel data are essential for incorporating (social) learning and belief updating, and field experiments could help in disentangling the mostly embedded social network and knowledge effects on innovation adoption, and in testing different extension methodologies.

Annex





Madagascar

Cereal production

	2009-2013 average	2013	2014 forecast	change 2014/2013
	000 tonnes			percent
Rice (paddy)	4 348	3 611	4 300	19
Maize	413	455	400	-12
Wheat	10	10	10	0
Others	1	1	1	0
Total	4 772	4 077	4 711	16

Note: percentage change calculated from unrounded data.
Source: FAO/GIEWS Country Cereal Balance Sheets

Taken from FAO (2014). GIEWS Country Brief Madagascar.

5 Adoption of an improved bean seed variety and consumption of beans in rural Madagascar: Evidence from a randomised control trial[14]

Abstract

This paper studies access to, and adoption of improved seed, as well as the diffusion of improved seed information in a remote area of central Madagascar. The analysis is based on panel data gathered from 2012 to 2014 from 390 households in three villages. In 2013, a randomised control trial was applied. Half of the 390 households were randomly assigned to receive improved lima bean seed (*Phaseolus lunatus*), which were specifically bred for dry regions. Of the seed-receiving households, 50% were randomly assigned to receive information on how to store, plant, and cultivate the improved seed, as the variety was unfamiliar in the region. The control group and the two treatment groups are compared with respect to baseline characteristics, bean cultivation, information exchange with other farmers, legume consumption, and willingness to pay (WTP) for improved bean seed. To account for non-compliance, contamination and spillover effects, local average treatment effects (LATE) are estimated. Of the seed-receiving households, 54% cultivated the seed, reaping an average yield of 6.3 kg per kg of seed obtained. Seed information did not lead to higher yields. A small significant positive impact of seed distribution on legume consumption is found. WTP is 171% of the local market price for bean seed, free provision of seed and information did not result in a higher WTP.

5.1 Introduction

Agricultural productivity in Madagascar is low due to climate hazards and limited adoption of improved agricultural technologies. This limited adoption is attributed to: labour and liquidity constraints at planting time (Moser & Barrett, 2003b, 2006); increased prices and high transaction costs for inputs due to remoteness and poor transport infrastructure (Minten et al., 2013; Stifel & Minten, 2008); and risk aversion, social conformity, and customs (Barrett, 2008; Barrett et al., 2004; Moser & Barrett, 2003b; Stifel et al., 2011). In addition to the low demand from farmers, low supply and the resulting limited access to agricultural inputs are constraints to adoption (Minten et al., 2013).

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This low supply and uptake of technologies has also been studied in the seed market and through the lens of seed aid as a disaster response (Sperling et al., 2008). Several authors (Alemayehu, 2009; Sperling & McGuire, 2010; Katungi et al., 2011a) argue that informal seed markets, while not fully understood, present a potential for more, higher quality, and more diversified seed. Establishing links between variety innovators and those who can multiply and distribute seed at affordable prices, is suggested. Newly created seed material could be delivered directly to important community-based nodes, instead of solely to parastatal and commercial entities (Gibson, 2013; Sperling et al., 2008).

Randomised control trials to study adoption and diffusion of improved agricultural technologies are increasingly popular (Banerjee & Duflo, 2008; Barrett & Carter, 2010; Duflo et al., 2008). Some of the experiments showed that rates of return of improved agricultural technologies, like improved seed or fertiliser, are not as positive in real world situations as they are in demonstration plots or controlled conditions (Bulte et al., 2014; Vandercasteelen et al., 2013). One study found positive impacts on yields, but not on profits (Beaman et al., 2013). Fixed costs, including the psychological costs of changing habits, might be substantial (Duflo et al., 2011). A growing number of studies is testing how information can best be disseminated among farmers (Culbertson et al., 2014; Hotz et al., 2012; Vasilaky, 2013).

Under- and malnutrition is prevalent in Madagascar, where 33% of the population is undernourished (FAO, 2015). Calories are mainly obtained from staple foods, such as rice and cassava. Given the poor diets, hidden hunger is widespread. The share of cereals, roots and tubers in Madagascar's dietary energy supply was 79% in 2011, which is by far the highest value globally. At 48 g per capita per day, protein intake is very low and is less than the average of all least developed countries (FAO, 2011b). Higher dietary diversity among Malagasy children is highly correlated with micronutrient intake (Moursi et al., 2008). Legumes improve diets by adding essential vitamins and minerals, especially iron, and are high in protein and dietary fibre (Aykroyd & Doughty, 1982).

The lima bean (*Phaseolus lunatus / kabaro* in Malagasy) is a perennial plant that achieves highest yields in the hot and humid tropics. Lima beans are tolerant to mild drought, high temperatures, and poor soils. In Madagascar, mean yield is one ton per hectare (Ministère de l'Agriculture, 2004). To raise yield and quality, a research station of FOFIFA (National Centre of Applied Research and Rural Development) in Toliara, southwestern Madagascar, is developing an improved variety (personal interview with FOFIFA representative, 2014).

Willingness to pay (WTP) can be defined as the amount of money an individual assigns to the benefits or costs of a particular product or service. WTP surveys have often been used to assess social benefits of environmental policies or projects. The application to private goods, like agricultural products, is rather uncommon, as these goods are traded in markets and have observable prices.

However, when it comes to the assessment of non-traded goods or value components that are not (yet) reflected by real market data, WTP surveys are a useful tool. Recent studies assess WTP for improved or certified seed (Dalton et al., 2011; Kaguongo et al., 2014; Kassie et al., 2014), traditional and locally produced foods (Chelang'a et al., 2013), fertiliser (Minten, Randrianarisoa, et al., 2007), and extension services (Ulimwengu & Sanyal, 2011).

This paper explores the impact of seed and seed information distribution on yield, willingness to pay and consumption, for the case of lima beans. The following research questions are addressed: (1) If seed is distributed for free, do households plant or consume it? (2) Does the inclusion of agronomic information with the distributed seed increase seed utilisation and bean yield? (3) How much are farmers willing to pay for improved seed? (4) Does the inclusion of agronomic information with the distributed seed increase the willingness to pay for improved seed? (5) Does seed receipt and bean cultivation increase legume consumption?

5.2 Materials and methods

5.2.1 Randomised control trial: sampling strategy and study design

The study was carried out within the framework of a household panel that ran from 2009 to 2014 in three villages in the community of Fenoarivo, which belongs to the district of Ambalavao in the Haute Matsiatra region (Figure 5.1). Fenoarivo is the local centre of administration, is connected with transport, and hosts a weekly market. The other two villages in the sample, Maroilo and Sakafia, are eight and twelve kilometres away from Fenoarivo, respectively.

Figure 5:1: Map of the study area

Baseline characteristics originate from a household survey that took place between December 2012 and February 2013. Bean seed was obtained from the research station of FOFIFA in Toliara and distributed during a second survey from September to November 2013. Of the 390 eligible households in the panel, 196 (50%) were randomly assigned to receive 0.6 kg of bean seed[15]. Of those, 84 (43%) were randomly assigned to receive detailed information on how to store and cultivate the seed, following recommendations by the Ministry of Agriculture (2013). It was recommended to plant the seed in April 2014 and to harvest in September/October 2014.

From November to December 2014, after the harvest of the beans, a follow-up survey and additional focus group discussions were carried out. Net-maps, a participatory, interview-based mapping technique developed by Schiffer & Hauck (2010), were used to enable participants to visualize and discuss the bean seed market, the actors involved, their linkages, their importance and influence, and their individual objectives, as well as existing knowledge about and attitudes towards improved seed. Because of the remoteness of the research area, not all actors involved could be present. Representatives of the agricultural extension service and the research station of FOFIFA in Toliara were interviewed separately.

[15] Households received 1.5 *kapoaka* of beans. *Kapoaka* is a common expression for milk tins used to measure amounts of various items. For beans, 1 *kapoaka* is equivalent to approximately 390 g.

5.2.2 Descriptive statistics

The baseline characteristics used in this study are variables that are expected to influence the adoption of lima bean seed and related production and consumption outcomes. In addition to demographic and agricultural characteristics, this includes information on innovations and social capital of the households. Innovations were elicited for five years prior to the interview and include dummies for five categories, namely crop diversification, technology adoption, access to new markets and traders, as well as innovations in work organisation, resulting in a score ranging from 0 to 5 innovations (Hartmann & Arata, 2011). The index on social capital comprises seven questions on trust, honesty, and willingness to help in the villages. Answers range from full agreement (1) to no agreement at all (5) on a Likert scale. The index is the mean of the seven answers. Attitudes towards work are elicited using the question "Can hard work improve your living standard?".

Some villagers have cultural taboos (*fady* in Malagasy) concerning certain bean types that prohibit consumption, cultivation, or talking about the beans, since they are believed to inhibit rainfall or successful prevention of cattle rustling. Common beans (*Phaseolus vulgaris / tsaramaso* in Malagasy) are widely cultivated in the area and not considered as taboo for the village fields. Apart from a climbing variety grown in home gardens, lima beans were an unknown bean species in the villages and it was unknown whether they are assigned with a taboo when grown in fields. Therefore, as a proxy, we use taboos for Bambara groundnut *(Vigna subterranea / voanjobory* in Malagasy*)*, a legume introduced from West Africa and widely believed to inhibit rainfall if cultivated in village fields.

In the follow-up survey, the following issues were examined in the control and the two treatment groups (seed-only and seed-and-information-receiving households): seed utilisation, problems during cultivation, the importance and diffusion of information, potential spillover effects regarding this information, evaluation of and WTP for improved seed, and bean consumption. For yield the seed multiplication rate is used as an operational proxy variable, given in kg per kg of seed. Lima bean and legume consumption data were elicited for different recall periods. Ravallion (2008) and Deaton (2010) recommend the use of intermediate indicators, in addition to outcome indicators, to understand the processes determining impacts. Descriptive statistics are based on the initial assignment of the households to the three groups. Statistical differences for categorical variables were determined with the help of chi-square tests, and for ordinal and interval variables with Kruskal-Wallis tests. The Wilcoxon rank-sum test served as the post-hoc test. All tests were done with STATA.

The contingent valuation method (CVM) is a survey-based method to elicit WTP which does not rely on experimental or real purchase decisions (Bateman et al., 2002; Whittington, 1998). Potential buyers are asked how much they would be willing to pay for the product contingent on a description of an alternative or a hypothetical scenario. Following Haab & McConnell (2002), enumerators described the benefits of improved bean seed (yield roughly twice that of locally available beans, higher pest and disease resistance, and higher drought tolerance) and explained the need to pay. Because lima beans were assigned with a taboo, households were given the choice between lima and common beans. Enumerators then showed the household a so-called payment card with a list of price ranges, ordered from lowest to highest. The lower bound was set roughly double the price of bean seed available at the local market. The household was asked to pick the range that included the maximum amount they were willing to pay. WTP is estimated by taking the mean value of these price ranges. Compared with open questions, the payment card has the advantage that it offers respondents a visual aid for the choice.

To check for the reliability of stated WTP, additional questions were included: “Do you think the seed would be available at the market?”, “What amount of seed would you buy for the indicated price?”, and “Would you be able to afford the seed at the indicated price?”.

5.2.3 Empirical strategy

Impact evaluation generally aims to assess a program’s effect against a counterfactual, showing the situation in the absence of the program (Ravallion, 2008; Rubin, 1974). Random assignment of households to a treatment group seeks to ensure that the control group is a valid counterfactual and allows simple comparisons of outcomes. If there are no differences in household characteristics between the control and treatment groups at baseline, any changes of outcomes can be attributed solely to the program. Significant differences in baseline characteristics could indicate a problem in the random assignment of treatment.

The average treatment effect (ATT) is the average gain of households from having received the seed, whether they received them from an enumerator or from another household, ignoring random assignment to treatment groups. By adding control variables, heterogeneity of impacts for observed control variables can be estimated as:

$$y_i = \beta_0 + \beta_1 treated_1 + \beta_2 treated_2 + \beta_{\mathrm{i}} x_i + \varepsilon_i$$

where y_i are the outcome indicators (lima bean yield, consumption, and WTP) $treated_1$ and $treated_2$ are dummy variables for seed and information received, β_1 and β_2 are the respective treatment effects, x_i are household characteristics at baseline, β_{i} the respective coefficients, and ε_i the error term (Ravallion, 2008). Ceteris paribus, the regression model predicts how a unit change in an explaining variable would increase (or decrease) the outcome variable. ATT is likely to be overestimated as it is subject to self-selection. Control households who received seed might differ from the average household, for example in bean production experience. The intention-to-treat estimate (ITT) approximates the average treatment effect on those intended to treat with random assignment:

$$y_i = \beta_0 + \beta_1 treat\_intended_1 + \beta_2 treat\_intended_2 + \beta_i x_i + \varepsilon_i$$

where $treat\_intended_1$ and $treat\_intended_2$ are dummy variables for the assignment to seed and information receipt. ITT is likely to be underestimated, as not all households intended to treat actually received, kept, and cultivated the seed. In the latter case, outcomes do not just depend on random assignment, but also on purposive assignment of others. Selective compliance and contamination into the control group can lead to biased estimates of the impacts of treatment. Imbens & Angrist (1994) showed that an average treatment effect under mild restrictions (local average treatment effect - LATE) can still be identified, even when there is no subpopulation for whom the probability of treatment is zero. Using assignment to treatment in a randomised trial as an instrument variable, LATE requires three conditions to be held: (1) eligibility for the treatment group has to be exogenous that is held under random assignment by the design of the study, (2) the use of an instrument requires an exclusion restriction, meaning that random assignment to treatment only affects outcomes through actual participation in the program, (3) anyone who would take the treatment if assigned to the control group would also take treatment if assigned to the treatment group. If these conditions are met, LATE is the average treatment effect for those households who always comply with their assignment and for those whose treatment status is changed by the instrument (Angrist et al., 1996; Ravallion, 2008). Instrumental-variable regressions are estimated with the help of the ivreg2 command in Stata (Baum et al., 2007).

5.3 Results

5.3.1 Baseline characteristics

Table 5.1 compares household characteristics at baseline between the two treatments (seed-only and seed-and-information-receiving households) and the control group. Because of randomization, we expect that there are no significant differences between the groups. This holds true for all variables, except for subjective wealth and the possession of cattle. Wealth is significantly correlated with cattle, an important status symbol in the region. The significant difference is based on two verified outliers with 20 cattle per capita that were assigned to control and seed-and-information-receiving group, respectively. In the 2012/2013 season, 83% of households planted one or more types of legume, and for the 34% that sold legumes in 2013, average sales amounted to 10.2 EUR[16]. Legumes are also important for consumption: in September 2013, they were consumed two days per week on average. The households who bought legumes at the market (27%) spent an average of 0.4 EUR per week. Almost half of the households reported a taboo for Bambara groundnut. However, by 2013, 38% of households were growing it.

Table 5.1: Household characteristics at baseline in 2012/2013

	Seed-and-information (n=112)		Seed-only (n=84)		Control group (n=194)		Total (n=390)	
Age of household head (years)	44.3	(12.5)	47.1	(15.4)	46.6	(14.0)	46.0	(14.0)
Education of household head (years)	4.5	(3.2)	4.1	(3.3)	4.2	(3.1)	4.3	(3.2)
Maximum education among household members (years)	6.3	(3.3)	6.1	(3.1)	6.8	(3.3)	6.5	(3.3)
Household size (n)	6.0	(2.4)	6.0	(2.5)	6.3	(2.8)	6.1	(2.6)
Household members in working age (n)	4.0	(1.8)	3.8	(2.0)	4.4	(2.4)	4.1	(2.1)
Dependents in household (n)	2.2	(1.4)	2.3	(1.3)	2.3	(1.4)	2.3	(1.4)
Legume consumption (number of days, past 7 days)	1.9	(1.7)	2.0	(2.0)	2.0	(2.0)	1.9	(1.9)
Dietary diversity (7 days)	43.1	(13.4)	44.7	(13.4)	44.0	(14.0)	43.9	(13.4)
Cultivated land per capita (ha)	0.4	(0.5)	0.3	(0.4)	0.3	(0.4)	0.4	(0.4)
Seasonally flooded land (dummy)	0.5	(0.5)	0.6	(0.5)	0.6	(0.5)	0.6	(0.5)
Wealth self-assessment (1-10)	4.0	(1.7)**	3.5	(1.4)	3.7	(1.7)	3.7	(1.6)
Cattle per capita (n)	1.3	(2.7)*	0.8	(1.3)	1.0	(2.2)	1.0	(2.2)
Agricultural equipment (dummy)	0.7	(0.5)	0.6	(0.5)	0.6	(0.5)	0.6	(0.5)
Bean production (kg per household)	27.6	(67.0)	29.0	(75.7)	28.3	(54.8)	28.2	(63.4)
Legume types cultivated (n)	1.5	(1.0)	1.5	(1.1)	1.5	(1.0)	1.5	(1.0)
Selling crops to trader (dummy)	0.9	(0.3)	0.9	(0.4)	0.9	(0.4)	0.9	(0.3)
Legume sales revenue (year, in €)	11.2	(37.1)	8.4	(17.7)	9.4	(34.6)	9.7	(32.3)
Innovations (number, last 5 years)	1.9	(1.0)	1.7	(1.1)	1.8	(1.1)	1.8	(1.1)
Taboo for at least one bean species (dummy)	0.5	(0.5)	0.5	(0.5)	0.4	(0.5)	0.4	(0.5)
Cultivation of Bambara groundnut until 2013 (dummy)	0.4	(0.5)	0.3	(0.5)	0.4	(0.5)	0.4	(0.5)
Attitude towards work (mean agreement, 1-5)	4.0	(1.0)	4.1	(0.8)	3.9	(1.0)	4.0	(1.0)
Social capital (mean agreement, 1-5)	2.8	(0.5)	2.8	(0.5)	2.7	(0.5)	2.8	(0.5)

Numbers in parenthesis indicate standard deviations. ** (*) indicates differences at the 5% (10%) significance level.

[16] Euro (EUR) values in this paper are converted from Malagasy Ariary (MGA) using official yearly averages: 1 EUR = 2,945 MGA (2013) and 3,273 MGA (2014).

5.3.2 Utilisation and cultivation of bean seed

Of the 390 panel households, 354 were revisited to evaluate the seed distribution. The remaining 36 households had moved away, or were not available in the survey period (table 5.2).

Table 5.2: Household attrition after baseline survey and seed distribution

	Seed-and-information	Seed-only	Control group	Total
Households in baseline survey (2013)	112	84	194	390
Households dropping out	6	12	18	36
Households in follow-up survey (2014)	106	72	176	354

At baseline in 2013, 88% of the 390 households stated planting the seed, if given, 1.2% would give the seed to another person, and 1.8% rejected the seed due to taboos or would cook them. In 2014, 98 out of the 354 revisited households reported having cultivated the received seed, mostly out of curiosity and with the objective of home consumption or as food for agricultural labourers. Seed-and-information-receiving households (n=55, 52%) were not significantly more likely to cultivate the seed than seed-only-receiving households (n=34, 45%). Nine control households (5%) reported having received lima bean seed from other sources (neighbours, family, friends) and cultivated these. Insect damage (50%), consumption of seed (41%), or taboos were reported as main reasons for not planting, with no significant differences between the groups. Three households reported having replaced other legumes; the remaining households said they cultivated the seed in addition to existing legumes. Women were more involved in bean cultivation than man, with no significant differences between the groups.

Seed quality, seeding, cultivation, and yield of lima beans were evaluated as better than average and better than other legumes. Control households planting lima beans perceived cultivation compared with other legumes to be significantly easier than treatment households. The average yield was 6.3 kg beans per kg of seed used. Taking out those households who did not achieve any yield (48%), gives an average yield of 12.2 kg per kg of seed. Control households planting lima beans achieved a significantly higher yield, whereas information provision did not result in a higher yield (Figure 5.2).

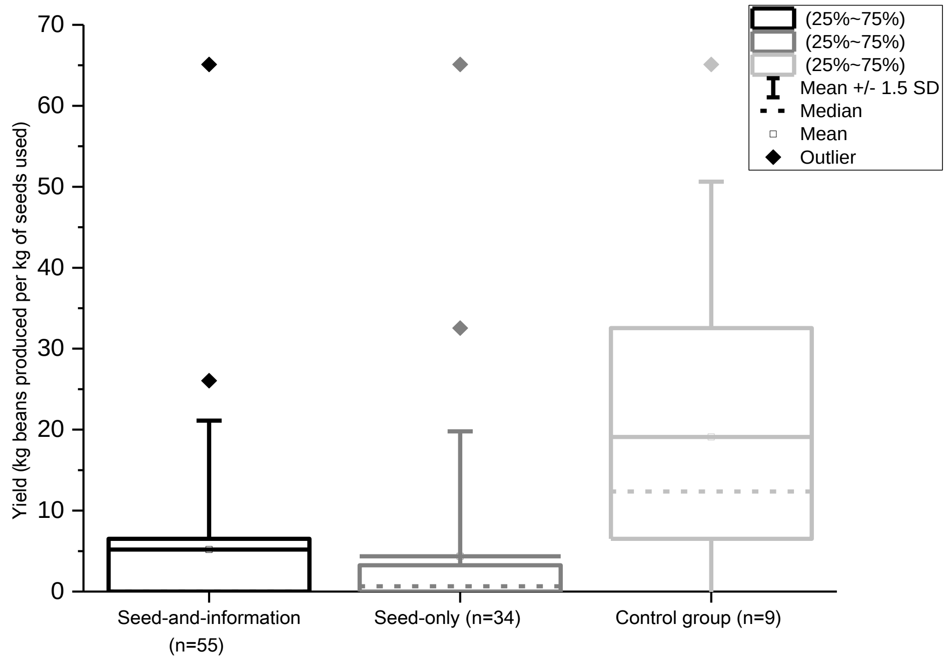

Figure 5:2: Yield of lima beans, 2014

The most cited reasons for low yield were drought and destruction of the plants by cattle or insects, with no significant difference between the groups. Of the legume-cultivating households, 63% rated climatic conditions for legumes in 2014 ‘much worse’ or ‘worse’ than in the past five years.

5.3.3 Information dissemination

Of the information-receiving households, 83% rated the given information as useful. For 80% of those households, the information was sufficient. Out of the seed-and-information-receiving group, significantly more households (20%) also received information from others, compared with 12.5% of the seed-only-receiving households. Households receiving additional information from sources other than the enumerators, achieved a significantly higher yield. Most reported information sources were family (49%), neighbours (43%), and friends (8%). Only 7% of the control households were informed about the new bean variety.

Significantly more seed-and-information-receiving households (74%) planted the bean seed on seasonally flooded fields next to a river or rice fields, as advised in the included information. Seed-only-receiving households planted mostly on other fields (62%), and the control households mostly next to the house (56%). Yet the planting location had no significant impact on reported bean yield.

Table 5.3 shows the impact of seed and information distribution on lima bean yield. The regression models do not predict a significant impact of information on yield. Adding control variables shows that next to seed distribution, a household's willingness to take risks and innovations are positive and significant predictors of yield. Dependency ratio and access to traders are negative predictors of yield.

Table 5.3: Local average treatment effect (LATE) of information provision on lima bean yield

	LATE		LATE with controls	
Seed-only	3.87	(2.1)*	4.29	(2.0)**
Seed-and-information	-1.45	(2.1)	-1.18	(2.0)
Age of household head (years)			0.07	(0.05)
Maximum education among household members (years)			-0.07	(0.4)
Dependency ratio (dependent members/members in working age)			3.40	(1.0)***
Gender of household head (dummy)			-1.14	(1.7)
Willingness to take risks (self-assessment, 1-10)			0.36	(0.3)
Cultivated land per capita (ha)			-0.80	(1.5)
Legume types cultivated (n)			0.28	(0.6)
Selling crops to trader (dummy)			-4.15	(1.9)**
Innovations (number in the last 5 years)			1.29	(0.6)**
Adjusted R^2				0.12
N				354

Numbers in parenthesis indicate standard deviations. *** (**) (*) indicates significance at the 1% (5%) (10%) level.

5.3.4 Consumption

Almost all households (98%) reported consuming their harvested beans. Seven households saved seed for the next cultivation period and two households sold parts of their harvest. No significant differences with respect to the use of the harvested crop between the three groups could be detected.

Of the 354 households, 45% stated having eaten lima beans in the past year. Control households were significantly less likely to consume lima beans than treatment households were. No significant differences could be detected when looking at legume consumption in general in the week prior to the interview (table 5.4).

Table 5.4: Consumption of lima beans and legumes, differentiated by recall period, 2014

	Seed-and information (n=106)		Seed-only (n=76)		Control group (n=172)		Total (n=354	
Lima bean consumption (dummy, 12 months)	0.6	(0.5)***	0.6	(0.5)***	0.3	(0.4)	0.5	(0.5)
Legume consumption (dummy, 12 months)	0.9	(0.4)	0.8	(0.4)	0.8	(0.4)	0.8	(0.4)
Legume consumption (n, 7 days)	3.2	(2.4)	3.4	(2.5)	3.2	(2.5)	3.3	(2.4)
Legume consumption from own production (dummy, 7 days)	0.7	(0.5)	0.8	(0.4)	0.7	(0.5)	0.7	(0.5)
Expenditures for legumes (€, 7 days)	0.1	(0.3)	0.1	(0.3)	0.1	(0.3)	0.1	(0.3)

Numbers in parenthesis indicate standard deviations. *** indicates difference at the 1% significance level.

Table 5.5 shows the impacts of seed distribution on the frequency of legume consumption in the past seven days before the interviews. When controlling for household characteristics, a significant positive impact of seed distribution on legume consumption is observed.

Table 5.5: Local average treatment effect (LATE) of seed distribution on legume consumption

	LATE		LATE with controls	
Seed-only	0.63	(0.47)	0.89	(0.5)**
Seed-and-information	-0.49	(0.47)	-0.67	(0.5)
Education of household head (years)			0.03	(0.1)
Dependency ratio (dependent members/members in working age)			-0.28	(0.2)
Gender of household head (dummy)			-1.04	(0.4)***
Agricultural equipment (dummy)			-0.57	(0.3)*
Crop diversity (number of different crops)			0.11	(0.04)***
Selling crops to trader (dummy)			-0.47	(0.4)
Livestock sales (dummy)			0.48	(0.3)*
Income from own business (dummy)			-0.79	(0.3)***
Income from agricultural labour (dummy)			-0.85	(0.3)***
Access to mutual help (dummy)			0.50	(0.3)
Adjusted R^2				0.05
N				354

Numbers in parenthesis indicate standard deviations. *** (**) (*) indicates significance at the 1% (5%) (10%) level.

5.3.5 Willingness to pay

More than half (58%) of the farmers stated they usually produce their own legume seed, 30% of the farmers said they usually buy their seed at the market, 10% buy them from other farmers, and the rest mostly receive seed from family members. In total, at least once in the last five years, 49% of all households cultivating legumes bought seed at the market, 64% used their own seed, and 21% bought from other farmers in the village. The net-maps compiled during focus group discussions in 2014 (Figure 5.3) show the most important seed and information sources.

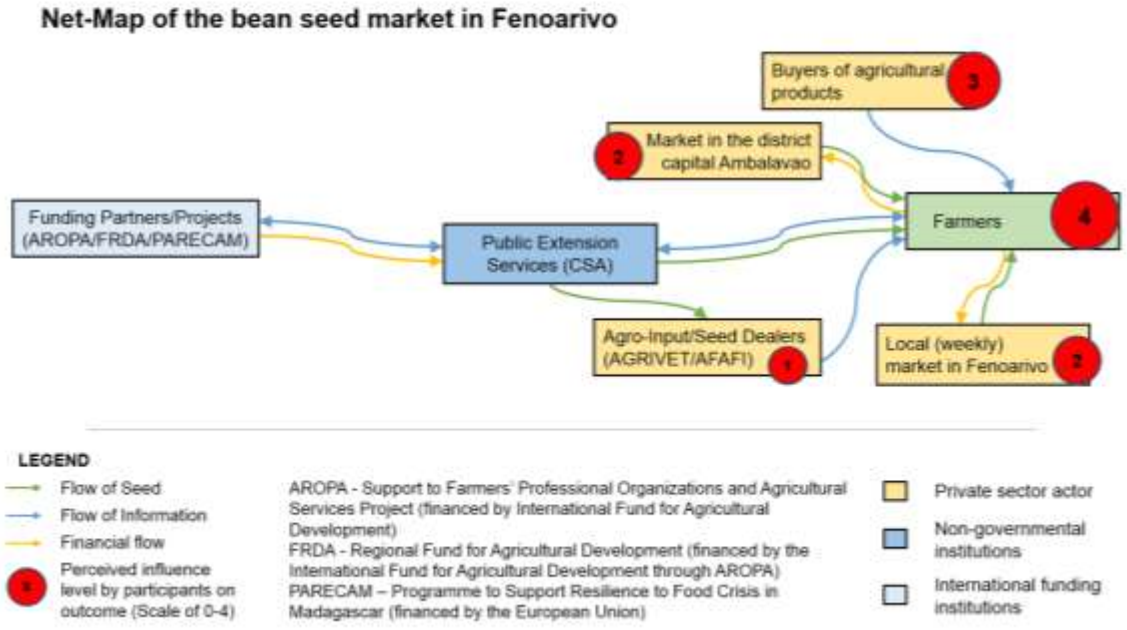

Figure 5:3: Exemplary net-map of the bean seed market in Fenoarivo

The Malagasy agricultural extension service, Centre de Services Agricoles (CSA), an NGO funded by the European Union and managed by local officials, is distributing improved seed to farmers. It aims to increase agricultural productivity by linking service demands of farmers with appropriate service providers, operating in the rural districts, and training village representatives (Ministre auprès de la Présidence chargé de l'Agriculture et de l'Elevage, 2015).

In the district capital Ambalavao, CSA provides free samples of improved rice and bean seed, for which farmers can apply directly or indirectly through local administration with a written contract. In 2013, very few farmers knew about this possibility and none had received seed. There are also problems on the supply side: those who had applied for improved seed were told that reserves had already been exhausted. On the local market, there is no improved seed. Due to a breeding and dissemination project on improved common beans, a farmer who is being trained as village representative of CSA understood yield and quality advantages of improved bean seed.

When asked about the importance of seed traits, farmers listed yield and potential for sale, followed by taste and ease of cultivation as most important. Pest and disease resistance and drought tolerance were not highly ranked by most households. Results from focus groups showed that the majority of households were unaware of the possibility of breeding resistant and tolerant seed. It was stated that improved seed is properly sorted, thus the biggest and least damaged seed.

According to focus group discussions and information from traders at the local market, a reference value of 0.2 EUR was chosen, the average price for local bean seed. Mean WTP of all households amounts to 0.3 EUR/*kapoaka*, which is 171% of the reference value (premium of 42% compared with the average bean price). Interviewees stated a higher mean WTP for common bean seed than for lima bean seed, the differences between species and between treatment and control households were not significant.

Almost two-thirds (63%) of respondents thought it was likely that improved bean seed would be offered at the market in Fenoarivo, and 60% that they could be offered at their stated WTP. The majority (86%) of households thought it was likely that they could afford the bean seed at their stated WTP. No differences between treatment and control households could be detected.

No significant impact of either seed or information on WTP could be observed in the regression models (table 5.6). Positive predictors of WTP were: additional information sources on improved seed, cultivated land area, social capital, willingness to take risks, and household wealth. Legume consumption was a negative predictor.

Table 5.6: Local average treatment effect (LATE) of seed distribution on willingness-to-pay for improved seed

	LATE		LATE with controls	
Seed-only	-62.25	(42.8)	-48.40	(38.0)
Seed-and-information	3.89	(42.9)	-32.73	(37.7)
Information from other sources			123.85	(34.4)***
Age of household head (years, squared)			0.01	(0.01)
Maximum education among household members (years)			-1.46	(7.1)
Gender of household head (dummy)			-41.4	(31.6)
Dependency ratio (dependent members/members in working age)			5.42	(18.5)
Willingness to take risk (self-assessment, 1-10)			35.29	(4.9)***
Subjective wealth assessment (1-10)			11.82	(7.1)*
Cultivated land per capita (ha)			59.91	(27.2)**
Mutual help (dummy)			49.70	(28.1)
Selling crops to trader (dummy)			48.41	(35.2)
Frequency of legume consumption (number of days, past 7 days)			-10.94	(5.8)*
Social capital (mean agreement)			24.92	(13.0)*
Positive attitude towards work (mean agreement)			4.09	(11.0)
Adjusted R^2				0.20
N				350

Numbers in parenthesis indicate standard deviations. *** (**) (*) indicates significance at the 1% (5%) (10%) level.

Of all households, 40% stated that they would purchase lima beans for consumption and 49% said being interested in cultivating the beans. Seed-and-information-receiving households are significantly more likely to buy and cultivate lima beans in the future than the two other groups. The majority of households would prefer to buy improved seed in March (217), February (54), and April (31), and at the local market rather than from other farmers or the extension service.

5.4 Discussion

5.4.1 Utilisation and cultivation of lima bean seed

Although seed utilisation rates (55%) seem low, they are comparable to other areas in Madagascar. Snoeck (2016) reported for the northeast of Madagascar that about one out of two freely distributed improved clove seed has been planted. Moser & Barrett (2003b) reported an adoption rate of only 25% for improved rice technology (SRI) over a period of five years for different sites in the island's central and southern highlands. Utilisation rates were affected negatively by limited storage possibilities and long storage time, as seed was distributed six months before sowing time. This might have led to the high number of households reporting that insects destroyed their seed. Taboos against beans were a significant hindrance to utilisation. Some households who were intended to receive seed rejected it, and were not willing to cultivate, eat, or talk about them, while others wanted to keep them for consumption. This confirms that social conformity in Madagascar limits adoption of new varieties and technologies (Moser & Barrett, 2003b). The adoption process of Bambara groundnut shows that it might take some years, but that if beliefs are updated, taboos can be overcome. After its introduction at a nearby large-scale Jatropha plantation and by some innovative farmers, villagers realised that rainfall had been unaffected and started planting the beans.

Seed was planted mostly by older family members in home gardens with the objective of contributing to household consumption. The seed quantity distributed was low and unlike in the Toliara region, farmers do not have access to lima bean markets. According to focus group discussions, reliable access to markets would increase investments in agricultural production. The maximum production obtained was 65 kg, which is very close to the yield expectation of FOFIFA (43 - 69 kg of beans per kilogram of seed). Households with an above-average lima bean yield were more experienced in bean production at baseline and also cultivated Bambara groundnut. Seed-receiving households unwilling to cultivate might have given their seed to people they knew were experienced in bean cultivation. Prior to the seed distribution a climbing lima bean variety was known in the villages and grown by some farmers in home gardens, and in home gardens people might spend more time weeding and watering and therefore achieve a higher yield.

5.4.2 Information dissemination

Information-receiving households did not have significantly higher cultivation rates or lima bean yields than their seed-only-receiving counterparts. Seed-only-receiving households, however, were more likely to consume the seed at the beginning of the lean season and not take the risk of keeping them until the planting season. Information-receiving households might have kept the seed with the intention to plant them, pointing to the importance of information dissemination.

As illiteracy is still widespread in the region, information was given verbally only, thus households were not able to look up information that they might not have remembered at sowing time. Lima beans had not been planted before in the villages, there was no local contact person to consult, and the nearest place to access information was in the district capital. Households with above-average yield recalled or knew more information concerning lima bean cultivation. One reason for the rather low information dissemination from information-receiving households to others might have been that lima beans were considered taboo by some households, and it is common to avoid talking about taboos. Furthermore, the distributed information did not target the most mentioned problems, drought and destruction of the plants by cattle or insects. Interestingly, out of the seed-and-information-receiving households, significantly more households also received information from others, thus were more likely to discuss and to be consulted by others. FOFIFA Toliara is training technicians from farmers' organisations in lima bean cultivation, who are then responsible for disseminating this expertise to farmers in their organisations. Hotz et al. (2012) found that group-level trainings in nutrition and cultivation of orange sweet potato had a significant impact on production and consumption of rural households in Mozambique. One-year and three-year interventions were found having the same significant impact on vitamin A intake, suggesting that group training could be limited to the first year of intervention.

5.4.3 Consumption

Bean seed distribution did lead to a small, but significantly higher legume consumption for the seed-only-receiving households. Additional information provision did not lead to higher legume consumption, which might be due to the lower achieved yield of this group, and due to the possibility that households had already consumed their supply by the time of the interview. A trader at the market confirmed that after the seed had been distributed, he sold lima beans originating from the region of Toliara. This might explain the high percentage of control households having consumed lima beans, also because only two households sold part of their harvest. Larochelle et al. (2015) found that adoption of improved bean seed in Uganda led to increased dietary diversity through the channel of home consumption, and indirectly through farm income, productivity, and empowerment of women. Because beans are mainly cultivated by women, the authors hypothesize a positive effect for dietary diversity as women might have control over bean sales and, therefore, might be in a better position influencing household nutrition outcomes. Similarly, Kabunga et al. (2014) showed that fruit and vegetable production led to significant improvements in household nutrition. Although many studies support the hypothesis that household agricultural production is correlated with household and individual consumption, the evidence for a pathway from agriculture to nutrition is mixed. Types of food (especially when comparing crops and dairy products), context, and location cause the effects to vary greatly in size (Carletto et al., 2015). According to Sibhatu et al. (2015) the effect of crop and livestock diversification on dietary diversity diminishes with farm size, probably because of foregone benefits from specialisation for already diversified farms.

5.4.4 Willingness to pay

Mean WTP for improved bean seed was estimated at 171% of the market price for traditional seed or at a premium of 42% compared to traditional seed. This result is comparable to other studies. Kaguongo et al. (2014) valued certified potato seed in Kenya, where farmers on average are willing to pay 190% of the price of farmer seed for certified seed, and 170% for clean seed. Chelang'a et al. (2013) found that consumers prefer African leafy vegetables to exotic ones and are willing to pay an average premium of 79%.

The FOFIFA research station sells its improved lima bean seed to farmers at a price of 1.2 - 1.5 EUR per kilogram (0.5 – 0.6 EUR/*kapoaka*). Seed originating from farmers' own seed production ranges from 0.5 – 0.6 EUR per kilogram (0.2 EUR/*kapoaka*) with regional and seasonal differences (personal interview with representative of FOFIFA, 2014). Comparing these prices with WTP from this study, farmers cannot or do not want to afford improved seed directly from research stations, but would be willing to pay a premium for farmer's own produced seed. FOFIFA had a similar experience in the Toliara region when marketing their improved bean seed to farmers' organisations (personal interview with representative of FOFIFA, 2014). As the case of AfricaRice in the Antsirabe region shows, bean seed could be marketed through participatory varietal selection (personal interview with representative of AfricaRice, 2015).

An interesting result is that 87% of households answering the WTP question chose the familiar common bean over the lima bean, when asked which of the two they prefer to buy. An explanation for this can be that households selecting lima beans were significantly more willing to take risks, regardless of whether they were successful in cultivating the seed or might have been disappointed by their experience. Risk aversion was also associated with a significantly lower WTP for weather-index insurance (Hill et al., 2013). Common beans are not taboo in the village fields, therefore taboos for lima beans and consequent social pressure might have played a role in this decision.

Households who received additional information on improved lima bean seed reported a significantly higher WTP. This aligns with the study of Kaguongo et al. (2014) where farmers' awareness of seed quality had a positive impact on WTP. Cultivated land per capita and subjective household wealth increase WTP significantly. Ulimwengu & Sanyal (2011) also indicated that the amount of land owned and the income level increased farmers' WTP for agricultural services. Legume consumption is a negative predictor, suggesting that households cultivating legumes mostly for home consumption are willing to invest less in inputs. Similarly to Kaguongo et al. (2014), remoteness to markets does not result in a lower WTP neither does proximity to markets increase WTP. Contrary to Chelang'a et al. (2013), gender, education, and dependency ratio have no significant influence on WTP.

Whittington (1998) summarizes potential biases of WTP studies. Both overstatements due to prestige effects and understatements due to consumers trying to influence the final price can occur. As in this study no data on the purchasing of improved beans is available, these biases cannot be ruled out. To minimize hypothetical bias, which is the difference between stated and revealed values, lower bounds were set for the payment card, but with an effort to keep a realistic range of prices from which households could choose (Murphy et al., 2005).

Contrary to the results of Bates et al. (2012) that receiving a product for free increased peoples' WTP for it later, in this study neither seed distribution nor information provision increased WTP. Insect damage, low yield due to climatic conditions, and not following cultivation recommendations may be to blame. Households planting the bean seed might have had higher expectations or might have been disappointed by the performance of the seed. CRS et al. (2013) discuss the downside risk of free distribution of seed in Madagascar. Institutions are still buying the largest amount of seed, which is hindering the development of a sustainable private sector serving smallholder farmers.

5.5 Conclusions and recommendations

This study leads to several conclusions and recommendations both for future research and for program implementation by state agencies and non-governmental organisations.

The amount of seed distributed to households was small and only 54% of the seed-receiving households cultivated the lima bean seed. Of those, 48% reported zero yield, mainly due to drought. Seed information did not increase cultivation. Taboos played a role, as did insect damage due to the long storage time. A timely distribution of packaged seed could avoid those problems. Local seed could be tested in comparison to improved seed on demonstration plots of farmer field schools, so that farmers could experience the differences. Similarly to FOFIFA Toliara, some farmers could be trained in the use of improved seed and other agricultural technologies and given incentives to disseminate this knowledge to farmers in their organisations and villages. CRS et al. (2013) suggest participatory varietal selection, decentralised seed production (by farmers or farmers' associations), low-cost delivery mechanisms (e.g. through village committees or with the help of radio programs), and technologies to minimize storage losses. These results also strengthen importance and need for public extension services in rural Madagascar. We recommend participatory community-level interventions that match farmers' needs and focus not only on technological issues in introducing new varieties, but also allow to consider social processes that hinder innovations. Net-maps compiled during the focus group discussions turned out to be a helpful and easy-to-implement tool, as participants learned about the breeding program of the Ministry of Agriculture and the possibility of obtaining improved seed from the extension service.

Seed information did not increase yield. Reasons for low yield are climatic conditions as well as crop losses due to insects and cattle. The explanatory power of the factors determining lima bean yield is low, suggesting that unobserved factors, like cow dung application, irrigation, plot-specific rainfall during critical times of bean growth, or time invested played a role. If cultivation is more closely monitored, inputs used or problems during cultivation could be used as intermediate indicators to better explain yield variances. Local representatives could be trained in storage and cultivation techniques and serve as contact persons for households in case they have questions or encounter problems. This would allow for information sharing on topics that initial information provision cannot address. Group training sessions or demonstration plots could give impetus to information dissemination. As mostly women are responsible for bean production, female contribution and knowledge sharing at the demonstration plot and effects on cultivation and decision making could be tested. Information diffusion via videos or visual aids containing pictures and short sentences could be tested. While targeting farmers, the extension service could cooperate with schools. Educating children in agricultural production processes and the agricultural market might lead to long-term benefits and to more participation of the rural population in development programs.

A small positive effect on legume consumption was found. As unobserved factors, like food or cooking preferences or taboos might have played a role, cooking and nutrition information should be included during the dissemination of new varieties (Katungi et al., 2011b).

Neither seed distribution nor information provision increased WTP. The training of a local farmer in the commune has shown to be an effective means of disseminating knowledge about improved inputs from the extension service to the village, however no improved seed has been supplied yet. Given the poor infrastructure and high poverty rates, as well as market failures in a remote and underdeveloped setting lacking cash crops, continued state and non-governmental organisations support might be justified.

6 Discussion and conclusions

In the last decade, Madagascar has experienced political crisis and instability with severe effects on peoples' livelihoods, which were already characterised by high poverty and food insecurity rates. Against this background, high hopes were held with regard to foreign investors who next to contributing to economic growth also promised to contribute to much needed investments in infrastructure and rural development. Given the remoteness and insecurity of the study area and the high wage work offer, manifold spillover effects were expected. This thesis explored the linkages between wage work on the Jatropha plantation and household food security, and spillovers to agricultural and food production through the pathway of better access to information, higher capacity to adopt innovations in the agricultural value chain and the use of improved agricultural inputs. These topics were addressed by four research questions and corresponding hypotheses. The three preceding chapters contain the analysis with regard to these questions. The purpose of this chapter is to summarize and discuss these findings, highlight shortcomings as well as implications for rural development policies and identify the potential for future research.

6.1 Discussions of research findings and policy implications

The first research question is about the quantification of the relationship between labour income earned by smallholder farmers in a Jatropha biofuel plantation and their food security. The results clearly show that Jatropha work leads to improvements in access to food and dietary diversity. However, Jatropha incomes did not reduce the prevalence of food shortage and Jatropha households saw a significant decline of their rice stocks from 2008 to 2013. This might hint to time constraints between working on the own farm as opposed to earning wage labour income on the Jatropha plantation. Since Jatropha households are poorer, i.e. they own less land and cattle, and have less access to other income sources, it might also indicate other constraints to food production, e.g. access to fertile land and equipment. A benefit that was mentioned by Jatropha workers was the improved access to credit. Obviously, local lenders were willing to lend more to Jatropha workers as they were known to earn a cash salary. Results show that in the 5-year period from 2008 to 2013, Jatropha workers took more credit than control group households did. Yet, Jatropha households took significantly more credit for food and less for productive investment. Mostly rice is borrowed on credit for consumption or seed, and the common practice is to give back the double or triple amount after harvest. If the harvest does not allow for that, rice fields or cattle change their owners. Richer households are less likely to borrow money, they rather would sell agricultural produce or cattle. They also invested more in productive assets, like land and livestock and increased and diversified agricultural activities to reap the increased purchasing power of Jatropha households. In this regard, Jatropha incomes contributed to a decreased income inequality but did not reduce inequality in access to assets. Given that some households reported that the willingness to help within social networks declined due to the wage work offer on the plantation, those who are not able to work, e.g. old-age or handicapped people, might become more vulnerable to poverty. This might also hint to a possible debt trap for food-insecure households, and suggests that improving access to formal credit and complementary social protection or development programs to increase and diversify household food production targeted to these poorer households might further increase food security.

Regarding the first research question and hypothesis, that employment for the labour-intensive production of Jatropha can provide an additional income source for poor households, I shortly discuss similarities of Jatropha work with cash-for-work and cash transfer programs: The Jatropha project led both to a high employment offer and to a significant amount of cash input in a rather subsistence-oriented and non-monetized rural economy. Poverty in Madagascar has been shown to create a vicious circle leading to a poverty trap by Thomas & Gaspart (2015), who recommended short-run policies including safety nets, cash transfers, cash-for-work, and short-term credits. Social cash transfers in several Sub-Saharan African countries have been found to lead to positive and significant production spillovers (Thome et al., 2013; Tirivayi et al., 2016). Given that these programs target asset-poor and labour-constrained households, production increases occurred for non-beneficiary households (Thome et al., 2013), incentivized by higher expenditures of cash-receiving households.

The results of the first article of this thesis show that Jatropha incomes could only partially mitigate price and natural shocks, and lower food availability. Given the low income effects estimated in former studies (Bosch & Zeller, 2013; Grass & Zeller, 2011) these effects might have been too small for farmers to invest in productive like land and cattle. Moreover, for rice cultivation in Madagascar, Minten et al. (2007) show that in general it is sensitive to climatic shocks, and that the poorest income quintiles experience 2-3 times higher yield decreases than the richest quintiles in the wake of a shock, probably due to constraints in irrigation, water pumps or labour hiring. As a consequence of input and output market imperfections, but also of the importance of customs, e.g. sacrificing cattle for ceremonies, with negative impacts on soil fertility and rice productivity, Barrett (2008) argues that there exists a resource degradation poverty trap in Madagascar.

Agrofuel production by using marginal lands might therefore be an effective strategy to escape this poverty trap, especially when allowing for impact pathways contributing to increased soil fertility and crop productivity. The Jatropha project uses cattle manure for the cultivation of Jatropha plants, which in the long term might contribute to a higher manure application also on farmers' fields. In this regard, other studies in Madagascar have for instance found significant effects on compost application in the framework of vegetable production contracts. Against this background, Jatropha outgrower schemes (e.g. as hedges around fields) might lead to better outcomes, in terms of reducing soil erosion and increasing soil fertility. This however, needs an improved institutional framework, established value chains, extension services to farmers and the provision of improved Jatropha planting material and related inputs to overcome the above-mentioned market imperfections and could be complemented with efforts promoting locally available strategies increasing soil fertility.

With regard to the second research question, this thesis could confirm the hypothesis that Jatropha workers had better access to information while working on the Jatropha plantation, and that this information on agricultural production technologies and market opportunities disseminated to the villages. As shown in chapter 4, the hypothesis that Jatropha households are more aware of market opportunities and improved technologies, and that they diffuse this knowledge in their villages, can clearly be confirmed. Especially information on the cultivation of the profitable but former taboo legume variety, Bambara groundnut, was disseminated from Jatropha workers to farmers. This suggests that providing farmers with the opportunity to observe costs and benefits of technologies and facilitating information exchange between farmers can enable learning without the production risks involved and support the adaptation of innovations to local conditions and norms.

The second hypothesis to be tested within chapter 4 of this thesis was that the knowledge and the incomes generated from plantation work contribute to investment in agriculture and the adoption of agricultural innovations. This can be clearly confirmed for the cultivation of the legume Bambara groundnut, where I show with the help of a proxy variable, being the number of Jatropha households in the network, that having more Jatropha households in the network significantly increases the likelihood of cultivating the legume. Jatropha households themselves however were not more likely to cultivate it. A reason might be that in the village which provides the majority of Jatropha workers, norms and taboos are stronger and more persistent. For instance, next to holding off rain, Bambara groundnut in this village is also associated with cattle thefts and villagers were very proud of successfully preventing any theft in the last decades.

For other innovations reported, like line planting for rice, and processing and commercializing of agricultural products, this thesis could not find an impact pathway, neither through Jatropha incomes nor through information dissemination through Jatropha workers. However, better-off households who do not work on the plantation were motivated by the higher purchasing power, the improved security in the area and the higher presence of foreigners and traders to invest in agricultural production. Jatropha households, next to assuring food security for the household, needed to make several investment-related decisions, e.g. regarding education, health, and housing. Livelihood strategies, which lead to higher returns, like land or cattle, involve high initial investments (like land clearing and soil preparation), opportunity costs, or substantial risks (like climatic shocks or cattle losses) for farmers. Other studies provide insights in constraints of land investment, for instance in the highlands of Madagascar, unclear land rights and a lack of technologies and capital lead to the situation that land remains idle despite the fact that households would benefit from land expansion

(Radison et al., 2008). Barrett (2006) showed that returns on assets depend on the initial wealth of farmers in the highlands of Madagascar. Poor farmers choose low-risk and low-return strategies, and reduce their consumption to smooth assets after shocks. A study on agricultural investment decisions in Northern Ghana shows that by providing rainfall insurance to smallholder farmers, that uninsured risk is the key hindrance to investment, not financial constraints (Karlan et al., 2014). Even for the the Lac Alotra region, the main rice producing region in Madagascar, Stoudmann et al. (2017) found that coping and adaptation methods of farmers to respond to climatic shocks are mostly ex-post income diversification strategies and by no means sufficient to cope with changes.

As explained in chapter 4, this study used a very broad definition of innovations. The cultivation of Bambara groundnut is a simple diversification strategy but due to the former existing taboo represents a significant innovation. Only looking at the adoption of modern technologies might therefore underestimate farmers' innovation capacity. Innovative and better-off farmers stated continuously that their adopting and adapting of technologies was not induced by a development project. This suggests that strengthening innovators in their capacity to access, test and adapt technologies, might improve access to locally beneficial technologies and enhance dissemination of innovation. Participation in collective action, e.g. restoration of school buildings, is very high in the villages. Since organisation of farmers is also a requirement for access to extension trainings, strengthening collective action might improve this access as well as facilitate community-based climate change adaptation strategies. In the long-term, investments into education and extension to farmers might lead to a higher adoption of improved agricultural technologies. For instance, for a community-based nutrition project in Madagascar, Galasso & Umapathi (2009) found that nutrition knowledge was best translated into child care practices and nutrition outcomes when the mothers did not belong to the poorest and least educated population groups. If these technologies increase labour productivity, poorer farmers would also benefit from increased employment. Targeting especially poorer and less-educated farmers with a combination of income-increasing programs and asset- or productivity-increasing programs might lead to outcomes that are more sustainable.

As shown in chapter 4, the most adopted innovation in our sample was crop diversification, a livelihood strategy with possible beneficial effects on income creation and nutrition. Lowland rice production in the research region is constrained by climatic factors. Cultivation and marketing of cassava represents a high potential in reaching and impacting the poor, since the crop is mostly cultivated and consumed by the poor(compare Randrianarisoa & Minten, 2001). During fieldwork, it became apparent that especially women started cultivating and selling vegetables. Moreover, for vegetable cultivation a higher input use was observed. Especially for tomato and leafy vegetables, improved seeds and insecticides are available and bought at the market in Fenoarivo. Chicken or cow dung, which is taboo to use on other fields, is readily used in home gardens for vegetables. Another study in Madagascar found that while improved rice growing technologies were not readily adopted by farmers because of labour and capital constraints in the rice planting season, a majority of the same farmers had adopted cash-intensive vegetables in the rice off-season, when cash and labour is not a constraint (Moser & Barrett, 2003b). The promotion of value chains especially in the lean season might therefore be a promising intervention for increasing nutrition and income. Moreover, value chain approaches for specific crops might give insights into the reasons for the low farm gate prices and might offer entry-points for policy strategies or institutional innovations like producer organisations to share some production and market risks and increase benefits for smallholders.

The fourth research question explores one specific hypothesized spillover from the Jatropha project to agriculture, the increased use of agricultural inputs. I hypothesised that seed and seed information provided to farmers relaxes information, financial and supply-side constraints farmers face concerning the use of agricultural inputs. Apart from contributing to filling the knowledge gap on the very low use of agricultural inputs in Madagascar, this study applied a randomized control trial in the field of agriculture. More than half of the households, who received the improved legume seed, cultivated the seed and increased their consumption of pulses. Seed was distributed in the lean season; therefore, household preferences for present consumption might have played a role in a high number of households consuming the seed in the lean season instead of cultivating it and benefiting from it in the future. Taboos concerning legumes led to a high number of rejections of the seed. Information was not always followed, since manure application is taboo for many households and watering not always possible. Moreover, insect damage and lack of rainfall in a critical period contributed to low yields. This shows that even when seed is freely provided, farmers face other constraints in adopting new technologies. Other studies in Madagascar have shown that the presence of extension agents can increase the adoption of improved technologies, therefore participatory breeding and community-based seed production would likely lead to higher adoption and higher productivity increases. For instance, for a mining project and an accompanying agricultural productivity-enhancing project in Madagascar, Andrianaivoarimanga (2017) found that extension and provision of equipment and inputs led to an increase in rice yields and self-sufficiency. However, after the end of the extension, these gains were gradually lost again, indicating that the positive effects were mediated not only through the provision of equipment and inputs but also through the presence of extension agents.

Based on this result, strengthening local representatives of extension services could lead to higher information dissemination from extension services to farmers, a broader participation in farmer groups and a higher adoption of beneficial innovations. From a political perspective, either policies or market-based incentives to investors to contribute to agricultural development could increase technology adoption among farmers. These insights could help in establishing links between the insufficiently funded research institutes, extension services and innovative farmers in more remote regions. Since it is not feasible for the agricultural research institutes to send staff to remote villages, innovative extension services, e.g. through videos (see chapter 4) could help in reaching farmers.

The Jatropha project could test improved seed from research stations and disseminate to workers as part of their salary. As well, offering tractor services for the preparation of additional land would allow poorer households with less land to increase their agricultural production. To overcome market imperfections, the Jatropha project could also be an intermediary for collective input purchasing, storage and output marketing.

Other authors pointed to more sustainable outcomes when agricultural development programs are jointly implemented with asset- and income-increasing programs. For instance, an impact assessment of food and cash transfer programme in Ethiopia found that impacts on food security, livestock holdings and productive assets are higher the more years the household participated in the program. For the adoption of stone terracing, fencing and water harvesting, the additional participation in other programs relying on extension services and credit for adoption packages were relevant (Berhane et al., 2011).

Not accounting for indirect effects of large-scale land investments and focusing only on households offering labour to plantations might underestimate the spillover effects to smallholder agriculture or overlook more long-term effects. Villagers reported that deforestation is contributing to climate change and land degradation, and had observed an increase in rainfall due to the afforestation with Jatropha; an interesting effect of large-scale tree plantations which has been further investigated by Wulfmeyer et al. (2014). Moreover, the Jatropha project is creating awareness on the negative impacts of bushfires on soil erosion.; Bush fires in the central highlands of Madagascar are mostly used by cattle owners for pasture maintenance, especially before the rainy season, so that the grass benefits from nutrients released from burning. Next to that, fire is also used for pest and parasite control and by cattle rustlers to hide their tracks (Klein et al., 2008). Accounting for these spillovers in large-scale land investments might also partly respond to the critics that argue that both basic needs and human rights as well as peoples' livelihood options are not sufficiently taken into account (Mann & Buergi Bonanomi, 2017) and may therefore help improving the design of large-scale agricultural production.

With regard to microfinance, this thesis found that villagers have low trust in institutions, and that credit is associated with a high probability of losing one's land if not repaid. High transaction costs for formal credit are faced, like seeking information about requirements and opening hours of the office, transport and time. Extension services and a microfinance institution are offering subsidized loans for agricultural equipment, which has however hardly been used. Offering locally adapted saving options could lead to building trust in microfinance institutions, while allowing farmers to invest in their livelihoods, and increase their resilience to shocks.

In addition to agricultural development as the most effective means of increasing productivity, and reducing poverty and food insecurity, Minten & Barrett (2008) observed that factors outside of the hands of individual farmers are essential for that: improved security, land tenure and infrastructure, education and extension and irrigation and the maintenance of livestock herds. This means that there are no easy solutions, but long-term efforts, and commitment to investment are needed. Therefore, foreign direct investment in land can be beneficial especially in channelling necessary investment to rural areas neglected by the state. Given that farmers would benefit most from public goods, a political will to active and long-term public investment in rural areas, as well as effective control mechanisms regarding investors by the state and local government are essential. Impacts on local livelihoods might differ from the impacts shown in this thesis when other energy crops than Jatropha or food crops are cultivated, and when outgrower schemes are applied. In the light of the contributions to food security and spillover effects to rural and agricultural development, which this thesis has provided evidence for, further breeding efforts in Jatropha (or other suitable crops) and a continuation of adaptive research and development of local marketing value chains might lead to more beneficial investment in degraded land in remote poor areas.

Finally, with regard to large-scale land investment and large-scale agricultural production, as shown in chapter 3, creating transparency and assisting local communities during negotiations and project implementation, and in the creation of a local monitoring mechanism might prevent conflicts and increase participation and wellbeing of local stakeholders. Developing and strengthening local capacities to assess existing rules, e.g. land rights or biofuel production standards might increase better outcomes of land investments (Florin et al., 2014). Burnod et al. (2012) argue that investors do not have secured land rights in Madagascar, therefore from a political perspective, securing local land rights might even be favourable in attracting investors. Increased bargaining power might also be important to address equity problems, for instance in situations that is shown by Ferraro (2002) who estimated that less than 2% of funds for agricultural development near a national park have actually reached farmers. Francken et al. (2009) show for the Malagasy education sector, that elite capture of public funds can be decreased both by central government agencies and by increasing information at the local level through e.g. radio programs in remote and poor regions. Therefore, participatory methods like the net-maps shown in chapter 5, by visualizing actors, their connections, objectives and power, could give important insights in governance and institutional arrangements of development programs.

6.2 Limitations and recommendations for future research

This thesis has investigated relevant aspects of the wide spectrum of topics regarding agrofuel production in marginal areas in Madagascar. Linkages with food security, as well as spillover effects to agricultural and food production appeared to be most relevant for addressing the research gap on the long-term and indirect effects of biofuel production in developing countries as well as responding to insights during fieldwork. It was beyond the scope of this study to address further spillovers and/or externalities with regard to environmental and institutional aspects, and access to energy

A methodological limitation arises from the fact that the study was limited to one Jatropha project, which was heavily subsidized through the investor and therefore does not allow for generalization of findings to other biofuel investors in Madagascar (see also Grass & Zeller, 2011). Studies on other still existing Jatropha projects in Madagascar, although using different approaches (Gingembre, 2015; Neimark, 2016) found local resistance towards projects, loss of access to land, and therefore came to quite different conclusions. The focus on Jatropha as biofuel feedstock provides substantial insights into possible impact pathways and can indicate a direction of effects also for other biomass feedstock plants, but these would have to be investigated further.

Moreover, the limitation of data collection to three villages close to each other and with similar characteristics regarding e.g. climate, livelihood strategies, market access and consumption patterns led to a lack of variability in outcomes of interest. For example, no farmer had received improved seed from the extension service, and less than 2% of households took a credit for agricultural equipment in the recall period of 5 years. This was among others because the suggested options were not well adapted to site-specific problems and because of a lack of trust in microcredit services. Therefore, further research could explore alternative options in providing these services and identifying institutional arrangements, which are more likely to be accepted and utilised by farmers. For instance, credit or savings preferences could be elicited with the help of choice experiments. Following the participatory elicitation of perceptions on risks and shocks for households in Madagascar (Stoudmann et al., 2017), preferences and site-specific technology options to proactively adapt to shocks, e.g. local grain storage options could be explored with the participation of extension services and agricultural research institutes. Collecting gender-disaggregated data on perceptions and adoption of innovations might reveal interesting policy options regarding technology dissemination. Moreover, opening the household black box and explore intra-household decision-making could open up options for gender- or nutrition-sensitive interventions, like home gardens.

This thesis used dietary diversity indicators and lack of food / food shortage as proxies for access to food. Lack of food has shown to be a very subjective indicator, which might depend on the interviewed person in the household and the wealth level of the household. Poorer households rely more on cassava, which is available the whole year. Cassava is an inferior food in the region; richer households might therefore be more sensitive to a decline in their rice production and might have reported a longer hunger period. The household food insecurity access score, which was calculated for the last survey round, would be a more comprehensive indicator of household access to food. With regard to dietary diversity, distinguishing between nutrient-rich food groups, like vitamin A-rich vegetables and fruits, might provide further insights into the nutrition status of people. Moreover, food and nutrition security is a multidimensional phenomenon, where food intake is only one aspect. This thesis could not look into health aspects, which however appeared very relevant during fieldwork. Access to safe drinking water and sanitation is extremely low, and diseases like diarrhoea, Malaria and Schistosomiasis are widespread. A basic health centre (CSB) exists, but since it is not regularly attended and not well equipped, people especially from the more remote villages do not take the risk to walk there in case of an emergency. Services are free, medicine can be accessed in the village pharmacy, but are not affordable for many households, and there is widespread misuse of medicine, e.g. antibiotics due to a lack of knowledge. Galasso & Umapathi (2009) found that compared to national negative trends in both short and long-term nutritional outcomes, the program SECALINE, a community-based nutrition program, has been successful in improving children's nutritional status. These improvements depended on community infrastructure, access to public services, as well as poverty and education of the mothers. Therefore, future research could test how to exploit local nutrition and health knowledge and how best to disseminate this and other knowledge in remote areas, e.g. through the village-pharmacy, community workers or schools. Dibba et al. (2017) show that the elicitation of health-related aspects in a household socio-economic approach is not trivial and recommend to use anthropometric indicators. The funding for this doctoral research did not allow for collecting such data. Moreover, especially Schistosomiasis often has diffuse or no symptoms and would therefore call for a public health intervention.

Another limitation was regarding education, where the impacts of the Jatropha project, policy reforms in the education sector and the political crisis could not be disentangled. Primary enrolment rate and primary school completion rates had significantly increased after a policy reform in 2004 (Francken & Minten, 2005), especially in the Fianarantsoa region and especially in poorer and remote regions. In the sample villages, the primary enrolment rate was almost 100%. Impacts of Jatropha income were reported to be ambiguous. Since better-educated villagers were more likely to be employed as group leaders, incentives for secondary schooling were reported and Jatropha income was reported to be devoted to schooling. In 2010, after the political crisis teacher salaries were delayed or not paid. Parents paid additional teachers through the association FRAM. Better-off parents send their children to private schools outside of the commune. To respond to the demand and to the increased student-teacher ratio, a local teacher founded a private primary school in Fenoarivo. Farmers also raise doubts about the benefits of secondary schooling since they fear that their children do not want to work in the fields anymore. Future research could therefore test how primary school quality could be improved, e.g. by reducing the student-teacher ratio. For secondary schools, integrating locally important knowledge on e.g. improved farming technologies, improved soil management and climate adaptation strategies, and how this could lead to a better perception of education, could be tested.

Measurement problems arose especially for the number of cattle, land sizes and the numerous taboos. Exact herd sizes were difficult to elicit, since cattle owners fear thefts and tax collection. A different entry point might be to study the various and important crop-livestock linkages like soil preparation, manure, animal nutrition or exploring value chains for animal products. Another interesting area for further research would be the perceptions of cattle holders on bush fires and tree planting, which might be a trigger for planting Jatropha or other tree hedges in order to prevent further soil erosion and increase soil moisture and fertility. Free-grazing cattle are a constraint to off-season crops, since rice fields as well as fields close to rivers are left to cattle after the rice harvest. Land-related data was difficult to elicit, both since exact sizes are not known by (illiterate) farmers and because of the fear of tax collection and especially in the early years of the Jatropha project because of fear of losing their fields. In land productivity analyses, plot sizes estimated by farmers have been found to lead to biased estimates. The process of the implementation of a land cadastre by the local government reveals a deep-rooted lack of trust in administrative bodies. Yet especially in the wake of large-scale investment in land, official titles might become more important for landholders. Then research accompanying local efforts to document land ownership with participatory mapping and GPS techniques could contribute to a higher (perceived) land security. Taboos often concern objects or practices people do not want to talk about in interviews. Yet since taboos have been shown to be beneficial for resource conservation or might explain reluctance or opposition to use improved agricultural technologies or latrines, an anthropological approach looking at the origins and importance of taboos might provide important insights and entry-points for policies.

Net-maps and interviews with farmers, FOFIFA, CSA, and MAEP pointed to numerous supply-side but also governance challenges that could not be addressed in this research. These institutions face (long-term) financial problems, e.g. the bean breeding programme in Toliara (at the time of harvest money for harvesting had not yet arrived from the government) or the fight against locust plagues, which due to financial constraints only targeted more accessible regions. The extension and microfinance services likewise face high transaction costs in targeting more remote villages, transport and time requirements for farmers in applying for the services are high, and supply for subsidized inputs is not given. Elite capture at the local level occurred in the framework of the Jatropha project, as well as public health and sanitation projects. Birner et al. (2011) compared different strategies for agricultural input provision in Northern Uganda and found that a cash-for-work program has less governance challenges than input-supply or voucher programs, especially due to self-targeting, but are also not suitable for complex interventions and similar to other strategies also prone to capture by staff. Therefore, testing different input provision strategies in the framework of field experiments would provide useful evidence for policymaking.

Moreover, this thesis has also not looked into funding and monitoring mechanisms, which are however very relevant for the biofuel sector. Certification as an instrument of securing (social) sustainability standards is only feasible when exporting to international biofuel markets. Substituting fossil fuels in local markets might create additional economic and environmental benefits and might have positive spillover effects on access to energy and infrastructure. Outgrower schemes and small-scale oil production are likely to have higher spillover effects to agricultural production and farmer wellbeing. Since outgrower schemes or small-scale production shifts investment and risks to farmers, investments into social protection measures as well as extension and microfinance services would be required. Venghaus & Selbmann (2014) therefore suggested an international redistribution mechanism between countries importing biofuels, and farmers and affected population in producing countries. Combining the characteristics and conditionalities of cash transfers and payments for environmental services, this could have positive effects on environmental, social and economic sustainability of biofuel production and decrease global inequity (ibid).

Against the background that the mostly private and non-governmental land investments lead to a low transparency and a lack of public knowledge for policymakers there is still a big scope for socio-economic research in Madagascar. With both rigorous impact assessment techniques and mixed method approaches the regions targeted by agricultural research institutes and development programs could be evaluated and recommendations given how to scale up these programs to other regions in Madagascar. Given the interlinkages between agricultural development, environmental conservation and on- as well as off-farm livelihoods, this might involve a multi-disciplinary and -multisector approach, involving research institutes, policy makers, affected farmers, and their communities. Acknowledging the complementarities between income-increasing and agricultural productivity increasing programs, further research might try to explore the potentials of policies addressing both.

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Appendices

A Maps

Figure A1: Map of the sample villages, source: commune of Fenoarivo, 2011

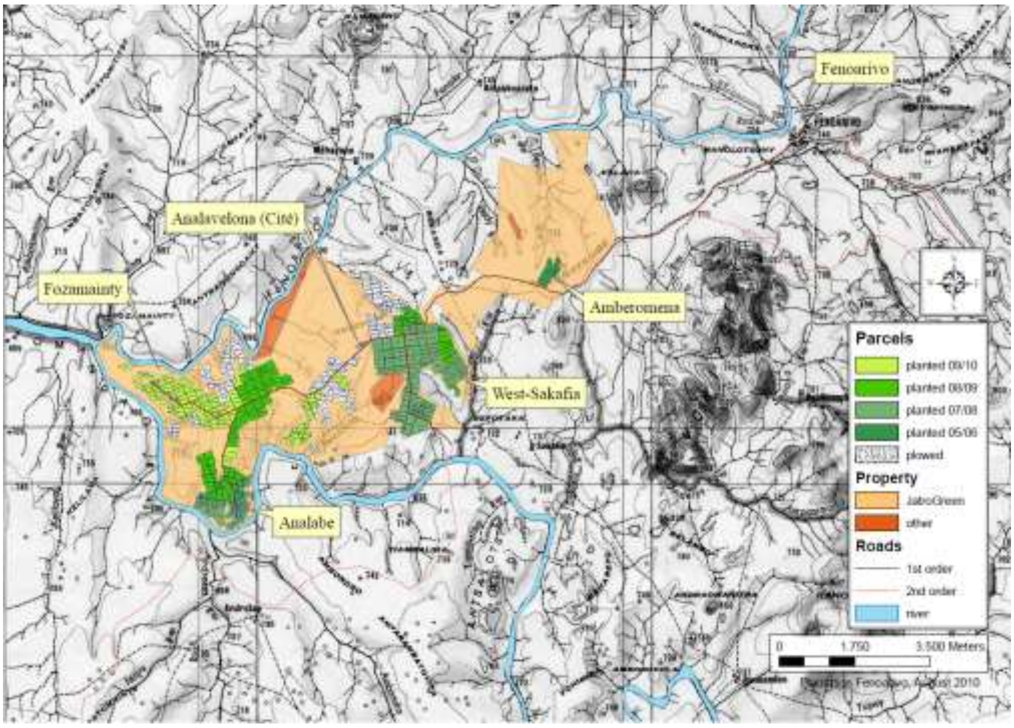

Figure A2: Map of the Jatropha plantation, 2010, source: JatroSolutions GmbH

CURRICULUM VITAE

HIGHER EDUCATION

11.2013 – 04.2018 University of Hohenheim, Germany	***Ph.D. Candidate*** Ph.D. topic: Agrofuels, large-scale agricultural production, and rural development – The case of Jatropha in Madagascar (supervisor: Prof. Dr. Manfred Zeller)
03.-06.2015 University of Sao Paulo, Brazil	***Research scholarship***, Strategic Network Bio-Economy (BECY), impact assessment with panel data (supervisor: Prof. Dr. Ana Kassouf).
10.2009 – 11.2011 University of Hohenheim, Germany	***M.Sc., Agricultural Economics*** Master thesis: Impacts of a Jatropha plantation on income and food security using household panel data. (Fiat Panis Research Grant for M.Sc. thesis contributing towards combating hunger and alleviating poverty).
03.2006 – 07.2009 Universities of Reutlingen, Germany and PUCV, Chile	***BBA, International Economics*** Bachelor thesis: Public Private Partnerships as instrument of Corporate Social Responsibility - opportunities and risks for companies.

WORK EXPERIENCE

Since 11.2011 – 01.2018 Chair of Rural Development Policy and Theory, University of Hohenheim, Germany	***Research associate*** ***Socio-economic effects of a Jatropha plantation on rural households and their communities in Madagascar*** (funded by Stiftung Energieforschung through the project A29812) - Financial and narrative proposal, budget responsibility and reporting Coordination of data collection, questionnaire design, hiring and training of enumerators for household surveys in rural Madagascar, - Design and implementation of RCTs on improved seed and information (leafy vegetables, beans, rice). ***Teaching:*** - *Food and Nutrition Security* - *Rural Development Policies and Institutions* - *Poverty and Development Strategies* - *Project Evaluation and Monitoring* - *Introduction to STATA* Supervision of M.Sc. students.
02.2010 – 02.2012 Thinkstep, Leinfelden-Echterdingen, Germany	***Student Assistant***: Client support for a software (GaBi) for Product Lifecycle Assessment.
12.2010 – 10.2011 Chair of Rural Development Policy and Theory, University of Hohenheim, Germany	***Research Assistant***: Data collection and analysis, preparation of presentations for workshops and reports for an interdisciplinary research project on Jatropha cultivation in Madagascar.

11.2009 – 11.2010 Food Security Center (FSC) University of Hohenheim	***Student assistant:*** Mentoring of guest researchers, event and conference management (FSC inauguration, 117th EAAE Seminar “Climate Change, Food Security and Resilience of Food and Agricultural Systems”).
07.2009 – 10.2009 ZfW Compliance Monitor GmbH, Tuebingen, Germany	***Intern:*** Monitoring and marketing of an ethics management system, development of audit questionnaires and reports.
02.2008 – 08.2008 EnBW AG Stuttgart, Germany	***Intern:*** Business plans for new energy products and services with technical staff, analyses and concepts for strategic planning, for the implementation of a continuous improvement process and process management methods.
07.2006 – 10.2006 Laboratorios Francelia Tegucigalpa, Honduras	***Intern:*** Selection of new suppliers, offer analysis for raw materials, supplier development for a pharmaceutical company.

LANGUAGES

German	Mother tongue
English, French, Spanish	Fluent, both oral and written
Portuguese, Malagasy	Basics

COMPUTING

MS Office, STATA, SPSS

SELECTED PUBLICATIONS AND PRESENTATIONS

Bosch, C., Zeller, M. and D. Deffner. Adoption of an improved bean seed variety and consumption of beans in rural Madagascar: Evidence from a randomised control trial. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 118 (2017) No. 2, 217–231.*

Are seed distributions effective? Evidence from a randomly controlled experiment with improved bean seeds in Madagascar. *Oral presentation at the 5th AAAE Conference, Addis Ababa, Ethiopia, 2016.*

Lessons on inequality from a large-scale bioenergy project in Madagascar. *Oral presentation at the 6th Latinamerican and European Meeting on Organization Studies. Viña del Mar, Chile, 2016.*

Socio-economic Impacts and Lessons Learned of a Large-scale Biofuel Project. *Contribution to the call for ideas “Climate Protection in the future”, Energiecampus, Karlsruhe, Germany, 2015.*

Food Security Impacts of Rural Households’ Employment at a Large-scale Biofuel Project in Madagascar. *Posters at the Global Bioeconomy Summit, Berlin, Germany, and at Tropentag, Berlin, Germany, 2015.*

Measuring the effect of informal social networks on information available to rural households in Madagascar. *Oral presentation at the 6th EAAE PhD workshop, Rome, Italy, 2015.*

Bosch, C. and M. Zeller. The Impacts of Wage Employment on a Jatropha Plantation on Income and Food Security of Rural Households in Madagascar – A Panel Data Analysis. *Quarterly Journal of International Agriculture, 52 (2013), No. 2, pp. 119-140.*

The Impacts of a Jatropha plantation on Food Security and Income of Rural Households in Madagascar – A Panel Data Analysis. *Oral presentation at 128th EAAE Seminar, Ravello, Italy, 2012.*