Wageningen University - Department of Social Sciences

MSc Thesis Agricultural Economics and Rural Policy Group

The treadle pump in Zambia:

Stepping out of subsistence farming

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IDE INTERNATIONAL DEVELOPMENT ENTERPRISES

Summary

The treadle pump is a man-powered pump, designed for the irrigation of small plots of land. According to the International Development Enterprise (IDE) in Zambia, the pump increases farm income by more than $100 per year. The FAO states that irrigation can increase crop yields from 100 to 400%. This paper evaluates the contribution of the treadle pump to smallholder welfare.

Adoption
Households with relatively low labor availability have a higher probability of adopting the treadle pump. These households benefit most from increased labor productivity. Households who classify there welfare as low, the group IDE targets, have a higher probability of adopting the treadle pump, than households with a higher self-assessed welfare. IDE can increase adoption of the treadle pump by establishing demo-sites, as they increases the 'learning by doing' opportunities; by improving affordability in order to reach farmers under the $2 a day poverty line; and by establishing farmer groups in order to increase adoption, by increasing the potential benefits of the treadle pump. IDE is working on the affordability issue with credit schemes and cheaper irrigation technology for the future. Farmer groups and demo-sites are being established at this moment. Interviews show that adoption is closely related to credit. The price of a pump is $156; this is only 60% of the estimated annual increase in income. A household living on less then $2 a day will not be able to save the necessary amount. However, these results indicate that if these low income households were offered a credit scheme, they should not have difficulty repaying this credit.

Income
The treadle pump increases income, as farmers can produce more and higher value crops under irrigation. Income is an important, but in no sense complete, measure of welfare. The data does not show that the treadle pump increases yield per cropping cycle or increases the number of cropping cycles per year, as the FAO states. The treadle pump increases labor productivity of smallholders and enables them to cultivate a larger area of irrigated crops. The increase in area cultivated, increases the income of the adopting households through more marketable produce. The income of treadle pump users is $208 higher than that of households using buckets. Propensity Score Matching shows the income of a household using a treadle pump increases by $250. This is substantial for households living on less than $2 a day. This estimated increase in income is 2.5 times higher than the increase according to the IDE website.

Welfare
The treadle pump increases welfare, as people have more money to spend and better food for household consumption. Households graded their overall welfare on a scale from 1=unable to survive to 4= well-off. The welfare was very similar for the different households, independent of the irrigation they use. However, according to Propensity Score Matching, the treadle pump increases welfare by 0.15 points. According to OLS, the treadle pump increases welfare by 0.17 points. Adopting and non-adopting households state that the treadle pump increases welfare.

Preface

This thesis presents the results of my research at IDE Zambia. This thesis is the final part of my master in Management and Economics at Wageningen University. This research was assigned to me by the LEI, Wageningen University and Research Centre. The objective was to establish the contribution of the treadle pump to rural welfare in Zambia as part of the larger monitoring and evaluation that IDE is performing on their projects.

I had a very pleasant time writing this thesis; both in Wageningen and in Zambia. I learned a lot, and although I would have handled some parts of the research differently now, I am proud of this result. I hope that anyone reading this thesis will find it is interesting and informative, and will enjoy reading it.

I want to take this opportunity to thank my supervisor at Wageningen University, Jack Peerlings from the Agricultural Economics and Rural Policy group, for the extensive comments and encouragement I received during the realization of this research. I want to thank every-one at IDE Zambia and IDE visitors from oversees, for showing me the work they are doing and helping me to understand what I was seeing. I want to thank Giel Ton from the LEI for offering me the opportunity to perform this research.

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1. Introduction

Research background

In retrospect to the high amount of aid that Zambia received over the last decennia, it is still a country with a very high level of poverty. Erratic rains and consequent droughts have caused many food shortages over the last two decades. This thesis focuses on one of the projects of the International Development Enterprise (IDE). In 1997 IDE came to Zambia to set up sustainable supply chains for treadle pumps, to improve the welfare of farming households living under the $2 a day poverty line. Treadle pumps are appropriately sized for small scale farming and are kept affordable for smallholders (see glossary for definition). The efficient step-action operation makes it possible to pump large volumes of water. The pump is designed to be light in use, so that also children can operate it, allowing farmers to make efficient use of family labor. Treadle pumps are typically used to grow vegetables during the dry season for home consumption and for sale. IDE has been involved in the distribution of about 7000 pumps in Zambia.

Low-cost irrigation is a practical way to address poverty and hunger. According to the FAO irrigation can increase yields for most crops by 100 to 400% (FAO, 2006c). Irrigation enables the farmers to switch from subsistence production to market-oriented production, with higher-yielding and higher-value crops. General available irrigation technology is expensive and often far out of reach of the poorest smallholders. Irrigation with buckets is a cheap way of growing irrigated crops. However the method is very labor intensive.

When IDE started they focused on technology adoption and measured their success by the number of treadle pumps distributed. Since a report of Shah (2001) the focus has shifted from distributing technology to increasing productivity, because technology is only one of the factors that determine welfare (see glossary for definition).

According to IDE, farmers are on average able to generate more than $100 extra income annually by using the treadle pump (IDE, 2007). This research fits into the activities of LEI, Wageningen University and Research Centre to monitor the household incomes of IDE-beneficiaries from 2007 to 2010.

The paper will evaluate the contribution of the treadle pump to rural welfare mainly with the existing IDE PRISM dataset collected by IDE-Zambia in 2005. This dataset was collected to monitor PRISM; ‘Poverty Reduction through Irrigation and Smallholder Markets’ approach. The dataset contains data on 900 households. Interviews were used to collect data on the irrigated crop production, irrigation technology, and self-assessed welfare of the households. The dataset contains variables on household characteristics, the membership of farmer groups (see glossary for definition), livelihoods, irrigation methods (see glossary for definition), high value crops, income (see glossary for definition) and self-assessed welfare (see glossary for definition) of the interviewed households.

Objective and research questions

The objective of this paper is to evaluate the contribution of the treadle pump to the rural welfare of smallholders. The treadle pump is distributed by IDE and this research will obtain information that can be useful for IDE to improve the contribution of the treadle pump to rural welfare. The research questions are the steps that will be taken to reach the objective of this research.

Research question 1:
Which factors play a role in determining which households use the treadle pump compared to adopting other irrigation methods?

Research question 2:
What is the difference in farming practice between households that use a treadle pump and those who use other irrigation methods?

Research question 3:
Which part of the welfare of a household that adopts a treadle pump, can be allotted to the treadle pump?

Methodology
The following methodology will be used to answer the different research questions.

Research question 1:
This question focuses on the adoption of the treadle pump. Characteristics that distinguish the households that adopted the treadle pump from those that used other irrigation methods will be revealed here. A Multinomial Logit model shows which factors play a significant role in the decision to adopt one of the four irrigation methods. The results of the quantitative analysis are cross-checked and extended with feedback from farming households and experts on Zambian agriculture. More information on the feedback procedure can be found in appendix A.

Research question 2:
This question focuses on the difference in farmers' practices for those households that adopted the treadle pump and those that use other irrigation methods. This chapter will describe the differences between the different groups in for example cropping pattern and crop income. The results of the quantitative analysis are cross-checked and extended with feedback from farming households and experts on Zambian agriculture.

Research question 3:
The contribution of the treadle pump to the welfare of the households will be measured taking into account differences in household characteristics. Welfare is measured through income and self-assessed welfare. The contribution of the treadle pump is first measured with an Ordinary Least Squares model. A dummy for the use of the treadle pump will show the effect of the pump on income and self-assessed welfare, controlling for the other factors. The second way to measure the effect of the treadle pump is by comparing adopting households to non-adopting households that are similar in all other characteristics, by means of Propensity Scores. The results of the quantitative analysis are cross-checked and extended with feedback from farming households and experts on Zambian agriculture.

Outline of the thesis
This thesis is arranged in the following order: Chapter 2 introduces the research area of this study. Chapter 3 describes the dataset that is used. Chapter 4 will explain the factors important for adoption. Chapter 5 compares the farming practice of adopters and non-adopters of the treadle pump. Chapter 6 establishes the effect of the treadle pump on welfare. Chapter 7 concludes this thesis and entails some discussion points of the conclusions.

2. Research area

2.1 Introduction

Background information on Zambia will improve the comprehension of the data analyses in this report. This chapter describes the development of Zambia, the importance of the agricultural sector, and the work of IDE. Section 2.2 gives a description of the demographic and economic situation of Zambia as a whole. Section 2.3 describes the rural areas and the challenges agricultural producers face. Section 2.4 describes how the treadle pump fits in as an answer to those challenges and gives the three major constraints faced by treadle pump users. Section 2.5 ends the chapter with a summary and conclusions.

Figure 2.1. Zambia
Source: Compare Infobase limited

2.2 Zambia

Zambia is located in Southern Africa, land-locked by 8 countries (See figure 2.1). It has 11.7 million inhabitants; demographic trends show an annual growth rate of 1.7%. Zambia covers an area of 752.614 km2 (18 times The Netherlands), which results in a population density of only 15.5 inhabitants/km2 (Ministry of Foreign Affairs NL, 2007). 34.9% of the population lives in the urban areas of Zambia. 46% of the population is under 15 years of age; only 3% is aged 65 or older.

Zambia scores low on the Human Development Index; it is positioned at number 165 of the 177 countries listed. This index is based on three dimensions of human development: living a long and healthy life, being educated, and having a decent standard of living (based on the figures of 2004). Zambia scores especially low on life expectancy (37.7 years) due to the high rate of HIV/AIDS estimated at 17% of the population. Only Zimbabwe, Lesotho, Botswana, and Swaziland have higher rates of HIV/AIDS and lower life expectancy rates accordingly. Zambia also has a high prevalence of tuberculosis with a rate of 707 cases per 100,000 habitants. Only four countries in the HDI have more cases of tuberculosis (UNDP, 2006).

Zambia scores relatively high on education, with an adult literacy rate of 68%. The average annual change in the consumer price index in Zambia was 42.4%, indicating a high level of inflation. However this stabilized at 18% between 2003 and 2004. Zambia has been descending on the HDI ever since 1985, while Sub-Sahara Africa as a whole was improving their place in the HDI. Between 1975 and 1995 Zambia's per capita income fell by 60 % due to the crisis in the metal mining sector. Despite the positive growth in the last ten years (FAO, 2005b), it remains very low at an average $943 per capita for Zambia as a whole. The

recently increased price of copper offers new opportunities for Zambia is the near future. 75.8% of all Zambians are estimated to be living under the $1 a day poverty line. 94.1% has less than $2 to spend per day (UNDP, 2006).

According to the FAO, the Gini-coefficient representing equality was 0.53 for Zambia in 2006 (FAO, 2006a), while according to the UNDP it was 0.42. The higher the coefficient, the higher the inequality. Most developed European countries have a Gini-coefficient between 0.24 and 0.36 (UNDP, 2006). The Gini of food consumption is estimated by both FAO and UNDP at 0.17.

Zambia received $1.081 million of official development assistance in 2004 (or nearly $100 per capita) 20% of Zambia's total GDP. In April 2005, the International Monetary Fund and the World Bank agreed that Zambia had implemented the requested series of economic measures and structural reforms to reach the completion point under the enhanced Heavily Indebted Poor Countries (HIPC) Debt Initiative and was eligible for debt service relief of about $3.9 billion (FAO, 2005b).

Poverty is however not what you see when you arrive in the capital, Lusaka. Years of (esthetic) government policy have changed Lusaka in a spacious and for African standards, rather calm city with huge Western-style malls sprouting in the suburbs. Zambians in Lusaka are carefully positive about the future of their country

2.3 The challenges of the rural areas

When leaving Lusaka the surroundings change. Villages are rare and far apart. Except for some, often foreign owned commercial farms, only small plots of land are cultivated. These plots are cultivated in a labor intensive way, with little to no use of chemicals or equipment. The main goal of production is to feed the household.

Village in Southern Province

The majority of agricultural production is rainfed and therefore production varies according to variations in rainfall. Maize, cotton, and wheat are typical rainfed crops. Due to the subsistence nature of farming, loss of crops directly translates into food insecurity. Because of unpredictable droughts, dramatic food shortages frequently occur throughout the country. Food security is an important part of any aid project implemented in Zambia for the last decennia; short term projects aim to relief the occurring needs and long-term projects try to make households less vulnerable to crop loss.

Nearly 70% of the economic active population is active in agriculture, while a little more than 60% of the population lives in the rural areas. The FAO estimated the per capita income for the agricultural population at $92 per year. Poverty rates are higher in the rural (83.1% in 1998) than in the urban areas (56% in 1998) (FAO, 2006a); 5.2 million ha of Zambia is in arable land, 27 thousand ha is planted with permanent crops and 30 million ha is pasture land. The low population density shows that Zambia has no shortage of land for agriculture or other purposes.

The top three of most important commodities in value are: Maize ($135 million), indigenous cattle meat ($84 million), and cassava ($68 million). The most important commodities in quantity are: Sugar cane (1,800,000 metric ton), maize (1,161,000 MT), and cassava (950,000 MT) (FAO, 2006b). In the last few years, cattle population has declined because of the outbreak of certain animal diseases. The crops most grown by smallholders are maize, rape, tomato, and cabbage.

Between 2002 and 2004, for the first time since the 80's, food production grew at the same rate as the population (FAO, 2006a). An estimated 46% of the population was still undernourished however. This is very high, even compared to Sub-Sahara Africa as a whole (33%) (FAO, 2006c). The real number of undernourished people has increased from 1990-92 to 2002-04. However the proportion has slightly decreased, showing a more hopeful trend (FAO, 2006c).

Farmer group in Central Province

2.4 The treadle pump

The treadle pump consists of a cylinder and piston to draw water, using the power in feet and legs. The feet move the treadles that are connected to the pistons up-and-down to get a sucking movement in the cylinders. This way water can be pumped up from below ground level or water can be fed into a pipe under pressure to feed sprinklers. 2.5-5 m3 of water can be lifted per hour, enough to irrigate between 0.2-0.4 ha in most tropical and arid countries (Kay and Brabben, 2000). Under irrigation typically vegetables like tomatoes are grown.

Zambia has about 40 % of the water in Southern Africa (FAO, 2005b), but Zambia's agriculture is mainly rainfed. The main growing season runs from December to May. The average rainfall is 1049 mm per year, with high variability over the country. Water is one of the most critical factors for smallholders. Droughts are a major issue that threatens certain parts of the country. Although Zambia is very water abundant, the necessary infrastructure is not available to benefit from this asset. Irrigable land is estimated at about 420 000 has, but less than 10 % is actually irrigated, mostly by large, often foreign, farmers (FAO, 2005b). Smallholders usually own much more land than they cultivate. This means that they can expand their cultivated area without enduring any costs for land.

IDE offers advice on production and has been trying to establish sustainable supply chains for treadle pumps for the last ten years. The treadle pumps improve the access to water and reduce the labor necessary to irrigate the crops. The supply chain is meant to be sustainable meaning that IDE finds an importer or manufacturer for the pumps, connects them to a wholesaler, and connects them to local retailers. IDE and the retailer then promote the pumps and provide credit facilities, so the smallholder can buy the pumps. A big problem in the accessibility of the treadle pump for the poorest smallholders is the price of the pump. Due to the typical economic situation of Zambia the pumps there are about 5 times the price of a pump in Asia. A treadle pump in Zambia including inlet and outlet pipes costs nearly $100. For a family living below $1 or $2 a day, this sum is nearly impossible to pay. Credit schemes are thus inevitable to reach the poorest smallholders. In the future cheaper irrigation technologies will hopefully be available.

The treadle pump

A broken or faulty treadle pump is one of the three major constraints faced by adopters of the pump. During fieldtrips to villages that are beneficiaries of IDE, it is often seen that only 25% of the pumps are actually in operation. The others are broken and no-one took the effort to repair them or they have simply disappeared. People seem very passive about broken pumps. If they got the pumps with help of IDE or via a partner they turn to them for help, if they don't get help the pumps remains broken. According to an expert at IDE 70% of the 7000 pumps distributed in Zambia are expected to be in operation and this figure might drop to 60 or 50% over the coming years, due to declining quality of after service; there are only limited spare parts available and some pumps have been designed faulty.

The development of the treadle pump is still not finished and the perfect trade-off between simplicity, convenience and price not yet found. In most cases the owners of a treadle pump are creative and manage to make spare parts for the pump themselves or find hardware shops that supply the necessary parts. Ownership is the issue here; households who paid their pump at once or repaid their credit are more motivated to keep the pump working. The pumps that are still in use are often intensively used (by maybe up to four farmers).

The second constraint is the water availability. The available water for irrigation is finished when the used water source, typically a stream, falls dry. In some areas the government has build dams to keep the water for as long as possible upstream. In most areas however farmers have to build boreholes to extend the period that water is available. In most cases they extend the water availability with some months, other farmers have access to water year round. The villages that are naturally abundant in water are often for that same reason cut-off from the world for several months a year.

The third constraint faced by farmers is the market access. Farm households who manage to produce above subsistence level face the lack of market access. Due to the low population density access to local open markets can be hard or not available. If the markets are reached, prices are so low that transport to the market is often not worth the effort. According to an IDE expert this is the result of high competition on the Lusaka market. Lusaka market offers a high level of 'sales guarantee' as many retailers gather there. Therefore the smallholders prefer this market even if it is far away from their village. The price in Lusaka is low as the retailers know the farmer came from far and can not go home without selling the produce. Households in the proximity of developed local markets, like in Kafue, do not face this constraint. As production is low and highly erratic, contracts are not a usual method. According to the same expert the smallholders have to organize themselves so they can get access to other markets than Lusaka alone. Zambia has a growing number of supermarkets in the country who import most goods, including fruits and vegetables from South-Africa. Smallholders are dependent on occasional traders and open markets to sell their produce. As a result streets are lined with people selling thousands of watermelons in one place, while 5 kilometers further everyone is selling sweet potatoes

To overcome part of these constraints IDE tries to stimulate the establishment of farmer groups. The members of the group can help each other and together make use of the possibilities that IDE offers. Households grouped together can share information, have more bargaining power to access the market and have more possibilities to assure delivery standards necessary to get into contracts.

Most households struggle with the above constraints. However, in a typical project village there is usually a success story; a farmer who bought a treadle pump and managed to increase his production to such extend that he now bought a diesel pump and is now one of the richest households in the village.

2.5 Summary and conclusions

Zambia has a low level of development, even when compared to other countries in Sub-Sahara Africa. Average life expectancy is 37.7 years due to a HIV/aids prevalence of 17% of the population. 94.1% of the population is estimated to live below the $2 a day poverty line. Per capita income in the rural areas is only $92 per year. Frequently occurring droughts have caused many food shortages in the last two decennia.

IDE aims to increase the standard of living of those farming households that live under the $2 a day poverty line. Therefore IDE has different projects to increase the agricultural production of their beneficiaries. A main focus point is to make the abundant water sources that Zambia has accessible for smallholders. IDE has been establishing sustainable supply chains of treadle pumps. These pumps are developed for the typical demand of smallholder production to increase their production and thus their standard of living. However the contribution of the treadle pump to the welfare of the smallholder is constrained by the functioning of the pump, the availability of water and market access.

3. Description of the dataset

3.1 Introduction

IDE interviewed 900 households in October and November 2005. Sampling was done in 120 areas in 21 different districts in 4 regions; Central, Copperbelt, Lusaka, and Southern region. Figure 3.1 shows how many households were interviewed in each district. Of the households interviewed roughly 2/3 lived in the IDE project area. The interviews were used to collect data on the importance of irrigated crop production, the livelihood strategies and the revenue of the households. This resulted in an extensive dataset with about 3500 variables.

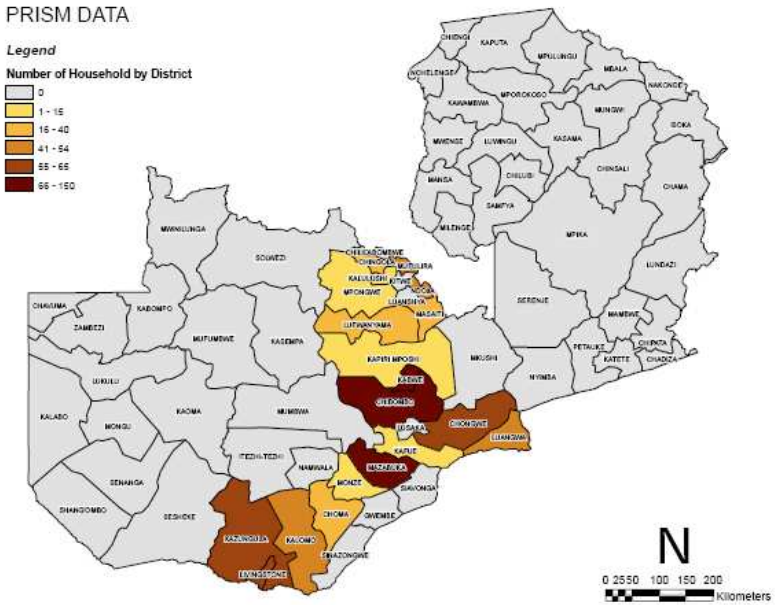

Figure 3.1 Distribution of the interviewed households
Source: G. Hudges, GIS Consultant

This chapter aims to give a description of the data that is available in the dataset. The next section will describe the data concerning household details, the data on the membership of farmer groups will be described in section 3.3. Section 3.4 describes the data available on livelihoods and section 3.5 concentrates on the data on technology. Section 3.6 describes the data on the high value crops and section 3.7 focuses on training and credit. This chapter is summarized and concluded in section 3.8.

3.2 Household details

Table 3.1 household details

	Obs	Mean (st.dev)	Min	Max
Living in project area	900	73% (44)	0	1
Age of household head (in years)	874	47 (13)	20	89
Female household head	900	14% (35)	0	1
Number of household members	900	7 (3)	1	20

Source: PRISM 2005 dataset

The data on household details contain variables on where the household lives, if the household lives in IDE project area, and the farmer groups where the household is member. Further variables contain the age, gender, marital status, educational level, former, and current occupation of the household head. Extensive data is collected on the composition of the household containing data on the gender, age, the relationship to the household head and which activities are performed by the household. If the respondent was not the household head, also data on the age, gender, and the relation to the household head of the respondent

was collected. Figure 3.2 and 3.3 show that most household heads were monogamously married and had followed upper primary education. Table 3.1 shows basic descriptives for some of the other household variables.

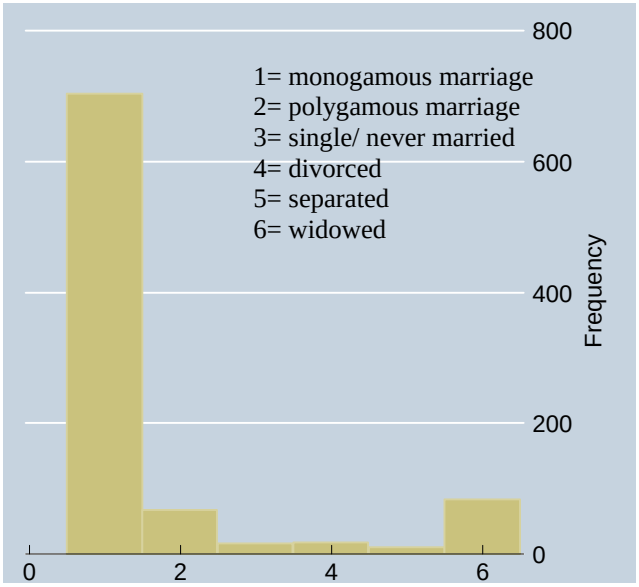

Figure 3.3 Highest level of education hh head
Source: PRISM 2005 dataset

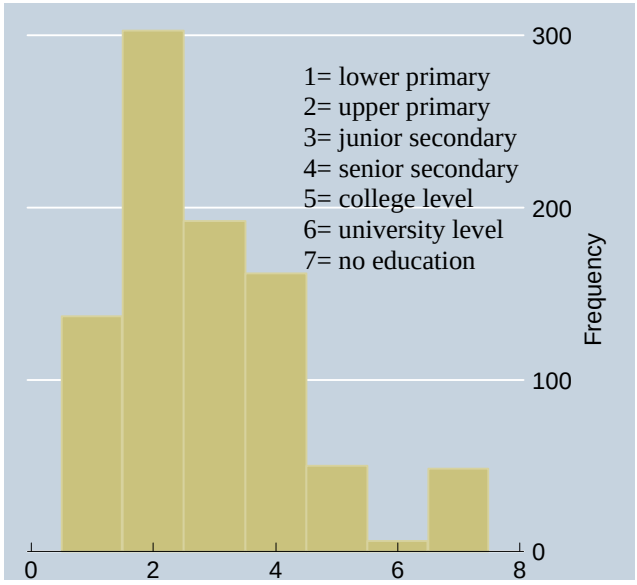

Figure 3.2 Marital status household head
Source: PRISM 2005 dataset

3.3 Membership of farmer groups

This part of the data establishes the rate of participation in different farmer groups. The first question asked is if the household is member of any group. For those households that are member of a group data is collected on the group(s) where they are member and the activities the farmer group offers. The households that were not member of a farmer group were asked why they had not become member of any groups. The households participating in any of IDE's activities were asked the year they started participating and the extent of benefit that the household has from participating. There is also data on which IDE activities the household benefits from. The households that did not participate in any IDE activities were asked why they had not become member. Figure 3.4 and 3.5 show that most households joined IDE in 2004 and most classified the extent of benefit as 'very much' or 'much' Table 3.2 shows basic descriptives of the data on membership of farmer groups.

Table 3.2 Memberships of farmer groups

	Obs	Mean (st. dev)	Min	Max
Member of farmer group	900	75% (44)	0	1
Member of IDE	840	68% (47)	0	1
Assisted by IDE:				
with irrigation training	540	72% (45)	0	1
with crop production training	537	69% (46)	0	1
with treadle pump	542	57% (50)	0	1
with output market arrangement	528	19 (39)	0	1
with input market arrangement	531	13% (34)	0	1
with output market training	524	6% (23)	0	1
with other	524	6% (23)	0	1

Source: PRISM 2005 dataset

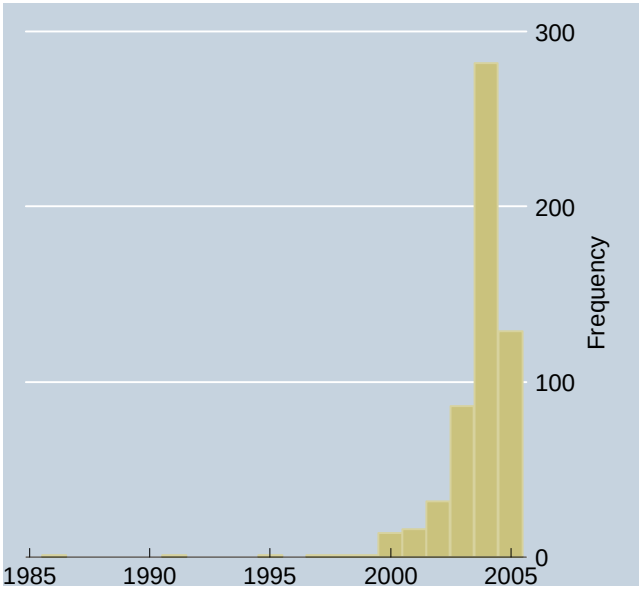

Figure 3.4 Year of joining IDE
Source: PRISM 2005 dataset

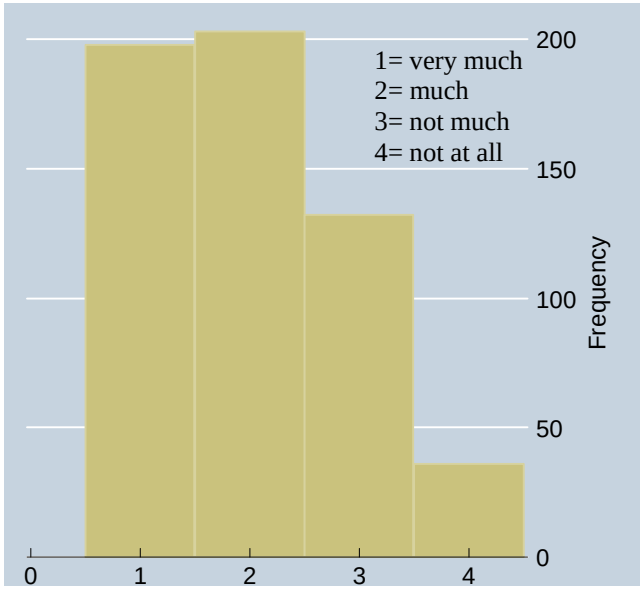

Figure 3.5 Extend of benefit from IDE
Source: PRISM 2005 dataset

3.4 Livelihoods and landownership

The variables in this part of the data describe the main sources of income for the household, which family members are responsible for the activity and which organizations helped them with the activity. These questions were asked for the situation now and for the time-span from 2000 to 2003. There is also data available on the amount of land a household owns and which part of this is used for rainfed and for irrigated crops. Figure 3.6 and 3.7 show that the most mentioned first source of income is irrigated vegetables, followed by rain fed vegetables, while the second source of income is exactly the other way round; with rain fed crops on one and irrigated vegetables on two. Table 3.3 shows that the average total land size in the sample is 12 ha. The average land cultivated with irrigated crops is 0.8 ha and the average land cultivated with rainfed corps is 3.5 ha.

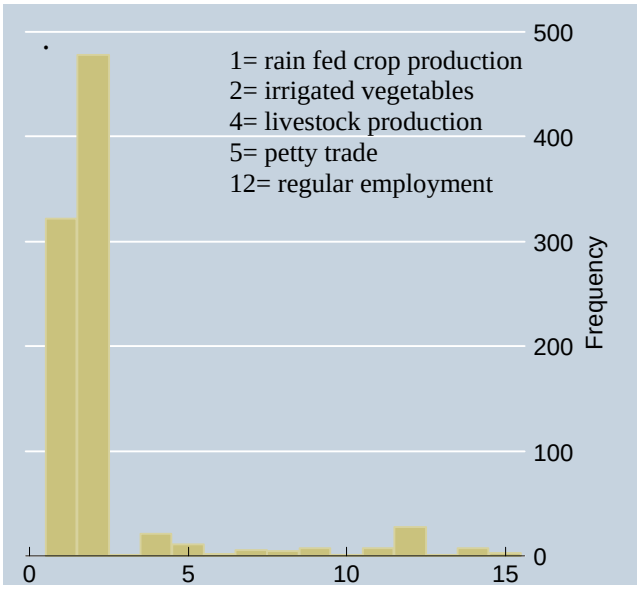

Figure 3.6 Main source of income 2005
Source: PRISM 2005 dataset

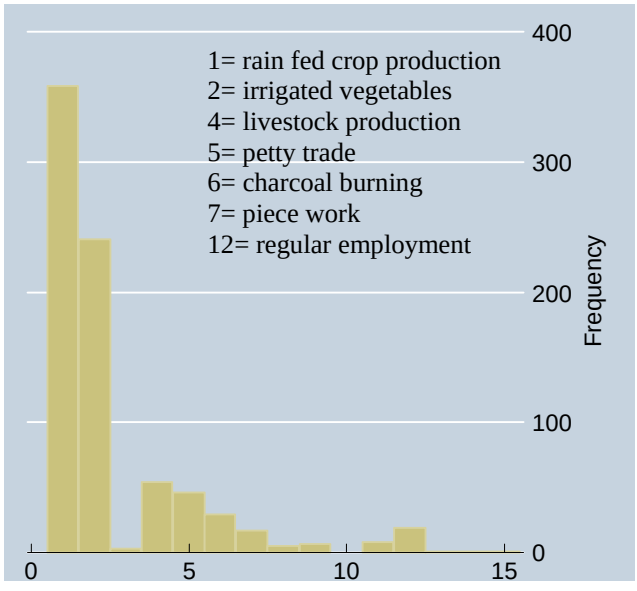

Figure 3.7 Second source of income 2005
Source: PRISM 2005 dataset

Table 3.3 Landownership

	Obs	Mean (st.dev)	Min	Max
Size land (in ha)	787	11.98(22.0)	0	200
Size land with rain fed crops (in ha)	788	3.5 (5.9)	0	95
Size land with irrigated crops (in ha)	762	0.8 (3.9)	0	99

Source: PRISM 2005 dataset

3.5 Irrigation technology

The data on the irrigation technologies used by the households contains information only for the households who use irrigation. Those who do not irrigate were asked what there motives are for that choice. For those households that irrigate there are variables available on which methods they use. The other questions are mainly about the treadle pump; how did they get it, how did they pay for it, and the price of the entire system. Those households without treadle pump were asked why they did not have one. There is also data about the size of the land before and after buying the treadle pump, diesel pump, petrol pump, electric pump, and drip irrigation. The source of water is established for irrigated household only. Figure 3.8 shows that most households in the dataset irrigate with buckets, followed fast by irrigation with a treadle pump. Figure 3.9 shows that the most important reasons not to buy a treadle pump are a lack of money or the price of the treadle pump.

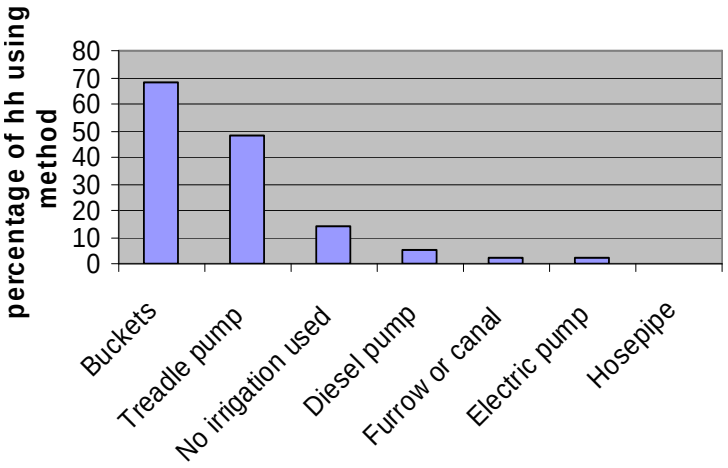

Figure 3.8 Irrigation method used
Source: PRISM 2005 dataset

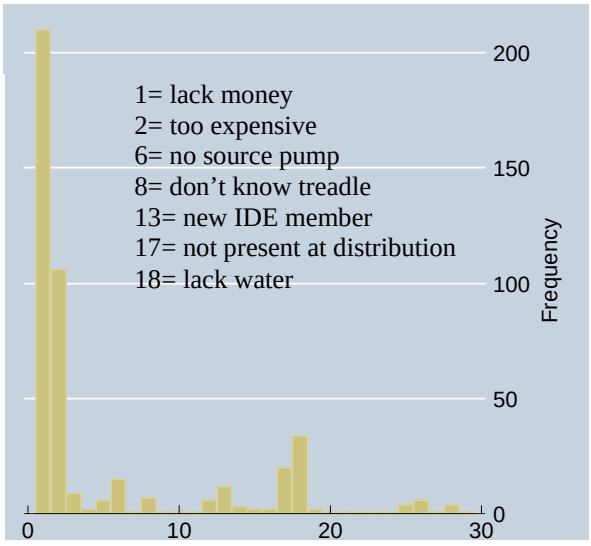

Figure 3.9 Reason not to have a treadle pump
Source: PRISM 2005 dataset

Table 3.4 shows some of the technology data. It is interesting to see that the 362 households that adopted the treadle pump increased the land they cultivated from 0.27 to 0.63 ha. Figure 3.10 shows that by far most treadle pumps are bought with credit. Figure 3.11 shows that the most important source of water mentioned by most households is a stream; a well is also often mentioned. Only few households get their water from a dam or dambo. Dambos are shallow wetlands that are particularly found in Zambia and Zimbabwe.

Table 3.4 Technology strategies

	Obs	Mean (st.dev)	Min	Max
Households involved in irrigation	900	86% (35)	0	1
Method of irrigation:				
Buckets	777	68% (47)	0	1
Treadle pump	769	48% (50)	0	1
Diesel pump	772	5% (21)	0	1
Furrow or canal	769	2% (14)	0	1
Electric pump	769	2% (12)	0	1
Hosepipe	769	0	0	0
Household owns a treadle pump	868	46% (50)	0	1
IDE is source treadle pump	402	68% (47)	0	1
Total costs of the treadle pump in $[1]	319	156 (494)	26	442
Hh uses treadle pump	672	55% (50)	0	1
Hh had training for treadle pump	303	84% (37)	0	1
Training was provided by IDE	303	84% (37)	0	1
Size land before treadle pump use (ha)	362	0.27 (0 .44)	0	6
Size land after treadle pump use (ha)	367	0.63 (1.42)	0.001	25

Source: PRISM 2005 dataset

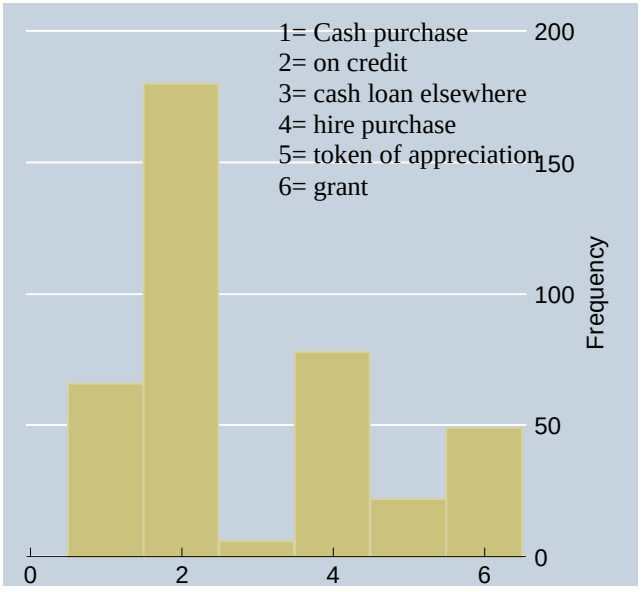

Figure 3.10 Method of payment treadle pump
Source: PRISM 2005 dataset

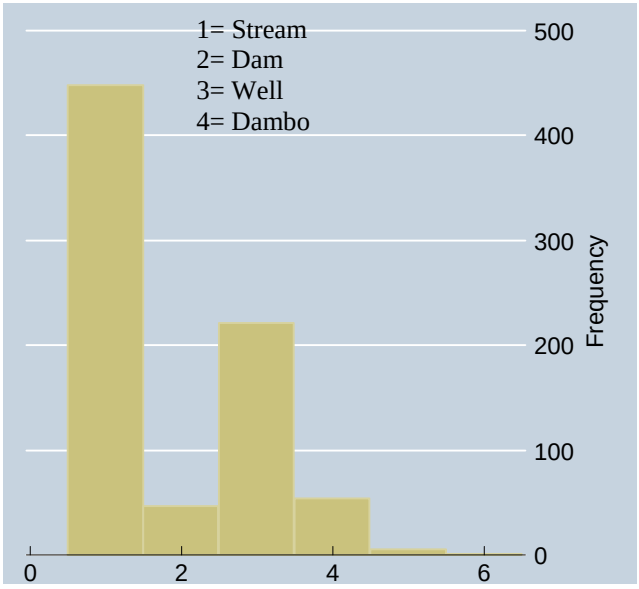

Figure 3.11 Main source water
Source: PRISM 2005 dataset

3.6 Cash crops

This part of the data contains information on the cash crops that are grown under irrigation in the household. The data is very specific on which crops are grown, which technology is used per crop, from which year on the crop is grown, why the household grows the crop and which organization helped the household. There is also data on the revenue per crop, and the total household revenue from irrigated cash crops. The constraints that households face are inventoried as are the reasons why not to grow cash crops under irrigation. There is also data in the dataset on the costs of inputs used in the production of the cash crops; seed, fertilizer,

[1] Based on the conversion rate of ZMK 3846= $1, the rate on the 18th of July 2007

pesticides, transport, hired labor, and possible costs for maintenance of the treadle pump Table 3.5 gives an example of the data that is available in this section.

Table 3.5 Cash crops (revenue in $)

	Obs	Mean (st. dev.)	Min	Max
Revenue from cash crops in 2004	601	494 (910)	0	10,894
Revenue from cash crops in 2005	809	442 (1,300)	0	20,020
Revenue from tomatoes in 2004	435	260 (546)	0	5,356
Revenue from cabbage in 2004	233	208 (520)	0	6500
Revenue from impwa in 2004	78	286 (416)	0	2106
Revenue from rapes in 2004	384	130 (234)	0	1690
Revenue from paprika in 2004	42	78 (78)	0	286
Reason to grow tomatoes:				
high cash return	572	80%(40)	0	1
easy to manage	547	27%(45)	0	1
easy to market	541	29%(45)	0	1
low costs of production	537	8.5%(28)	0	1
consumption	527	2% (14)	0	1

Source: PRISM 2005 dataset

3.7 Training and credit

This part of the data contains variables on the different training that is followed by the households (table 3.6). Special interest in on which organizations offered the training and how the household received it. Secondly the source of the households' market information is part of the content of this data. This part also contains data on how many households use credit to finance their production and if so, where they got their credit. The table shows that most households finance their crop production with savings.

Table 3.6 Capacity building and credit

Variable	Obs	Mean (st.dev)	Min	Max
Training for crop production	900	23%(42)	0	1
Credit for inputs	900	9%(29)	0	1
Savings for input	900	91%(28)	0	1
Gifts for input	900	9%(28)	0	1
Donations for input	900	0%(5)	0	1

Source: PRISM 2005 dataset

3.8 Summary and conclusions

Summary

68% of the households in the PRISM dataset are participating in one of the IDE projects. These households classified the benefit of the participation as 'very much' or 'much'. The most mentioned first source of income for the interviewed households are irrigated vegetables followed by rain fed vegetables. The average area of irrigated crops in the dataset was 0.8 ha and the average area of rainfed crops was 3.5 ha. 86% of the households interviewed were involved in irrigation; 68% of them irrigated with buckets and 48% used a treadle pump or both.

The most important source of water for the irrigating households is a stream, followed by a well. The households who had adopted the treadle pump had increased the average total land

they irrigated from 0.3 to 0.6 ha. Reasons not to have a treadle pump are a lack of money or the high price of the pump. The average price paid for a treadle pump with all necessary piping was $156. Most treadle pumps have been bought on credit, while seed and fertilizer are bought with savings.

Conclusions

This chapter shows were the restrictions and possibilities are with concern to the data, to find the answer to the questions asked in the introduction. The fact the data was collected at only one moment (cross-section data) makes is difficult to compare the development of treadle pump users considering the development they would have made without the pump in the same time span.

Most remarkable findings from this chapter are: 1. the importance of credit for households to buy the treadle pump. 2. The nearly doubled amount of land irrigated by treadle pump users.

4. Adoption of the treadle pump

4.1 Introduction

For policy purposes it is important to know which variables play a role in the adoption decision of a household for a certain irrigation method. IDE facilitates the supply chain development of treadle pumps. For IDE it is interesting to see what characterizes a household that decides to adopt the treadle pump instead of another irrigation method. Which factors play a role in determining which households use the treadle pump compared to adopting other irrigation methods? With this knowledge it will be possible to see how policies can be targeted to alleviate the constraints faced by farmers to adopt the treadle pump or any of the other irrigation methods. Special interest is on the rate of adoption by the least well-off smallholders.

A Multinomial Logit model can show which factors play a significant role in the decision to adopt a certain irrigation method (Bekele and Drake, 2003). By looking at the effect on all irrigation methods the effect of the variables on the adoption of the treadle pump will be more distinct. The results of the quantitative analysis will be cross-checked with qualitative interviews with households that adopted or did not adopt a treadle pump and with experts on Zambian smallholder agriculture.

Section 4.2 describes the theory on adoption of new technologies. Section 4.3 describes the empirical adoption model. Section 4.4 gives the test statistics of the Multinomial Logit. Section 4.5 gives the results of the Multinomial Logit and section 4.6 contains the feedback from the field. Section 4.6 ends the chapter with a summary and conclusions.

4.2 Theoretical background

Technological change allows higher production with the same quantity of inputs or the same production volume with less inputs. The shadow price of an investment represents the annual additional profit that can be obtained with an additional unit of this quasi-fixed input (Oskam et al., 2003). If the expected discounted shadow price is higher than the expected investment costs a profit maximizing household should invest (Dixit and Pindyck, 1994). The discounted shadow price depends on the expected prices of the marketable products, the expected prices of inputs, the quantity of other quasi-fixed inputs, and the discount rate.

The shadow price is uncertain and the decision maker may sometimes be more concerned about possible loss rather than possible gains. Subsistence farmers in developing countries have to make investment decisions in an uncertain economic climate and have a high degree of vulnerability. Risk is influenced by the magnitude of the investment, the degree of uncertainty, and how well financial setback can be observed (in assets and income). Moreover the risk attitude of a farmer is relevant. On the other hand, certain investments can mitigate risk (Oskam et al., 2003), for example wells can increase water availability in times of droughts. Risk has to be taken into account when modeling the investment decision. The distance to the nearest adopter and the intensity of the contact is one of the variables that Ghadim and Pannell (1999) use to model investment decisions. This is in line with the finding of Linder (1987) that the rate of adoption is primarily determined by the expected benefits of adoption to the potential adopters.

A farmer can consciously decide not to invest in spite of the investment costs being lower than the shadow price (a positive net present value). This is the case when the household

maximizes their utility instead of their profit. Other aspects, like leisure time, are then more important for these households. Their preferences have to be taken into account when modeling the adoption decision.

When maximizing profit or utility, the farmer faces constraints to their possibilities due to the quality and quantity of available (family) labor, land, availability of water, and their market access.

According to Namara et al. (2007) the following variables are proven most important in explaining technology adoption processes; human-capital, attributes of the technology, nature of the farming system, the tenure system, resource endowment, risk, social capital, and social psychological factors. For micro-irrigation in specific they found that the most important determinants included access to groundwater, cropping pattern, availability of cash, level of education, and the poverty status of the household.

4.3 Empirical adoption model

Multinomial Logit

The most suitable way to model the probability of the different investment decisions of a households in the dataset is with a Multinomial Logit (Greene, 2003). The Multinomial Logit is an adaptation to the binary logit model that offers the possibility for more than two outcomes. The probability of an individual choosing to invest in one of the alternative irrigation methods is an expression of the explanatory variables and the coefficients (formula 1). The Multinomial Logit is estimated by maximum likelihood. The Multinomial Logit assumes that there is no natural ordering in the alternative outcomes and independence of any two alternatives. This means that if one of the categories would be left out of the analysis the influence of the variables on the other categories would remain the same. This assumption is called the independence of irrelative alternatives (IIA) and implies that all error terms are independent. The Multinomial Logit gives a clear picture of the importance of the variables in explaining the adoption of the treadle pump in specific and not for irrigation as a whole.

$$\Pr(Y_i = j) = \frac{e^{\beta_j' x_i}}{\sum_{j=0}^{3} e^{\beta_j x_i}} \qquad (1)$$

Where:

Pr	probability;
Y_i	Irrigation method of household i;
j	Irrigation methods; 0=none 1=bucket irrigation, 2= treadle pump, 3= mechanic pump;
x_i	Characteristics variables household i;
β_i	Coefficients of the variables for the outcome j.

Dependent variable

Adopters of the treadle pump are those households who decided to acquire a treadle pump and are still using it. Table 4.1 shows the distribution of users and owners of the treadle pump. There are 397 households who own a treadle pump and 371 households who use a treadle pump. This means that most of the owners use their pump and most of the users own a pump.

There are 16 households who use a treadle pump, but do not own one. For this analysis on the adoption of the treadle pump we look at all households who use a treadle pump. Those households are taken as adopters too as probably they have to pay some contribution to be able to use a treadle pump and would maybe buy one if the shared pump was not available. There are 42 households who own a pump, but do not use it (dis-adopters). Of these 42 there are 8 who now use a motorized pump. These 8 are in the motorized pump group. 33 households use buckets and are in the bucket group. One household is in the not irrigating group. The dataset does not contain information about why the other 34 owners (or nearly 9%) do not use their pump. However looking at the research area it is very likely that these pumps broke and that the owners did not have the means or motivation to repair their pumps. Considering the amount of broken treadle pumps observed in the field, it is actually surprising that the percentage is not higher.

Table 4.1 Ownership and usage of the treadle pump.

	Does not use	Uses	**Total**
Does not own	348	16	364
Owns	42	355	397
Total	390	371	761

Due to the low number of adopters of furrow, hose, electric, and diesel pump irrigation these could no be used in the Multinomial Logit. As only two households use a furrow or canal for irrigation and no households use hose irrigation both are left out of the model. The adopters of electric or diesel pumps are limited; both have less than 30 observations. Therefore they are grouped together as they are both high investment irrigation methods. 22 observations had to be dropped due to inconsistent data; these households used no irrigation method, but did grow irrigated crops. Two observations were excluded from the Multinomial Logit due to expected errors in data entry in the size of the land owned, considering the values of the other variables.

Explanatory variables

The variables expected to explain adoption are grouped in: management potential, farming potential, irrigation potential, and risk attitude. It is expected that households who manage their farm in a more intensive and knowledge intensive way will be more likely to adopt a pump for irrigation as this is in line with their management. The decision to irrigate and how to irrigate is affected by the possibilities a household has in the terms of land assets. The irrigation potential is determined by the accessibility of water, funds to buy irrigation techniques, and the availability of these. The risk attitude determines if a household thinks it is wise to adopt. The variables used in the regression are described in Appendix B.

Management potential

There is no data on expected benefits in the dataset, one of the most important determinants of adoption according to Linder (1987). Management potential variables are expected to pick-up some of the expected benefit of the household, give some indication of their motivation; which factors they find most important for their overall utility and show there labor constraints.

The management potential is expected to depend on some of the household characteristics. The *age* of the household head is expected to proxy for the innovativeness of the household. The *age squared* is included to see if the age effect is different for young and old farmers. Education is expected to give information about the quality of the management skills. To see if the level of education influences adoption the household head's *level of education* and the

level of education of the spouse are included. Chapter 3 showed that most household heads had upper primary education or lower or upper secondary education. Therefore education is taken in the regression by adding dummies for low education (no or only lower primary) and high education (college or university degree). The *number of years a household has farmed* and if any *training* for crop production was followed is also expected to have a positive effect on the management skills of the household and thus increase the adoption of the treadle pump. The composition of the household is included by means of *the number of members in the household* and the *dependency ratio*. The dependency ratio is the proportion of household members who are aged lower than 14 or higher than 65. The available labor determines the quantity part of the management potential; irrigation with buckets is very labor intensive where irrigation with the treadle pump increases the productivity of the labor available. This could lead to less labor being needed on the farm and open opportunities for off-farm employment.

Farming potential

The second group of variables contains information on the farming potential of the household. The first variable is *location*. Different provinces have different natural and socio-economic possibilities for the household. The farming potential group also contains information about the *size of the traditional land owned*, private *land owned* (this is land that is legally owned by the household), and *land rented* by the household. The more land owned the more possibilities there are to grow crops. It has to be taken into account that the present acreage is used to approximate the acreage of the land before the adoption decision was taken. Information on the crops grown is not included in the Multinomial Logit. As there is only one year available, this data is a direct result of the adoption decision and can thus not be used as independent variable in explaining that decision. The variables available give an indication of a household's production possibility. Another important aspect of the farming system is the access to markets, which could be measured as the proximity of an urban area or distance to an asphalt road. However this data was not collected in PRISM and Zambia not yet mapped enough in GIS to find the information.

Irrigation potential

The third group of variables contains information on the irrigation potential of the household. Certain prerequisites are necessary for irrigation, like accessibility of water, and a source of investment. To proxy for the last variables on the self-assessed *welfare* of the household in 2000 are included. The possibilities to irrigate are also determined by location in an *IDE project area*, as the main supply of the treadle pump are set up through IDE. The main water source of the household and the accessibility of their main source are not included, as they are only available for irrigating households. Information on the number of months the household has access to water and the distance of the source tot the field is not available either, but would have been very relevant.

Risk perception

The fourth group of variables is on risk perception. The risk perception of the treadle pump and the farmers attitude towards risk have been proven to be very important in the adoption process of new technologies (Marra et al., 2003). However it is hard to collect data on these issues and therefore, there are no direct variables on this topic in the dataset. Three variables will be used to pick up some effect of the risk attitude. Firstly *sex* of the household head as females have often be proven to be more risk averse than men. Membership of a *farmer group* increases the understanding of the adoption process and thus decreases the risk of the decision. The third variable that is expected to influence the risk attitude is off-farm income, a

household that had a main source of income between 2000 and 2003 outside agriculture will be less risk averse as they have a more diversified source of income.

4.4 Test statistics for the Multinomial Logit

The Pearson Chi2 test shows that there is a significant relation between the real and the predicted outcomes. The Multinomial Logit predicts 53% of the outcomes correctly (table 4.2). This is a significant improvement to a random distribution, which would predict 25% correctly. 46% of the non-irrigators are predicted correctly, 49% of the bucket irrigators, 66% of treadle pump users, and 13% of the motorized pump owners. The highest predictive power is for the treadle pump, which is the main focus of this analysis. The prediction of the motorized pump adopters is lowest. The low value is probably due to the few observations in this last group and the fact that electric and diesel pump adopters are merged together.

Table 4.2 Predicted versus actual irrigation methods (in % of total)

		Predicted				
		No irrigation	Bucket irrigation	Treadle pump	Mechanic pump	Total
Actual	No irrigation	**6.7**	5.1	2.8	0.0	14.6
	Bucket irrigation	3.3	**19.9**	16.9	0.3	40.4
	Treadle pump	0.2	12.6	**25.9**	0.8	39.5
	Mechanic pump	0.2	1.7	2.8	**0.7**	5.4
	Total	10.4	39.3	48.5	1.8	100

The Hausman test for Independence of irrelevant alternatives (IIA) shows that the outcomes are independent of each other. This means the most important property of the Multinomial Logit is fulfilled. The Wald test for 'combining outcome categories' shows that none of the categories can be collapsed and thus all 4 irrigation methods have significantly different coefficient values.

The Likelihood ratio test and Wald test for independent variables show which variables are of significant (at 5%) importance to the adoption decision; the choice between the 4 irrigation methods. Age of the household head, living in Central Province, living in Southern Province, size of the land owned, size of the land with deed, size of the land rented, struggling to survive in 2000, living in IDE project area, being member of a farmgroup, and off-farm income between 2000 and 2003 all have a significant effect on the adoption decision. Other variables do not have a significant effect on the adoption decision.

4.5 Marginal effects of the adoption decision

A Multinomial Logit gives coefficients for the probability of a certain outcome compared to the base outcome. These coefficients are hard to interpret. The marginal effects are more meaningful. Greene (2003) recommends to only report the marginal effects. Marginal effects show the effect of a variable changing with one (or a dummy changing from 0 to 1) on the probability of choosing a particular method. The probability of any of the outcomes is a continues value between 0 and 1. The results can be found in table 4.3 and are described in this section. For the complete table that includes the t-values, see Appendix C, table C.1. All variables described are significant at a 5 % significance level unless stated otherwise.

No irrigation

The Multinomial Logit shows that there are no variables that significantly increase the probability of a household deciding not to irrigate (adopt none of the irrigation techniques). There are however variables that significantly decrease the probability of not irrigating. None of the management potential variables is significant. Living in Central province decreases the probability of a household choosing not to irrigate by 0.05, living in Southern Province decreases the probability by 0.13 compared to living in Lusaka Province. This indicates that the Central and Southern Province have less favorable conditions for growing rainfed crops. The marginal effect of an extra ha of private land is -0.02. It is intuitively correct that owning a larger parcel of land makes is less attractive not to irrigate as the potential revenues (opportunity costs) increase with the size and thus make more intensive cropping attractive.

Table 4.3 Marginal effects

	No irrigation	Buckets	Treadle pump	Motorized pump
Management skills				
Age	0.00	-0.03***	0.03***	-0.02
Age2	-0.00	0.00***	-0.00***	0.00
No education head	0.00	0.04	-0.02	-0.02
High education head	0.04	-0.12	0.19	0.07
No education spouse	-0.01	0.01	0.01	0.00
High education spouse	0.02	0.13	-0.17	0.03
Experience in years	-0.00	-0.01	0.01	0.01
Followed crop training	-0.00	-0.00	0.02	-0.02
Size of household	-0.00	0.01	-0.01	0.00
Dependency rate	-0.00	-0.02*	0.02*	0.00
Farm potential				
Central Province	-0.05***	0.02	-0.02	0.05
Copperbelt	0.00	0.05	-0.04	-0.02
Southern Province	-0.13***	-0.05	0.17***	0.01
Size of traditional land	-0.01	-0.01	0.01	0.01***
Size of private land	-0.02**	0.00	0.02*	-0.00
Size of rented land	0.06	0.28	-0.47	0.12***
Irrigation potential				
Welfare high 2000	-0.00	-0.04	0.03	0.01
Welfare low 2000	-0.01	-0.15***	0.15***	0.01
Welfare very low 2000	0.02	0.00	-0.02	0.00
Living in IDE area	-0.12***	-0.18***	0.29***	0.02
Risk				
Household head sex	0.01	0.11*	-0.11*	-0.02
Member farmer group	-0.07***	-0.12**	0.18***	0.01
Off-farm income	0.03	-0.06	-0.05	0.09**

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

The irrigation potential variables show that living in an IDE project area decreases the probability of not irrigating by 0.12; having IDE in the area increases the opportunity costs of not irrigating and thus makes it less attractive not to irrigate the land. The significant risk attitude variable is membership of a farm group. The Multinomial Logit shows that becoming

member of a farm group decreases the probability of not irrigating by 0.07. One explanation is that membership of farmer groups increases the information access. Increased information decreases the risk involved in taking investment decisions based on net present value. Therefore those households that are member of a farmer groups are more likely to take a decision to invest.

Bucket irrigation

The following variables have a significant marginal effect on the probability of using buckets for irrigation. The probability of adopting bucket irrigation decreases by 0.03 for every year a household head becomes older. The dependency rate shows that for every percent the dependency rate increases the probability of adopting bucket irrigation decreases (at 10% significance); households that have more children and elderly, compared to adults have relatively less labor available and thus are less likely to adopt labor intensive bucket irrigation. There are no variables in the farming potential group that have an impact here. Having a low self-assessed welfare status in 2005 decreases the probability of adopting bucket irrigation. Living in an IDE project are has a negative effect of 0.18 on the probability of choosing to use buckets, as the opportunity costs of not exploiting the land more intensively increase. The sex of the household head and farm group membership are the risk variables that play a role in the choice to use buckets or not; female household heads have a 0.11 higher probability of irrigating with buckets (at 10%), this could indicate that females prefer to work hard (irrigate with buckets), than take the risk of investing in irrigation technology. Membership of a farmer group decreases the probability of using buckets for irrigation by 0.12 this is for the same reasons as why it decreases the probability of not irrigating; membership increases potential benefits from more intensive exploitation of the land and it can be a proxy for farmer motivation.

Treadle pump irrigation

The following variables had a significant marginal effect on the probability of adopting a treadle pump. Age has a positive effect on the probability of adopting the treadle pump of 0.03 per year. The effect decreases by 0.00 every year. The older a farmer is the more years he has had to collect money to buy a treadle pump as the other investments in the household have already been made (e.g. children have finished school), but after 52 the willingness to invest decreases as the payback time becomes too short. Not the size of the household, but the dependency rate is significant. For every increase of the percentage of dependent household members the chance of adopting the treadle pump increases by 0.02 (at 10%). This is in line with the expectation that the treadle pump increases the efficiency of the available labor and is thus most attractive for households where labor is scarce. The treadle pump is a labor saving technology. It increases the production possibilities as it decreases the labor constraint. Living in the Southern Province increases the probability of adopting the treadle pump by 0.17, this is because the necessity to use irrigation is higher in Southern Province than in other provinces, due to lower availability of water. The size of the private land increases the probability of adopting the treadle pump with 0.01 per ha (at 10%). Irrigation potential in the form of a low self-assessed welfare in 2005 increases the probability of adopting the treadle pump by 0.15. This indicates that the richer poor are most likely to adopt the treadle pump. IDE targets the poor and this shows they reach one of the two lowest welfare groups. Living in an IDE project area increases the probability of adopting the treadle pump by 0.29 as the presence of IDE increases the accessibility of the treadle pump and complementary production technologies. Female headed households have a 0.10 lower probability of adopting the treadle pump (at 10%). Being member of a farmer group increases the probability of

adopting the treadle pump by 0.18 as it increases the potential benefit of the treadle pump through improved access to information and possibly market access.

Irrigation with motorized pump

The following variables show the marginal effect of the explanatory variables for the probability of adopting a motorized pump. None of the management potential variables are significant here. Farming potential variables are more important; for every ha of traditional land more owned the probability of adopting a motorized pump increases by 0.01. Traditional land can possibly be cultivated in the future and thus indicates expansion possibilities. For every extra ha of land rented the probability of adopting a motorized pump increases by 0.12. Renting in land shows the managerial tendency to farm on a larger more professional scale, which will also increase the probability to adopt a pump suitable for more intensive production. Off-farm income between 2000 and 2003 increases the probability of adopting a motorized pump by 0.09. Off-farm income can be a necessary pre-condition to be able to gather enough money to be able to buy a capital intensive motorized pump.

Adoption

So, how do these variables relate to each other in the adoption decision? Age decreases the probability of using bucket irrigation, but increases the probability of adopting the treadle pump. Education of the household head or the spouse does not influence the adoption decision. Probably because it had less of an effect on managerial skills than expected. Also farming experience and training are not relevant according to the regression. Following Linder (1987) this could be explained by the adoption being largely determined by the expected returns as can be expected from the success of the neighbors. In that case it is not the farming experience or training that determines the probability of adopting through managerial skills, but through having neighbors or friends who increased their welfare with a treadle pump. The size of the household does not significantly influence the adoption decision, but the dependency rate does. More dependent household members decreases the probability of using buckets and increases the probability of adopting the treadle pump, as it increases the labor productivity.

Living in Southern province increases the probability of adopting the treadle pump and decreases the probability of not irrigating at all, due to the low availability of water and thus low potential for rainfed crops. More private land increases the probability of adopting the treadle pump and decreases the probability of not irrigating, as the potential benefits are higher. Assessing the own welfare as low in 2005 increases the probability of adopting the treadle pump and decreases the probability of not irrigating, as IDE targets these households. Living in an IDE project area increases the probability of using the treadle pump and decreases the probability of not irrigating or using buckets for irrigation, as the irrigation technology becomes more available. Female headed households are less likely to adopt the treadle pump and more likely to adopt bucket irrigation. There are more reasons why women would be less likely to adopt a treadle pump. According to literature women are more risk averse, which could increase the probability of them adopting a new technology. On the other side also external factors can play a role; women might have less access to the necessary credit, information, or the technology itself.

The fact that IDE targets households below the $1 or $2 a day poverty line and the selection of households that receive credit, could mess-up the results of the regression for the treadle pump. However if the Multinomial Logit is run with only the treadle pump users that bought the pump on cash (selected themselves instead of being selected) the coefficients are similar

to the ones presented above. This indicates that indeed the Multinomial Logit fulfills the intention of showing which characteristics of a household determine the adoption decision and that the decision is not made for them, by the credit institutions who select their beneficiaries.

4.7 Feedback from the field

According to one of the experts at IDE; most smallholders are interested in adopting the treadle pump when they see a demonstration. In the past there were households that were able to buy a pump with cash. However the last years none of the smallholders for whom the treadle pump was designed have the cash to purchase one. If smallholders want to get a treadle pump they need to find a credit scheme they can apply too. Official credit institutions like banks are very difficult to access by smallholders. Informal 'money-go-rounds' (Chilimbas) and private money lending (Kaloba) are also less common in Zambia then in other countries, according to O'Reilly (1996) This means that only if the supplier of the treadle pump arranges a credit scheme the smallholders can purchase a treadle pump. In this case adoption is not determined by any of the variables used in the regression above, but adoption is determined by an available credit scheme. A credit scheme takes certain characteristics in account to insure payback, however this can not be done to rigorously by IDE as their aim is to help the poorest (the ones with the least prospects) smallholders. This could help to explain the relatively low R-squared of the Multinomial Logit.

From the 8 households interviewed 6 were introduced to the treadle pump by their neighbors. This in line with the non-significant effect of education and training, and Linder (1987) findings that adoption is mainly determined by expected returns, based on the returns of their neighbors. One household mentioned membership of a cooperative as the reason he had a treadle pump. 4 out of 5 adopters wanted the pump to increase their income and decrease the workload. According to these 4 households the reason they have a pump and other households do not, is because the other households were not willing to make the sacrifices necessary, work hard and save. The three households that did not have a treadle pump all wanted a treadle pump, but did not have the means to buy a treadle pump with cash. One household expected to earn enough with buckets to buy a treadle pump within a year, one household would be able to buy with the help of a credit scheme and one household had so little income they hoped some organization would give them a pump. Of the 5 treadle pump adopters interviewed 4 had paid for their pump in cash; the two households who actually paid the full price and only with income from farming, both bought their pump 10 years ago. This in line with what the expert said; when IDE just started, people were able to buy their pump with cash, but the last 5 years hardly any farming household still can. One household bought a pump more recently with cash after selling the maize, but as it was a secondhand pump the price had halved. One household paid with income from off-farm employment and only one household (indicating that the interviews are not representative) bought the pump on credit.

According to another expert the three most important factors in the adoption decision are if the household can save enough money to buy the pump, if the households had been introduced to the pump, and time to see the potential benefits of the pump. This is also the 'learning by doing' factor as mentioned before. He also mentioned that households who adopt the treadle pump, were bucket irrigating when they took the adoption decision. Growing irrigated crops is a reason to adopt the treadle pump. A third expert also emphasizes the money issue, saying that the price of a pump in Zambia of $100-$260 makes it very difficult for a farmer below the $1 or $2 a day poverty line to buy one without credit. One of the things IDE is doing, is making alterations to the pump to increase the affordability. According to

Polak and Yodar (2006) a whole range of affordable irrigation technology is still waiting to be developed.

The field officers questioned the fact that older household heads were more likely to adopt the treadle pump. However one officer mentioned that some of the treadle pump projects of Care International were targeted at older farmers and that this might have influenced the results. The field officers also mentioned that the income from sources other than cropping influenced the adoption; at this moment many farmers in are struggling because their cattle has died and now the demand for the treadle pump is increasing noticeably in the areas affected.

4.8 Summary and conclusions

Summary

The Multinomial Logit shows which variables determine the adoption of different irrigation methods. Age decreases the probability of using bucket irrigation, but increases the probability of adopting the treadle pump. Education of the household head or the spouse does not influence the adoption decision. Probably because it had less effect on managerial skills than expected. Also farming experience and training are not relevant according to the regression. Following Linder (1987) this could be explained by the adoption being largely determined by the expected returns. An indicator for the expected returns is the success of the neighbors who have already adopted a treadle pump. In that case it is not the farming experience or training that determines the probability of adopting through managerial skills, but through having neighbors or friends who increased their welfare with a treadle pump. The size of the household does not significantly influence the adoption decision, but the dependency rate does. More dependent household members decreases the probability of using buckets and increases the probability of adopting the treadle pump, as it increases the labor productivity.

Living in the Southern province increases the probability of adopting the treadle pump and decreases the probability of not irrigating at all, due to the low availability of water and thus low potential for rainfed crops. More private land increases the probability of adopting the treadle pump and decreases the probability of not irrigating, as the potential benefits are higher. Assessing the own welfare as low in 2005 increases the probability of adopting the treadle pump and decreases the probability of not irrigating, possibly because IDE targets poor households. Living in an IDE project area increases the probability of using the treadle pump and decreases the probability of not irrigating or using buckets for irrigation, as this irrigation technology becomes more available. Female headed households are less likely to adopt the treadle pump and more likely to adopt bucket irrigation probably due to risk attitude and limited access to institutions.

Evidence from the interviews with smallholders and IDE staff, indicates the relevance of Linder (1987) observations, who found that the most important factor in the adoption of technologies is expected success based on the practice of neighbors using the technology, ‘learning by doing’. This also explains the non-significance of the education and farming experience variables. The latter being surprising, because it contradicts with the results of other studies like the adoption of drip-irrigation by Namara et al. (2007). Now that households have seen the potential benefits, adoption has become an issue of affordability. Cash to buy a treadle pump is only seldom available for smallholders and credit schemes are necessary for them to adopt the pump.

Conclusions

This chapter established which factors play a role in determining which households use the treadle pump compared to adopting other irrigation methods. The treadle pump is most attractive to families with relative scarce labor as the treadle pump increases labor productivity. Households with a low self-assessed welfare have a higher probability of adopting the pump indicating that the poor smallholders are reached with this project.

The factors that have to be targeted by IDE to alleviate the constraints faced by farmers are complex; the establishment of farmer groups and demo-sites as IDE is doing increases the potential benefits and the adoption of the treadle pump. The demo-sites increase the 'learning by doing' opportunity and the farmergroups increase the adoption by complementing the potential benefits from the treadle pump (through increased bargaining power and increased access to information and markets). The credit issue is however not tackled at the moment. IDE is trying to establish credit facilities in collaboration with META, but this needs time. The development of cheaper pumps can alleviate the credit constraint in the future.

5. Farming practice and the treadle pump

5.1 Introduction

Irrigation benefits the poor though higher production, higher yields, lower risk of crop failure, and higher and year-round farm and non-farm employment, according to Hussain and Hanjra (2004). Irrigation enables smallholders to adopt more diversified cropping patterns and to switch from low-value subsistence production to high-value market-oriented production. This chapter aims to give an overview of the difference in farming practice between households that use a treadle pump and those who use other or no irrigation methods.

As the treadle pump requires a relatively small investment sum, this irrigation technology is especially suitable for smallholders. According to a FAO report the treadle pump 'increased the area under irrigation, reduced work time compared to bucket irrigation, improved crop quality, reduced frequency of irrigation to two or three times a week, decreased labor use compared to bucket irrigation, increased additional and new crops grown each season, and the number of growing cycles as crops are able to grow faster with full irrigation' (Kay and Brabben, 2000).

In this chapter the use of land, irrigation, labor, crop choice, yield, and welfare are compared for the adopters of the different irrigation technologies. The division of households is the same as in the Multinomial Logit model; households who do not irrigate, households that use buckets for irrigation, households that adopted the treadle pump and households who use a motorized pump. The differences in farming practice are tested for significance across the groups with t-tests. This chapter concludes with the most important differences between households with a treadle pump and the other households by giving an answer to research question 2, what are the differences in farming practice between adopters and non-adopters of the treadle pump? The results of the quantitative analysis will be cross-checked and where necessary extended with qualitative interviews with households that did and did not adopt the treadle pump and with experts on Zambian smallholder agriculture.

This chapter will compare the households following different irrigation methods. Section 5.2 focuses on land and irrigation. Section 5.3 explains the differences in use of labor. Section 5.4 looks at the area grown per crop. Section 5.5 compares the total crop income, section 5.6 compares the income for different ownership groups, section 5.7 compares the income per ha. Section 5.8 focuses on self-assessed welfare. Section 5.9 compares the welfare distribution. Section 5.10 contains the feedback from the field and section 5.11 summarizes the results and gives the conclusions

5.2 Land and irrigation

Irrigation enables farmers to increase their labor productivity. It enables households to cultivate a larger area of irrigated crops. Adopters of the treadle pump grow an average of 4.7 ha of crops, as can be seen in table 5.1. This is significantly more than non-irrigators (3.1 ha) and the bucket irrigators (3.5 ha). Treadle pump irrigators cultivate a smaller area than the owners of a motorized pump, but this is not significant. Households who own a treadle pump grow an average of 1.0 ha of irrigated crops. This is significantly more than the households who use buckets (0.6 ha). Households with a motorized pump also have an average of 1 ha under irrigation; it is remarkable that the owners of a motorized pump do not have a larger area under irrigation than the adopters of the treadle pump. Treadle pump adopters grow an average of 4.1 ha of crops. This is significantly more than the non-irrigators and the bucket

irrigators (2.8 and 3.0 ha respectively), but less than the motorized pump irrigators who grow an average of 6.3 ha of rain fed crops. The fact that treadle pump adopters grow a larger area of rainfed crops indicates that they use part of the labor freed and the income from irrigated crop production as input for the rainfed production to. The income from irrigation can be invested in buying more seed for rainfed crops or buying oxen or ploughs.

The above is consistent with one of the advantages that a FAO report (Kay and Brabben, 2000) mentions; the treadle pump increases the area under irrigation, because with the same labor a larger area can be cultivated. The figures also show that treadle pump adopters not only grow more irrigated crops than those who do not irrigate or use buckets, but also grow more rainfed crops. Treadle pump owners cultivate a larger total area than these two groups. As expected owners of motorized pumps cultivate an even larger area, as they grow more rainfed crops, but this difference is too small to be significant.

Table 5.1 Land and labor averages

	No irrigation (N=110)	Bucket (N=364)	Treadle (N=352)	Motorized (N=48)
Cultivated area (ha)	3.1**	3.5***	4.7	6.0
Irrigated area (ha)	-	0.6*	1.0	1.0
Rainfed area (ha)	2.8**	3.0***	4.1	6.3**
Household members	6.0***	6.9*	7.2	8.1**
Dependency ratio	34***	39	41	39
Household members working on-farm	85%*	80%**	82%	76%**

***Significantly different then treadle pump adopters at 1%
**Significantly different then treadle pump adopters at 5%
*Significantly different then treadle pump adopters at 10%
Source: PRISM 2005 dataset

5.3 Labor

The treadle pump is a labor saving technology. This means that either a larger area of land can be cultivated or that household labor can be freed for off-farm employment. Irrigation increases employment opportunities through increased demand for inputs and increased supply of outputs (Hussain and Hanjra, 2004). Households who adopted the treadle pump have on average 7.2 household members (table 5.1). This is significantly more than households who do not irrigate (6.0) or use buckets (6.9). Households with a motorized pump have the most household members (8.1). As household size does not influence the adoption decision, this means that households using a more advanced irrigation method get bigger families. Officially polygamy is illegal, but it is still common practice in the rural areas. Large sums have to be paid to the parents of the bride, so the richest men can buy the most wives and is likely to have more children.

The dependency ratio (percentage of household members under 14 or over 65) of treadle pump adopters is 41%. With an average family of 7.2 this would mean 3 dependants and 4 household members that can work on the farm or elsewhere. Non-irrigators have a lower dependency ratio of 34%; in an average family this would mean 2 dependants and 4 members who can work. In households with a treadle pump 82% of the household members work on the farm or in the household. This percentage shows that also household members indicated as ‘dependants’ work on the farm. Households who adopted the treadle pump have a lower percentage of household members working on the farm than households who do not irrigate

(85%), but higher than households who use buckets (80%) and higher than households with a motorized pump (76%).

None of these figures give evidence that the treadle pump increases the number of family members working off-farm, which the FAO reports suggests as one of the advantages of the treadle pump. This could be because when crop production becomes more profitable it is also more profitable to expand the farm instead of finding a job elsewhere. This would be in line with Hussein (Hussain and Hanjra, 2004) who stated that irrigation benefits the poor through higher and year-round farm employment.

5.4 Cropping

Irrigation increases the possibilities to grow high value crops. These are mostly vegetables, which are much higher value crops compared to rainfed crops, like maize and wheat. Irrigating households are able to diversify their production to spread risk and produce the crops that are expected to have the highest revenues. Table 5.2 provides information on the cropping pattern of the households, namely the area planted with the different crops and the number of households who grow the crop.

Table 5.2 Average area planted per crops (in ha)

Crop\ acreage	No irrigation (N=110)	Bucket (N=364)	Treadle (N=352)	Motorized (N=48)
Tomatoes	0.06 (N=1)	0.23 (N=139)	0.22 (N=150)	0.36 (N=29) ***
Rape	0.35 (N=2)	0.20 (N=139)*	0.24 (N=141)	0.38 (N=16)***
Cabbage	-	0.16 (N=72)	0.19 (N=84)	0.25 (N=15)
Green Maize	0.25 (N=1)	0.36 (N=64)	0.28 (N=60)	0.34 (N=12)
Onion	-	0.19 (N=40)	0.16 (N=35)	0.25 (N=10)
Okra	0.13 (N=1)	0.24 (N=9)**	0.21 (N=23)	0.21 (N=7)
Impwa	-	0.22 (N=27)	0.16 (N=28)	0.44 (N=9)***
Paprika	-	0.21 (N= 9)	0.18 (N=22)	0.29 (N=5)**
Watermelon	-	0.19 (N=24)	0.20 (N=14)	0.37 (N=10)*

***Significantly different then treadle pump adopters at 1%
**Significantly different then treadle pump adopters at 5%
*Significantly different then treadle pump adopters at 10%
Source: PRISM 2005 dataset

The crop grown most often by bucket, treadle pump, and motorized pump irrigators is the same; tomatoes. There is not much difference in the area planted with tomatoes between bucket irrigators (0.23 ha) and adopters of a treadle pump (0.22 ha), but the motorized pump irrigators do grow a significant larger area (0.29 ha). The second most grown crop for all groups is rape (a green leafy vegetable); however it is a lot less popular with motorized pump users than with the other groups. Bucket irrigators grew a smaller area (0.20 ha) with rape than treadle pump users (0.24 ha), but the motorized pump users who grow rape grow it on a significant larger area (0.38 ha) than treadle pump irrigators. The third most grown crop is also the same for all three groups. It is cabbage; grown on 0.16 ha, 0.14 ha, and 0.24 ha respectively for the three groups. The other crops grown are green maize, onion, okra, impwa, paprika, and watermelon. Okra is grown on a larger area by bucket irrigators than by the treadle pump users. Impwa (African eggplant), paprika, and watermelon are grown on larger areas by the owners of motorized pumps than by the treadle pump adopters.

There is no systematic difference in the cropping pattern of the bucket irrigators and the treadle pump irrigators. There is however a difference between the treadle pump adopters and the motorized pump irrigators; the last grow larger areas per crops. Considering that motorized pumps do not grow a larger area of irrigated crops (table 5.1) this indicates that the owners of motorized pumps specialize in certain crops; often crops less popular with the treadle and bucket irrigators.

5.5 Total crop income

Households that irrigate can increase their income by an increase in quantity and quality of production. Irrigation enables an increase in quantity through a more intensive use of the land (more cropping cycles and/or higher yield per cycle) and by enabling the cultivation of a larger area with the same amount of labor. Irrigation has a positive effect on the quality of the crops and lower risk of crop failure due to the increased availability of water, which can increase the price of the crops grown. To calculate the income per crop the total input costs per crop are deducted from the revenue. The costs of inputs are the costs of seed, fertilizer, pesticide, transport, and hired labor. The total cost of production is the sum of the costs per crop plus the costs of spare parts and maintenance. In general smallholders use little to no inputs. However those who own a treadle pump or a motorized pump do spend more on inputs.

Table 5.3 Average total income per crop (in $)

Crop\ income	No irrigation	Bucket (N=364)	Treadle (N=352)	Motorized (N=48)
Impwa	-	104 (N=31)**	390 (N=34)	598 (N=9)
Okra	-	0 (N=24)	312 (N=26)	130 (N=7)
Tomatoes	52 (N=2)	156 (N=202)**	260 (N=210)	1066 (N=36)***
Watermelon	-52 (N=1)	130 (N=29)*	234 (N=20)	416 (N=11)
Cabbage	-	182 (N=106)	156 (N=123)	286 (N=19)*
Green Maize	-26(N=1)	104 (N=73)	130 (N=69)	104 (N=14)
Rape	-0.0 (N=6)	52 (N=207)***	104 (N=207)	104(N=20)
Paprika	-	26 (N=15)	52 (N=26)	208 (N=4)*
Onion	-	26 (N=55)	52 (N=52)	650 (N=13)***
Total	78 (N=2)	312 (N=233)***	520 (N=256)	2132 (N=35)***

***Significantly different then treadle pump adopters at 1%
**Significantly different then treadle pump adopters at 5%
*Significantly different then treadle pump adopters at 10%
Source: PRISM 2005 dataset

In 2005 treadle pump owners who grew impwa, got the highest average income ($390) from that crop (table 5.3). The second highest income crop was from okra ($312), while tomatoes ($260) are the third most income generating crop. Bucket irrigators got significantly less income than treadle pump users from impwa ($104). If we look at table 5.2 we see however that they grew Impwa on a larger area (0.22 ha) than the treadle pump adopters (0.16 ha). This shows that the income per ha of the treadle pump users is higher for impwa. This is studied in more detail in the next section. The highest income crop for bucket irrigators was cabbage ($182). The income from cabbage was higher for bucket irrigators than treadle pump irrigators, because the latter had higher input costs. Tomatoes ($156) and watermelon ($130) came second and third. Owners of motorized pumps got the most income from tomatoes ($1066), onion ($650), and impwa ($598).

The average total income from crop production (including all crops sold, not only the ones mentioned in the table) for treadle pump users was $520. Household who used buckets to irrigate had a significantly lower average income of $312. The motorized pump owners had the significantly highest average income at $2132. The income of treadle pump users is thus $208 higher than the income of bucket irrigators, but a lot lower than the users of a motorized pump. The ratio of income between the bucket irrigators and treadle pump irrigators is 0.6; exactly the same as the ratio of the irrigated area between these two groups of households. This indicates that bucket irrigators get the same average income per ha from their irrigated area, but due to the labor intensive production they can irrigate a smaller area than the treadle pump adopters. We look at this in the next section. The average income from cash crops for the two not irrigating households, who sold cash crops equaled $73.

So, if we look at the costs of the technology; are households who own (expensive) irrigation technology better of despite investment costs? The treadle pump adopters paid on average $159 for the full system. Considering the average difference in income between a bucket irrigator (and even more a household that does not irrigate) and the adopter of a treadle pump, the extra income in one year is higher than the cost of buying a treadle pump. That would mean that a household using buckets, that buys a treadle pump could repay the investment costs within the year by increasing the area they cultivate. The households have little costs for expanding their cultivated area as most households have more land than they can cultivate. Households will need some extra money to buy variable-inputs for the extra area they want to cultivate. The average total costs for the production of the cash crop was $104 for the bucket irrigators, $156 for the treadle pump irrigators, and $286 for the households who used a motorized pump. This means that bucket irrigators had an income of 300% relative to their short-term investment costs for crop production. The treadle pumps were only slightly more efficient with 333%. The users of a motorized pump have the largest relative income with 550% of their short-term investment.

5.6 Income and ownership

During the fieldtrips one can see many badly maintained or less intensively used treadle pumps. Often these households are the households who got their pump on credit and have stopped repaying the loans. These households did not invest in their treadle pump and are less motivated to maximize the benefits they can get from the pump. Households who did make an effort to buy a treadle pump, feel a sense of ownership and maintain their pump much better to grasp the benefit of their investment. To see if there is any evidence in the dataset to back-up the hypothesis that ownership increases the income of the households with a treadle pump, the average income is compared for the different ways households paid for their pump.

Table 5.4 ownership and income (in $)

	Number of households	Average income (st.dev.)
Cash purchase	66	442 (182)
On credit	180	364 (52)
Cash loan elsewhere	6	650 (494)
Hire purchase	78	650 (208)
Token of appreciation	22	494 (208)
Grant	49	234 (78)

Source: PRISM 2005 dataset

Table 5.4 shows that the household who got their treadle pump on hire purchase or on a cash loan elsewhere, got the highest income ($650) and that the households who got the pump on a grant had the lowest income ($234). The households who got their pump on credit got the second lowest average income at $364. The table does not show that households who bought their pump on cash have a much higher income. It would be interesting to study this further in the future, to see if indeed investment of the household to get the treadle pump influences the increase in income they get from it. Another relation between ownership and income could be that the way the household received the pump proxies for their welfare and that better-off household get a higher income from the treadle pump. However this data gives evidence for neither of these hypotheses.

5.7 Income per ha

The FAO mentions a higher yield due to higher yield per cropping cycle and more cropping cycles, because the crops grow faster under full irrigation, as one of the benefits of the treadle pump. (Kay and Brabben, 2000). Table 5.4 shows the income (revenues-costs) of the different crops per ha (divided by the area the crop is grown on). This might give some interesting insight in the effect of the treadle pump on the yield of certain crops compared to using buckets or motorized pumps. The figures in this table are price multiplied by yield. The difference in income is thus not only caused in a difference in the quantity of yield per ha, but also by the price. The price can be different reflecting the quality and the level of guaranteed supply; owners of a motorized pump have higher yield and have a better bargaining position. However crop price fluctuates over place and time; the income per ha in 2005 can in no means be used as a prediction for any other year. As bucket irrigators, treadle pump irrigators, and motorized pump irrigators are however exposed to the same variability in market price the income for these groups can be (roughly) compared.

Table 5.4 Income per ha (in $)

Crop\ income p. ha	No irrigation	Bucket (N=364)	Treadle (N=352)	Motorized (N=48)
Impwa	-	17,784 (N=22)	2,730 (N=24)	2,002 (N=7)
Okra	-	416 (N=9)*	1,716 (N=19)	4,888 (N=6)**
Tomatoes	-52 (N=1)	1,352 (N=128)	2,002 (N=137)	3,328 (N=29)
Watermelon	-	1,170 (N=22)*	5,200 (N=14)	2,288(N=9)
Cabbage	-	3,146 (N=57)**	1,456 (N=74)	988 (N=15)
Green Maize	-	676 (N=54)	988 (N=46)	442(N=11)
Rape	-	1,248 (N=121)	1,274 (N=131)	1248 (N=15)
Paprika	-	208 (N=8)	286 (N=17)	494 (N=4)
Onion	-	572 (N=33)	546 (N=32)	1,300 (N=8)
Total	-	1,378 (N=217)	1,534 (N=235)	4,030 (N=32)**

***Significantly different then treadle pump adopters at 1%
**Significantly different then treadle pump adopters at 5%
*Significantly different then treadle pump adopters at 10%
Source: PRISM 2005 dataset

Okra is a crop that clearly flourishes under irrigation. The yield per ha increases nearly four fold by changing from bucket to treadle pump irrigation and three fold on top of that if the household uses a motorized pump. The treadle pump has the same effect on watermelon and increases the income per ha more than four fold. Cabbages get the highest income per ha under bucket irrigation; the income is more than double that of the treadle pump users. The average income per ha is not significantly different for treadle pump users than for bucker

irritators. This means that with the cropping patterns used by the two groups the overall income per ha is the same. This indicates that the treadle pump does not increase income by higher yield per cycle, more cropping cycles per year or a better price for better quality crops. The significantly higher income of treadle pump users compared to bucket irrigators is only due to the larger area they can cultivate. This is not in line with Kay and Brabben (2000). The motorized pump increases the yield per cropping cycle, and/ or the number of cropping cycles, and/or the price received for the crops as a result of selling larger quantities and better quality. Although motorized pump users cultivate the same acreage as adopters of a treadle pump, their total income is nearly three times higher.

5.8 Welfare

Irrigation has the power to increase the welfare of a household through higher returns to physical, human, social, financial, and natural assets. Irrigating households have a higher and more diversified nutritious intake and a better ability to pay for health and education. The transition to the market economy integrates the poor into land, labor, commodity, and information markets and it empowers them (Hussain and Hanjra, 2004). Data was collected on the self-established welfare of the households. The self-established welfare is the answer of the household to the question if they were; 'well-off' (able to make investments), 'ok' (able to meet needs but without extra investment), 'struggling' (able to meet needs by depleting assets and/ or help) or 'unable' (dependent on support for subsistence). The income data can be used to proxy for welfare. Slesnick (1998) states that income is not the same as welfare, but that analyses using income, instead of welfare do not have to be worse than analyses using theoretical better proxies for welfare

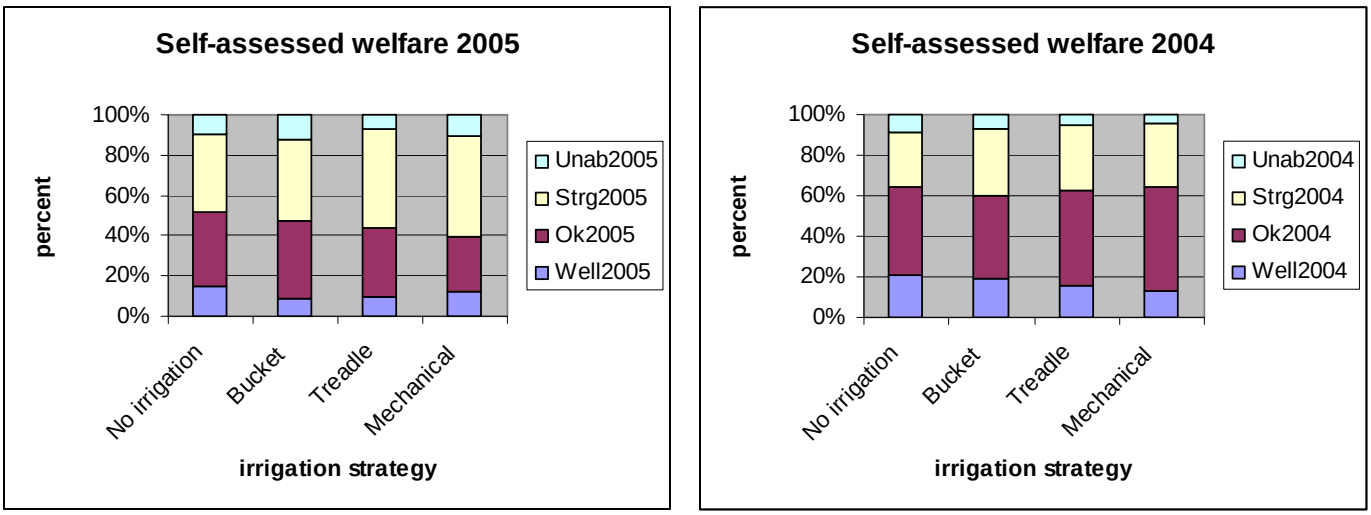

Figure 5.1 The self-assessed welfare of the different households for 2005 and 2004
Source: PRISM 2005 dataset

Figure 5.1 and 5.2 show the self-assessed welfare in 2005, 2004, 2000 and 1995. In all groups of households following different irrigation methods the welfare state most named is the same, but different over the years. In 2004, 2000, and 1995 most households independent of which irrigation method they follow classify themselves as 'ok'; the third out of four possible choices. In 2005 however for all groups the most mentioned self-assessed welfare was 'struggling'. This indicates that changes that affect all households (e.g. macro economic/ climatologically) are more important for the self-assessed welfare than the irrigation method. To check if the total crop income is related to the self-established welfare for 2005, 2004, 2000, and 1995, it is compared for the different households. The highest correlation is

between income in 2005 and being well-off in 2005 (a correlation of 0.21). It shows that crop income does not determine the self-assessed welfare of the households in this sample; households that have low to no income from crops (e.g. the non-irrigators) do not assess themselves as bad off. The non-irrigators actually have the highest number of households in the well-off group compared to the other groups, but also a higher percentage than the other groups in the unable group. A possible explanation is that part of this group does not irrigate because they have better sources of income than crops and are thus better off and a part does not irrigate but is dependant on crops and are thus worse off.

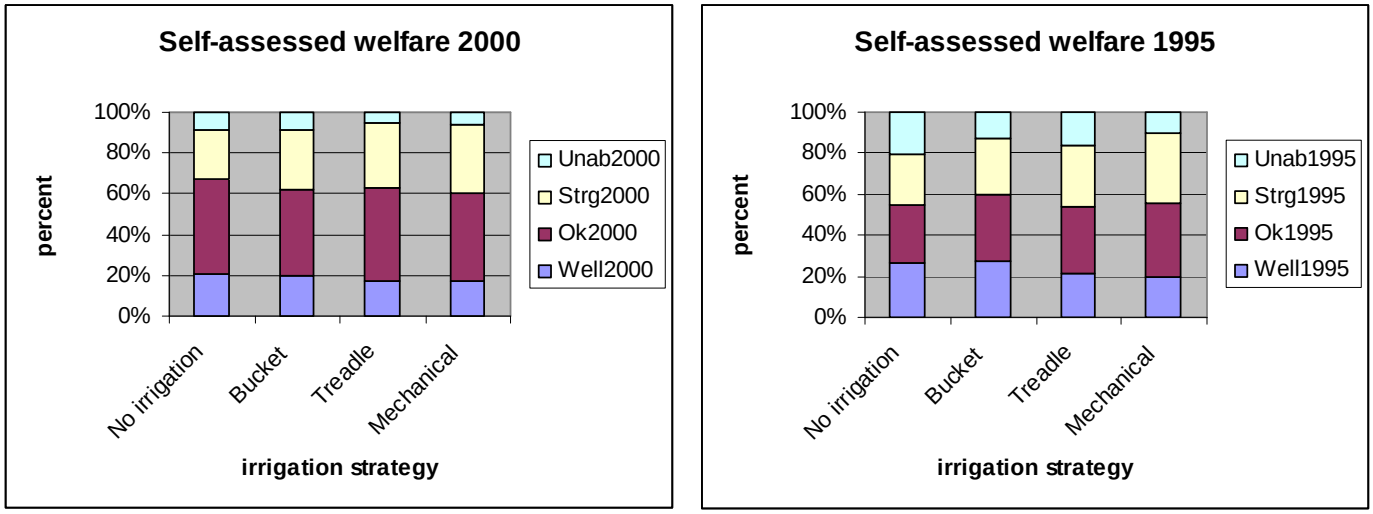

Figure 5.2 The self-assessed welfare of the different households for 2000, and 1995
Source: PRISM 2005 dataset

5.9 Welfare distribution

Irrigation should increase the productivity of land and labor. The owners of these assets can improve their welfare by using irrigation; however this increases the relative poverty for the non-irrigating and thus increases inequality. Increased productivity of labor can relatively worsen the position of the households that are affected by decreased labor availability due to HIV/AIDS, for instance, as they benefit less from the increase of productivity. IDE has special programs to help the households affected by HIV/AIDS to adopt the treadle pump, as it can help them increase their production with the labor available in the household and increase their nutrition. IDE aims to help the poorest to improve their standard of living. For IDE it is important the welfare of the households that do not adopt the treadle pump is not negatively affected, by an increase in inequality in a village.

Figure 5.1 shows no indication of inequality between the households using the different irrigation methods. As said in the former section the most named sell-assessed welfare per year is the same for the households independent of which irrigation method they follow. There is a large inequality however in crop income for the different households following different irrigation methods. There is no clear relation between crop income and self-assessed welfare, indicating that there are other factors influencing welfare that are not taken into account here. These can be income from other sources than crop production or welfare indicators that are not related to real income. Households that are good at exchanging products will have a low crop income according to this analysis, but a relative high welfare. Also environmental factors can play a role (e.g. having a health clinic in the proximity). More

sophisticated methods like the Atkinson's framework, where welfare depends on prices, expenditure and the demographic characteristics of the household can not be used due to insufficient information.

5.10 Feedback from the field

All the households that used a treadle pump increased the area they irrigated after they adopted the treadle pump. All households with or without a treadle pump said that the treadle pump increases the yield of the users. However the question why it increases yield was always answered by that treadle pump increases the area cultivated. None of the interviewed mentioned a higher yield per ha or an increase of cropping cycles due to faster growing crops.

According to an expert at IDE the fact that increased yield per cropping cycle per ha and an increased number of cropping cycles per year are not mentioned is probably correct. Households still lack knowledge on irrigation and will often over or under irrigate. Their beds are seldom leveled which means that some of the crops will get much more water than other crops.

According to the same expert the revenue from the treadle pump depends on the size of land a household is able to irrigate. It is possible to use bucket irrigation on the same sized areas as the treadle pump. If the bucket irrigation is done in a knowledgeable way the revenue is the same as when the land is irrigated with the treadle pump. However it is very likely that this irrigation knowledge is more widely available for the adopters of the treadle pump. This means two things; 1. If a bucket irrigating household has the same knowledge as a treadle pump adopters they can get the same income and if they want, gather enough money to buy a treadle pump on cash. 2. It means that dis-adopters who gained the knowledge while they were adopters can get the same revenue while not using the pump anymore.

Off-farm employment was not common among the households interviewed. One household sometimes worked on a large commercial farm during harvest time, but none had a regular job. This is in line with the high percentage of family members working on the farm; there seems to be little opportunity or necessity to find off-farm employment.

According to the interviewed households the poor did not get poorer in real terms, but the gap between them and the adopting households increased making them relatively worse off and without any opportunity to grasp any of the economic benefits. One household mentioned however that because they had a pump, fresh vegetables are now available in the village while in the past the villagers had to go into town to buy vegetables .

5.11 Summary and conclusions

Summary

This chapter aimed to establish the difference in farming practice between the households who use no irrigation, bucket irrigation, the treadle pump or a motorized pump. The more advanced the irrigation method the more land is cultivated, not only is a larger area planted with irrigated crops, but also the rainfed crops are grown on a larger area by those households using a more advanced irrigation method. Bigger households use more advanced irrigation techniques.

Irrigation increases the possibilities to grow high value crops. All irrigating households (independent of which irrigation method they use) planted the largest area with tomatoes,

followed by rape, and cabbage. In 2005 adopters of the treadle pump got the highest average income ($390) from impwa followed by okra ($286), and tomatoes ($260). Irrigation significantly increases the income of okra and watermelon per ha. Cabbages however get the highest income per ha when grown under bucket irrigation. On average bucket irrigators get the same income per ha from their irrigated area as treadle pump users. The motorized pump does increase the income per ha nearly three fold.

The average total income from crop production for treadle pump users was $520. Household who used buckets to irrigate had a significantly lower average income of $312. The motorized pump owners had the significantly highest average income of $2,132. The income of treadle pump users is $208 higher than the income of bucket irrigators.

In all groups of households following different irrigation methods the welfare state most mentioned is the same, but different over the years. In 1995, 2000, and 2004 most households independent of which irrigation method they followed classified themselves as ‘ok’; the third out of four possible choices. In 2005 however for all groups the most mentioned self-assessed welfare was ‘struggling’, the second out of the four possible choices. There is only a very low (0.21) correlation between self-assessed welfare and income.

All the adopting households increased the area they irrigated after they adopted the treadle pump. The treadle pump increases labor productivity. None of the interviewees mentioned a higher yield per ha or an increase of cropping cycles due to faster growing crops. According to one of the experts, households still lack knowledge on irrigation. They will often over or under irrigate, which can explain why the yield per cropping cycle or number of cropping cycles of treadle pump users is not higher than that of bucket irrigators.

Conclusions

The farming practice of households using a treadle pump is different from those using other or no irrigation methods. Irrigation enables farmers to switch from subsistence production to growing high value crops for the market. The treadle pump is a labor saving technology and therefore the area irrigated is significantly larger for the adopters, compared to bucket irrigators. The average income per ha is not significantly different for treadle pump users than for bucker irritators. However adopters of treadle pump cultivate a larger area of irrigated and rainfed crops. This indicates that the increase in labor productivity and possibly the extra income of the irrigated crops, increases the production of rainfed crops too. The income of treadle pump users is $208 higher than the income of households using buckets. The comparison of households using the different irrigation methods did not show a difference in their self-assessed welfare. The crop income is not correlated with self-assessed welfare.

6. Effect treadle pump on welfare

6.1 Introduction

This chapter aims to establish which part of the welfare of households that adopted the treadle pump, can be allotted to the treadle pump. According to IDE the treadle pump increases the annual income of a farmer with $100 (IDE, 2007). Chapter 5 showed that the annual difference in income between treadle pump users and non-irrigating or bucker irrigating households was $442 and $208 respectively. This chapter calculates the increase in welfare due to the treadle pump in two ways; through the effect on crop income and on self-assessed welfare. Total income would be the best proxy for welfare of the household, but the dataset does not contain information on income from other sources than agriculture. As only a few farms earned income from other sources than agriculture it is assumed that the income from crops is a proxy of total income. Self-assessed welfare is the grade households given to their own welfare. A very subjective, but important measure. Chapter 5 showed that households that adopted the treadle pump had significant higher income from crop production than households who used buckets or no irrigation. The chapter did not show a clear difference in self-assessed welfare. This chapter will try to establish which part of this difference in income and self-assessed welfare can be allotted to the treadle pump.

Self-selection hinders an easy establishment of the effect of the treadle pump. The treadle pump was not randomly distributed among households, but households selected themselves to get a treadle pump. Households with more management potential will possibly be more likely to adopt a treadle pump but also to have higher crop yields. Consequently those adopting will probably also had a higher income/welfare if they had not adopted the treadle pump. In that case it is not only the treadle pump that increases income. Ordinary Least Squares (OLS) and Propensity Score Matching (PSM) are two ways to control for the difference due to household characteristics. OLS is a simple technique, while the latter is more sophisticated.

We have to take into consideration that this chapter analyses only the effect of the treadle pump on the users of the treadle pump. Those households who own a treadle pump but are not using it are left out the analysis (8% in this dataset).

Section 6.2 describes the theoretical background of the analyses. Section 6.3 describes the Ordinary Least Squares specification. Section 6.4 gives the results of the OLS. Section 6.5 describes Propensity Score Matching (PSM) method. Section 6.6 gives the results of the PSM. Feedback from the field, is given in section 6.7. The conclusions of this chapter are presented in section 6.8.

6.2 Theoretical background

‘Enabling prosperity’ is IDE’s main goal. Welfare is the objective economic term for the prosperity that IDE wants to increase. Welfare is measured by income and by the self-assessed welfare of the household. The grade the households give their own welfare is the most accurate measure, but income is added as it has a much larger variation and is expected to be an important determinant of welfare. Income is revenue minus variable costs from crop production. Household are expected to maximize income given the technology and market constraints they face and the endowments of labor, land, capital, and water. Farm households are typically price takers, working with family labor and taking into account a high level of uncertainty with respect to the level of output.

A farm household can have a different objective or more objectives than profit maximization. There are suggestions that farmers adopt satisfying instead of maximizing behavior. In this case they set a minimum acceptable level of profits. Self-assessed welfare contains data on how the households themselves asses their situation. It can be expected that self-assessed welfare will be linked to income and will largely be explained by the same factors. Although self-assessed welfare is a much more subjective measure than income, it is a far more important one. Income alone does not determine the self-assessed welfare of a household. It is very interesting to analyze the self-assessed welfare, as in takes into account more subjective measures like relative welfare. An increase in income that is relatively lower than the increase in income of the other households in the village will leas to a lower self-assessed welfare.

6.3 OLS Specification

OLS can be used to determine the effect of the treadle pump adoption on welfare, controlling for other explanatory variables. It is assumed that the different irrigation methods have a different effect on welfare. To test for this assumption two regressions were run, with different dependant variables that can represent welfare; 1) income and 2) self-assessed welfare. Different irrigation methods are represented by dummies in the two regressions. Significant coefficients for the irrigation methods indicate a significant effect of the irrigation methods on welfare.

The same categories of explanatory variables are used as in the Multinomial Logit (management skills, farming characteristics, and risk attitude). Size of cultivated areas per crop is added to explain income / welfare differences. The variables used in the regression are described in Appendix B. The outcomes are expected to show the same effects as in chapter 5; treadle pump adopters have a higher income than non-irrigating households and bucket irrigators, but less than owners of a motorized pump. The self-assessed welfare is given in a number between 1 and four; 1= unable to survive without help, 2= struggling to survive, 3= ok, and 4 = doing well.

6.4 Results of the OLS

Specification tests for the OLS show that the error variances are not constant. This means the error terms are heteroskedastic. Although the OLS estimator remains unbiased and consistent, they are not efficient and the estimated standard errors are wrong. Because of this, confidence intervals and hypotheses tests are not reliable. The standard errors in this analysis are necessary to establish the significance of the coefficients. Therefore the robust option is used, to adjust the standard errors for heteroskedasticity and the non-normally distributed standard errors. Generalized Least Squares can not be used to adjust for the heteroskedasticity because the variance in the error term is unknown. The Variance Inflation Factor (VIF) shows that multicollinearity, correlation of the explanatory variables, is not present in this specification. Ramsey's reset test, does not reject the hypothesis of no misspecification.

Table 6.1 shows the effect of the irrigation techniques on income and self-assessed welfare in 2005. The t-values of the coefficients can be found in Appendix D, table D.1. The income regression has an R-squared of 0.19; this means that this regression explains 19% of the variation in income. Income depends on many variables that are not included in the dataset (e.g. the yield and prices) and unobservables like management skills (that we can only proxy for by household characteristics). The self-assessed welfare regression has an R-squared of 0.18. Self-assessed welfare is even more dependant on unobservables than income.

According to the OLS estimates, the treadle pump has a significant effect on welfare, but not on income. This is surprising. The difference in income between treadle pump users and bucket irrigators was $208, according to chapter 5. This is nearly the same value as the coefficient ($229) in the income regression, but it is only significant at a significance level of 15%. The OLS keeps all other variables (like land size) constant. This means that the effect of the treadle pump on the amount of land cultivated is not taken into account. This is unrealistic as chapter 5 gave evidence that the largest part of the increase of income from adopters was due to an increase of irrigated land.

Table 6.1 OLS estimates of income and self-assessed welfare

	Income in $	**Self-assessed welfare** 1= unable to 4= well-off
Irrigation method		
Bucket	66	-0.01
Treadle	229	0.17***
Mechanic	1252*	0.25**
Management skills		
Age	-87***	-0.12***
No education head	-97	-0.04
High education head	87	0.17
No education spouse	136	0.06
High education spouse	461	0.30
Experience in years	-8	0.03
Followed crop training	-75	0.03
Size of household	101	0.06
Farm potential		
Central Province	152	0.46***
Copperbelt	152	0.38***
Living in IDE area	130	0.10
Crops		
Tomatoes in ha	1027*	-0.08
Cabbage in ha	277	0.43
Impwa in ha	-724	0.18
Rape in ha	-2	0.01
Paprika in ha	-1092	1.37**
Green maize in ha	257	0.31***
Onion in ha	-587	0.66**
Melon in ha	156	-0.20
Okra in ha	4585	-0.75
Risk		
Household head sex	-14	-0.13
Member farmer group	-99	0.08
Constant	*231*	*2.52*
R-squared	*0.19*	*0.18*
Number of observations	*643*	*685*

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

The treadle pump has a highly significant effect on the self-assessed welfare of 0.17 (significance level of 1%). Bucket irrigation does not have a significant effect on either income or self-assessed welfare. A motorized pump increases income by 1,250 (at 10%) and self-assessed welfare with 0.25 (at 5%) points on a scale from 1 to 4.

The following control variables influence income and self-assessed welfare: Age decreases income and self-assessed welfare. For every ten years the household head increases in age the income will decrease with $87 and self-assessed welfare will decrease with -0.12 points (both at 1% significance). As in the Multinomial Logit for the adoption decision, none of the other variables to capture management skills are significant. Farming potential has a significant effect in the form of location. Living in the Central Province or in the Copperbelt increases welfare (0.46 and 0.48 respectively at 1%), compared to living in Lusaka Province. The cropping variables show that area per crops does not significantly explain income, except for the area of tomatoes. This indicates that yield and / or price varies so much that the area planted with a crop is not an indication of income. An extra hectare of tomatoes increases income with $1,027 (at 10%). Curiously the area per crop does affect self-assessed welfare. A hectare of paprika increases self-assessed welfare by 1.37 points (at 5%), a hectare of green maize increases welfare by 0.31 points (at 1%), and a hectare of onions increases welfare by 0.66 points (at 5%). This could either be through income; these crops maybe easily exchanged with neighbors for other goods; improve the diet of the household or through psychological factors like households feeling more satisfied if they grow these crops (maybe more difficult to grow).

Chapter 5 showed a significant difference in income between the users of the treadle pump and households using buckets or not irrigating at all of $208 and $442 respectively. However, the results of the regression show that the effect of the treadle pump on income is not significant. This gives more evidence for the statement made in the former chapter that income only increases through an increase in the area cultivated. The treadle pump has a positive and significant effect on the self-assessed welfare. This can be explained by the increase in income due to the treadle pump, because ownership of the treadle pump increases their status or because the increase in crops produced also diversifies the food consumption of households.

6.5 Propensity Score Matching method

Propensity Score Matching (PSM) is a way of establishing the effect of the treadle pump correcting for self-selection bias. PSM, matches the adopting household to non-adopting households. The OLS regression did not show a significant effect of the treadle pump on income. PSM estimation leaves space for other variables changing with the adoption of the treadle pump, like land size. PSM is a non-parametric estimation technique that estimates the Average Treatment effect of the Treated (ATT). PSM is based on the work of LaLonde (1986). The analysis in this chapter follows the more recent work of Becker, who focused on the analyses in Stata (Becker and Ichino, 2002).

The ATT is the increase in income or self-assessed welfare. It is the difference between the income or welfare for households with treadle pump and the income or welfare for the same household without the treadle pump. However the income or welfare of a household who adopted the treadle pump if they had not adopted the treadle pump is unknown. To show the effect of the treadle pump on the adopters, the ATT has to be established by comparing the income or welfare of a treated household with an untreated household that is as similar as possible to the treated household before they adopted the treadle pump. Every observation

gets a Probability Propensity Score (PPS) based on pre-treatment characteristics. Households who adopted the treadle pump and who decided not to irrigate or irrigate with buckets with the same PPS are then compared. In this way the missing data on the counterfactual of adoption of the treadle pump are filled in. This procedure is called PSM. The difference in income or welfare between users of the treadle pump and non treated households with similar characteristics is the result of the adoption of the treadle pump.

Probability Propensity Score

The PPS is the conditional probability of receiving a treatment given pre-treatment characteristics. Formula (1) shows that the probability of receiving a treatment given the pre-treatment characteristics is defined by the probability of exposure to the treatment conditional on the pre-treatment characteristics. In other words, the probability of adopting the treadle pump. The PPS score has to be assigned to test that the observations can be divided in balanced groups. This is the balancing property. The observations are divided into groups, until each group consists of treated and non treated observations that are not significantly different in any of their observable characteristics.

$$PPS \equiv \Pr\{D = 1 | X\} = E\{D | X\} \qquad (1)$$

Where:

PPS	Probability Propensity Score;
Pr	Probability of exposure to the treatment;
D	Dummy for receiving treatment;
X	Pre-treatment characteristics;
E	Expected value.

The pre-treatment variables included in estimating the PPS should affect both the probability of receiving the treatment and the outcome of the treatment. An important assumption for the matching process to take place is the Conditional Independence Assumption (CIA). This assumption states that if the observables variables are controlled for, the difference in outcome is due to the treatment. This assumption is the main idea of PSM.

The PPS are assigned to the households based on management potential, farming potential, irrigation potential, and risk attitude. The variables included in the estimation of the PPS are described in Appendix B. All independent variables have a relation with income / welfare and adoption of the treadle pump. The same variables are used in the PPS for receiving the treatment (adopting the treadle pump) as in the Multinomial Logit for adoption. If the pre-treatment characteristics (few of them were asked in the questionnaire) were not available the present characteristics of the household were taken as a proxy for the characteristics before adoption. This means the PPS are less reliable, but will still give a good indication of the effect of the treadle pump.

Propensity Score Matching

PSM can be used to compare the outcome of treated households to non treated households, given a population of matched households. The treatment is the adoption of the treadle pump. The effect of the treatment is the gain in income or welfare for the 2005 variables. The

Average Treatment effect of the Treated (ATT) is the difference in outcome between a treated and non-treated household with the same probability of receiving the treatment, the same PPS (Becker and Ichino, 2002).

There are different ways to perform PSM. The chance of finding a treated and a non-treated household with exactly the same PPS is very small. Therefore different matching techniques based on PPS exist. In these methods the households are matched based on the variables used in assigning the Propensity Score and satisfying the balancing property. It is difficult to decide on the suitability of these different methods. Therefore the three most commonly used methods are presented. This will increase the reliability of the results. The first method is the method of the Nearest Neighbor. All treated units are compared to the most similar non-treated unit. The second method used is Kernel matching. This method compares all treated units with a weighted average of the non-treated households based on the similarity. The third method used is the stratification method. This method calculates the average outcome per group and compares this with the non-treated units in the same group.

Two options that will be used here to perform PSM are dropping households outside the common support and bootstrapping the standard errors. The common support area is the area that most Propensity Scores are in, in other words the outliers (based on PPS) are outside the common support. Bootstrapped standard errors are the average standard error of the ATT based on multiple simulations of different samples with replacement from the data itself. Bootstrapped standard errors account for the uncertainty associated with the estimation of the Propensity Score.

6.6 Results of the PSM

This section will present the results of the Propensity Score Matching. In the first part the Propensity Scores are assigned to the households and the balancing property is checked. In the second part the households are matched based on the variables used in assigning the PPS and satisfying the balancing property, to give unbiased estimates of the effect of the treadle pump on the users of the treadle pump. In this section first the Probability Propensity Scores are assigned to the households and then treated and non-treated households will be matched to establish the effect of the treadle pump on income.

Estimation of the Probability Propensity Scores

PPS are assigned to the households to determine their probability of adopting the treadle pump. The households are divided in as many groups as necessary to form groups that are on average not significantly different. See appendix D, table D.2 for the observations per group. The PPS score shows that the households are divided in 6 balanced groups. The estimation of the Propensity Scores can be found in table 6.2. Appendix D, table D.3 includes the t-values of the coefficients. 63% of the adopting households are predicted correctly.

The estimation of the PPS shows a high amount of significant variables. There is a big overlap in de variables significant for the PPS and the variables significant in de Multinomial Logit. This indicates the robustness of the analyses. Age of the household head positively influences the PPS of adopting the treadle pump at 5% significance level. Age of the household head squared has a negative effect at 5% which means that the increased probability of adoption decreases with age. The dependency rate has a positive effect at 5%. Living in Central Province has a negative effect at 5%. Living in the Copperbelt has a negative effect at 1%, this means that compared to living in Lusaka Province households in the Copperbelt and Central province have a lower probability to adopt. Both the amount of

traditional and private land have a positive effect on the PPS at a 10% confidence level. Struggling to survive in 2000, increases the PPS at 1%. This could be because these households were searching more for ways to get out of their position, or because IDE targets these groups. Living in a project area increased the probability at 1%. Female headed households have a lower probability of adopting the treadle pump at 1% and membership of a farmergroup increased the PPS at 1% significance level.

Table 6.2 PPS estimates for adoption of the treadle pump

	PPS for adoption of the treadle pump
Management skills	
Age	0.72***
Age2	-0.00***
No education head	-0.06
High education head	-0.03
No education spouse	-0.06
High education spouse	-0.47
Experience in years	0.05
Size of household	-0.11
Dependency rate	0.05**
Farm potential	
Central Province	-0.32**
Copperbelt	-0.51***
Size of traditional land	0.01
Size of private land	0.01*
Size of rented land	0.09
Irrigation potential	
Welfare high 2000	0.04
Welfare low 2000	0.42
Welfare very low 2000	-0.05
Living in IDE area	0.78***
Risk	
Household head sex	-0.40***
Member farmer group	0.51***
Constant	-2.91
R-squared	0.1216

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

Propensity Score Matching

Before matching the PPS, some alterations are made to the data. To get the best matching results, the households that are outside the common support are dropped in the matching procedure. There are 351 treated (users of a treadle pump) households in the PSM procedure. The number of controls depends on the matching method. There are different methods to perform the PSM. The results of three methods are presented. The standard errors are bootstrapped to account for the uncertainty associated with the estimation of the propensity score. Table 6.3 shows the result of the different estimation methods for the two different dependent variables.

The estimated Average Treatment effect of the Treated for income is very similar for the three different matching methods used. Table 6.3 gives the results. Matching the adopters of the treadle pump to the most similar non-adopting household, with Nearest Neighbor Matching shows an ATT of $252. Matching according to the Kernel matching method shows an ATT of $250 and according to the Stratification method the effect is the lowest at $240 per household. All matching methods show a significant ATT (at a significance level of 1%) of nearly $250. This means that those households that use a treadle pump will on average have a crop income that is nearly $250 higher than if they had not adopted the treadle pump. Section 5.5 showed that the difference in income between a household that used buckets or a treadle pump was $208 and between non-irrigating households and treadle pump users was $442.

Table 6.3 Average Treatment effect of the Treated

	Average income effect (in $)		Average self-assessed welfare effect (on a scale from 1 to 4)	
	ATT	No controls	ATT	No controls
Nearest Neighbor Matching	252***	155	0.10	177
Kernel Matching	250***	411	0.15***	411
Stratification Method	240***	411	0.15***	411

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

The ATT for self-assessed welfare is very similar for Kernel Matching and matching with the Stratification Method, but different for Nearest Neighbor Matching. Nearest Neighbor matching shows that the ATT, the average effect of the treadle pump on the self-assessed welfare of the adopters, is not significant. However both other methods show a significant effect of 0.15 points on the scale from one to 4. Section 5.6 did not show a significant higher welfare for adopters of the treadle pump. The OLS in section 6.3 however did show a significant effect on the adoption of the treadle pump on self-assessed welfare of 0.17 points, compared to not irrigating.

6.7 Feedback from the field

The interviews with the households cast no doubt on the contribution of the treadle pump to rural welfare. All adopters said they are better off now, than they would have been without the pump and that they are better off than their neighbors, who do not have a pump. The improvements they made to their standard of living were impressive. Households now have a more diverse diet with the food products they grow and buy products like fish, meat, milk, and vegetables. All the households with a treadle pump are able to send all their children to school. Some households had problems paying all school fees before they got the treadle pump and 1 household said its children have reached a higher level of education due to the treadle pump.

All households that adopted the treadle pump increased their household assets; a cement house with iron roof sheets, a radio-cassette, a video-deck, and a solar system are some examples. Productive assets bought are; a bicycle, a plow, a harrow, an engine pump, goats, and oxen for plowing. However there was also a household that decreased her livestock activities. Three households that owned a treadle pump now have savings, something they were sure they would not have without the treadle pump. The interviewees emphasized an

increase in household assets due to the use of the treadle pump. Productive assets were mentioned less. Shah (2001) found the distribution between household and productive assets was about 50-50. Also the IDE field officers thought that the increase in household assets was stressed more, because these assets are more status enhancing.

The insignificant effect of the area planted with a certain crop in the OLS regression can be due to the highly fluctuating prices. For example, households sold a box of tomatoes for between $5 and $32 depending on the time of the year and the market conditions at that moment. This shows the moment of sales is more important than the size of the area cultivated. Increased market information probably has a more important effect on income than the acreage planted.

The adopters were all sure they would have never managed to acquire their current standard of living if they had not adopted the treadle pump. The eagerness of the households without a treadle pump to get a treadle pump confirms the idea that the treadle pump contributes to welfare. Only one household mentioned that the pump was great in theory, but that there was a long way between using the treadle pump and welfare; water availability, availability of spare parts, market access, and transport play an important role. The story of this household is probably representative for more households all over Zambia who adopted the treadle pump. But also this household had managed to increase its standard of living.

6.8 Summary and conclusions

Summary

The dataset offers two ways of measuring welfare; income and self-assessed welfare. Methods used are Ordinary Least Squares regression and Propensity Score Matching (PSM). The latter corrects for the bias due to self-selection.

OLS regression estimates the effect of the treadle pump keeping other explanatory variables constant. The dummies for the irrigation methods show that the treadle pump only has a significant effect on self-assessed welfare, not on income. The effect on the self-assessed welfare is 0.17 at a scale from 1 to 4 (at 1%). The crop areas did not play a significant role in explaining income, indicating that the yield and / or price vary too much to make acreage a good indicator for income.

PSM compares the income of adopters with the income of similar (based on pre-treatment characteristics) non-adopting households. All matching methods show a significant Average Treatment effect of the Treated (at a significance level of 1%) on a yearly base of $250. The effect of the treadle pump on self-assessed welfare is 0.15 points according to two of the applied matching methods and not significant according to one of the methods.

The interviews with the households cast no doubt on the contribution of the treadle pump to rural welfare. All adopters said they were better off than they would have been without the pump. They feel they are better off than their neighbors who do not have a pump. The eagerness of the households without a treadle pump to get a treadle pump, confirms that households feel that the treadle pump contributes to their welfare. One household mentioned that the pump had great potential, but that there are a lot of obstacles on the road between getting a treadle pump and benefiting from it to its full extent.

Conclusions

This chapter aims to establish which part of the welfare of households that adopted the treadle pump can be allotted to the treadle pump. The OLS regression in this chapter shows that the effect of the treadle pump on income was not significant, as OLS keeps other variables (like land size) constant. PSM estimation leaves space for other variables changing with the adoption of the treadle pump and shows an average affect of nearly $250. This shows that the increase in income goes through variables that the OLS forces to be constant.

The OLS regression shows a significant positive effect of the treadle pump on self-assessed welfare. PSM shows that there is a significant positive effect of 0.15 point on a scale from 1 to 4. Interviews with adopting and non-adopting households confirm that the treadle pump has a significant affect on welfare. IDE aims to increase welfare through increasing agricultural productivity and measures this by income. This chapter shows that the increased agricultural productivity also has a direct positive effect on self-assessed welfare, not necessarily through income.

The effect of the treadle pump mentioned above is only for the users of the pump and not for those households who own a pump, but are for some reason not using it. The risk of broken or not functioning pumps is not addressed here. Smallholders who invest, independently if it is cash or credit, in a treadle pump that they are not able to use have decreased their income. The effect of a decrease in income on a household living on less than $2 a day can be disastrous. IDE has to prevent that faulty treadle pumps are distributed in Zambia. The problem of pumps breaking is a problem that the adopters should be able to solve themselves. According to the analyses in this paper, households have the means to pay for repairs. However an estimated 25 to 30% of the pumps will not be in use anymore in some years due to broken parts, which is substantial. There is a role here for IDE to empower the smallholders to find a solution for their broken pumps; either by repairing it themselves or finding a dealer that can repair the pump for them.

7. Conclusions and discussion

Conclusions

According to the International Development Enterprise (IDE), farmers are on average able to generate more than $100 per year in extra income in Zambia by using the treadle pump (IDE, 2007). The FAO states that irrigation can increase yields for most crops by 100 to 400%. The objective of this paper was to evaluate the contribution of the treadle pump to the rural welfare of smallholders in Zambia. Different estimation procedures and a relatively new dataset were used to obtain information that can be useful for the future projects of IDE. This chapter summarizes the conclusions of the paper to accomplish the objective and discusses the results.

Adoption

The following factors play a role in determining which households use the treadle pump compared to adopting other irrigation methods: labor availability, self-assessed welfare, and membership of farmer groups. The treadle pump is most attractive for households with relative low availability of labor as the treadle pump increases labor productivity. Households with a low self-assessed welfare have a higher probability of adopting the pump, indicating that the poor smallholders are reached with this project. The factors that have to be targeted by IDE to alleviate the constraints faced by farmers are complex. The establishment of farmer groups and demo-sites, as IDE is doing, is the right way. The demo-sites increase the 'learning by doing' opportunity and the farmergroups increase the adoption by complementing the potential benefits from the treadle pump. Access to credit is a very important factor in the adoption of the treadle pump. This factor was not measured in the PRISM dataset and could not be used as an explanatory variable in the Multinomial Logit. This was however, one of the most mentioned factors during the interviews. The credit issue is not tackled at this moment. IDE is trying to establish credit facilities in collaboration with META, but good schemes need time. The credit constraint will also be alleviated by the development of cheaper pumps in the future.

The average price of a treadle pump with pipes in this sample was $156. IDE is targeting smallholders living on less than $2 a day and therefore the price is considered a major constraint for adoption. This paper shows that the price of the pump is only 60% of the estimated average increase in income that the household will have in a year. A household living on less then $2 a day will not be able to save the necessary amount to buy a pump. These results indicate however that if a credit scheme was offered to them they should not have difficulty repaying it. Considering this, IDE is certainly enabling smallholder welfare by stimulating smallholders to buy on a treadle pump and teaming up with MEDA to offer them credit schemes to do so.

Farming practice

The farming practice of households using a treadle pump is different from those using other or no irrigation methods. Irrigation enables farmers to switch from subsistence production to growing high value crops for the market. The average income per ha, is not significantly different for treadle pump users than for bucker irritators. The data does not show increased yield per cropping cycle or an increase in cropping cycles per year, as the FAO states. Adopters of treadle pump however, cultivate a larger area of irrigated and rainfed crops. This indicates that the increase in labor productivity and possibly the extra income of the irrigated crops, increases the production of rainfed crops too.

The income of treadle pump users is $208 higher than the income of households using buckets, due to the increase in the area cultivated. The crop income is not correlated with the self-assessed welfare.

Income
A significant part of the welfare of households using the treadle pump can be allotted to the pump. Propensity Score Matching (PSM) leaves space for other variables changing with the adoption of the treadle pump and shows an average effect of $250. This is substantial for households living on less than $2 a day. The estimated increase in income is 2.5 times as high as the increase according to the IDE website. Ordinary Least Squares estimation shows that the effect of the treadle pump was not significant, but this can be explained because the OLS keeps other variables (like land size) constant.

The effect of the treadle pump on income is constrained by the accessibility of markets, the availability of water and other variables not accounted for in this analysis. Finding ways to address these constraints will improve the overall benefit from the treadle pump. The accessibility of markets can be increased by establishing farmergroups for increased bargaining power. The availability of water can be increased by offering means for digging wells. The problem of broken pumps can be addressed by increasing the sense of ownership of the treadle pump.

Welfare
OLS shows that the effect of the treadle pump on self-assessed welfare is 0.17 points on a scale from 1 to 4. PSM establishes the effect at 0.15 point, in two of the three matching procedures. Interviews with adopting and non-adopting households confirm the result that the treadle pump has a significant effect on the welfare of the households that use the pump. IDE aims to enable prosperity through increasing agricultural productivity and measures this by income. This chapter shows that the increased agricultural productivity also has a direct positive effect on welfare, not necessarily through income. This can be because ownership of the treadle pump increases the status of a household or because the increase in crop production improves the food consumption of households (both through an increased bargaining position and a more diversified and secure food production).

Discussion
The following sections give three points of discussion. These points influenced the results of the thesis and allow the reader to judge the trust wordiness of the conclusions. The discussion points lead to some recommendations for further research. These are presented in appendix E.

The PRISM dataset contains information on 900 households on an extensive amount of subjects. This dataset offered the opportunity for the analyses done in this thesis. The results presented in this thesis give a good idea of the variables that play a role in the adoption of the treadle pump and the effect of the treadle pump on income and self-assessed welfare. The dataset was collected by many different enumerators. This resulted in inconsistencies in the data. This limited the amount of variables suitable for analysis. One important variable that was included in the survey, but proved unusable was the year of acquisition of the different technologies. Another was the accessibility of water sources, which was not collected for most of the non-adopters. These variables would have been very beneficial for the analyses in this thesis.

This thesis uses Propensity Score Matching (PSM) to give an unbiased effect of the treadle pump. The effect is unbiased because the results of an adopting household are compared to a similar non-adopting household, based on pre-treatment characteristics. The PSM is however constraint by the data available in the dataset. More data on pre-adoption characteristics would have increased the possibilities to measure the effect of the treadle pump and would have improved the PSM used in this thesis. The estimated effect of the treadle pump would probably have been larger than the $250 that is established now, with current data proxying for the pre-treatment data.

This thesis focuses on the effect of the treadle pump on income and welfare. The treadle pump offers the opportunities to increase production by lifting the labor constraint. This enables the cultivation of a larger area and thus to produce more marketable crops. However the treadle pump may not be the most production increasing technology that is available to smallholders; better seed and fertilizer will also improve production. Other factors improving production can be better education, empowerment of women or access to credit. This thesis focuses only on the effect of the treadle pump and some complementary factors without intending to look at productivity as a whole.

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Glossary

Smallholders	Smallholders are farmers cultivating between 20 square meters and 2 ha of land. Smallholders can either be subsistence farmers or farmers producing for the market.
Subsistence production	Subsistence production is production to feed the own household to remain alive. IDE targets their projects at households who live below the $2 a day poverty line. Most subsistence farmers live below this line.
Adopters	Adopters are those households who use a treadle pump for growing irrigated crops
Dis-adopters	Dis-adopters are those households who own a treadle pump but are not using it (these households are not part of the adopters).
Welfare	Welfare is the outcome of the utility maximization under restrictions. In this thesis welfare is measured by total crop income and self-assessed welfare.
Income	Income is the revenue (the proceeds of sales) minus the costs of variable inputs, like fertilizer and seed.
Irrigation method	Irrigation methods can be: no irrigation, bucket irrigation, irrigation with the treadle pump or irrigation with a motorized pump (an electric or diesel pump).
Farmer group	A group of farmers who want to achieve a mutual goal (e.g. market their produce or increase production) by learning from each other and facing the outside world in a one body. IDE is active in establishing local farmer groups, so the farmers can learn from each other and increase their bargaining power.
Self-assessed welfare	Self-assessed welfare is the grade households give to their own welfare. The self-assessed welfare is given in a number between 1 and four; 1= unable to survive without help, 2= struggling to survive, 3= ok, and 4 = doing well.

Appendix A. Feedback methodology

A.1 Methodology

To ensure that the results of the data analyses would be as close as possible to reality, constant feedback was collected on the results. During the first months, experts at IDE Zambia were consulted. The structure of one of these interviews can be found in section A.2. Other interviews were often more casual at the IDE office, where some of the results would be given to the experts for them to comment. Four experts were consulted at different stages of the research; sometimes very adhoc, sometimes in a more structured way.

When most analyses were finished, the results were checked in the field among the farming households. These semi-structured interviews were held in 2 regions in Zambia. The structure can be found in section A.2. The first area, was a village about 20 km North of Lusaka. Two households were interviewed here; one with and one without a treadle pump. These two households were randomly picked from a meeting about the treadle pump. The second region was 40 km South of Lusaka, around the town of Kafue. Here another 6 households were interviewed in three different 'villages'. Two of these households did not have a pump; four had adopted the treadle pump. The households were selected by the field officer in Kafue. He was repeatedly asked to pick the households without making any considerations. The answers of the 8 households were all in line with each other and the results of the data analyses.

In the last months the results were presented during a workshop at IDE. All 6 field officers attended the presentation, as did two experts from IDE Zambia and a visitor from IDE head office and a consultant from the LEI. During this presentation a lot of feedback was received on the results from all parties present.

In the final stage before leaving IDE Zambia, the results were presented to the experts at IDE in a 'working paper'. This was the final check to get feedback on the results from the data analyses and the interviews.

A.2 Semi-structured interview

The last three months I have been in Zambia to look at the effect of the treadle pump on households. I am from Wageningen University in the Netherlands. I would like to know what you think of certain aspects of the treadle pump. I will be asking these questions to people who use a treadle pump and people who do not use a treadle pump, as well as agricultural experts. Please speak freely as these interviews are anonymous and you will help me a lot by being honest.

Adoption of the treadle pump

1. a. Does interviewee own a treadle pump?
   b. *For treadle pump owners:* since which year?
   c. How where you introduced to the treadle pump?
   d. Have you seen any demonstration before you bought the treadle pump?
   e. *For treadle pump owners:* How did you pay for the treadle pump?
   f. *For treadle pump owners:* Have you finished paying for your treadle pump?
2. Does interviewee use a treadle pump?
3. Why do/don't you have a treadle pump, while others in your village do/ do not?
4. a. *For non-adopters:* Do you use irrigation?

b. How many years have you been irrigating with treadle pump/ buckets?
c. Where did you learn to use irrigation?
d. *For adopters:* Have you had any training on how to use a treadle pump?

5. a. How many hectares of land do you own?
   b. How many hectares of land do you cultivate?
6. a. Does your household have any income from off-farm employment?
   b. Did the off-farm employment influence your possibilities to acquire a treadle pump?
7. Is your household female of mail headed?
8. a. Is your household member of any farmer group?
   b. Did your membership/ the fact that you are not member of a farmergroup influence your possibilities to acquire a treadle pump?
9. a. Which source of water do you use?
   b. Did your water source influence your decisions to start using / not use a T.P?
10. Are there any other factors that influenced your possibilities to acquire a treadle pump?

Income of Households

11. a. What crops do you grow?
    b. *For adopters:* Which crops did you grow before you used the treadle pump?
12. Do you think that your household has a different income from crops than households that do / do not use a treadle pump?
13. Do you think that your household has more opportunity to find off-farm income than households who use/ do not use a treadle pump?
14. Is the standard of living of your household in general different then the standard of living of households who use/ do not use a treadle pump?

Impact assessment of the treadle pump

Only for users of a treadle pump:

15. Do you eat different food products since you have started to use the treadle pump?
16. Have you been able to buy any household assets because you started using the treadle pump (e.g. radio, mobile phone)?
17. Have you had more opportunity to send your children to school since you have started using the treadle pump?
18. Have you increased the amount of land you own since you have started using the treadle pump?
19. Have you increased the amount of land you cultivate?
20. Have you been able to buy any livestock because you acquired the treadle pump?
21. Do you have savings or insurance that you did not have before using the treadle pump?
22. Do you think that you have increased your welfare since you started using the treadle pump (resume answers to questions above)?

Village welfare

23. When did the first treadle pump arrive at your village?
24. Have you noticed any difference in the welfare of the village as a whole since then?
25. How many treadle pumps are working in your village now?
26. Do you think that the treadle pump changed the welfare of the households without treadle pump?

A.3 Expert interview

1. What is the budget of IDE Zambia and which part of this budget is spend on treadle pump related activities?
2. How many households are using a treadle pump in Zambia? How many pumps did IDE distribute over the years?
3. I read the statement from IDE that the treadle pump increased income with $100 a year; is this household income of per capita income?
4. In the dataset there is a distinction between size of the land owned, size of the land with deed and size of the rented land. In Kafue the households talked about traditional land. What is the difference between these terminologies?
5. I've been to Katoeba and Kafue and saw two different ways in which the treadle pump can work. What are the differences in characteristics of these areas? The difference I noticed (but my sample was too small) was that in Kafue they use the old-fashioned pump that seems to be easier to maintain, the vegetables price is higher, the market can be reached by bike and the people had all bought their pumps with cash instead of with a loan.
6. What do you think is the most important distinction between a household that has and a household that has not adopted a treadle pump? According to my analyses of the data the households are different. Households are more likely to adopt if they are older, if there is a higher rate of dependents in the household, if they live in the Southern province, if the land the have deed on is larger, if they live in an IDE project area, if they are male and if they are member of a farmgroup. Do you think adoption is the result of the random choice of households which were offered a treadle pump with a credit scheme, or are there certain characteristics that play a role?
7. When I compared some characteristics of the adopters of the treadle pump with the not irrigating households and bucket irrigators, it showed that they cultivated a larger area of irrigated crops, a larger area of rain-fed crops, that their total production was higher and that they thus got more income from crops. This was confirmed in the interviews However according to the literature irrigation should also increase the yield per cropping cycle and increase the amount of cropping cycles per year. I have seen no evidence of this; what do you think?
8. Do you think it makes a difference to the effect of the treadle pump on income if the households bought it on credit or paid for the pump in cash?
9. Do households that grow only rain-fed crops ever buy/ get a treadle pump?
10. According to the dataset nearly 9% of the households who own a treadle pump are not using it, but have gone back to buckets. Do you think this figure is representative? The explanation for this dis-adoption according to me, is that the pumps were broken and the gain was too little for the households to be motivated to repair them; do you agree?

Appendix B. Variable description

Variable	Description	Values	Obs	Mean	Std. Dev.	Min	Max
Income	Expected crop income for 2005 in $	Continuous	809	339.5	1203	-1706	19,756
method	The most advanced irrigation method used	1 = none 2 = buckets 3 = treadle 4 = motor	896	2.35	0.79	1	4
bucket	Household uses buckets for irrigation	0 = no 1 = yes	896	0.59	0.49	0	1
treadle	Household uses treadle pump for irrigation	0 = no 1 = yes	896	0.41	0.49	0	1
diesel	Household uses diesel pump for irrigation	0 = no 1 = yes	896	0.04	0.20	0	1
electric	Household uses electric pump for irrigation	0 = no 1 = yes	896	0.01	0.12	0	1
hhage	Age of the household head	Continuous	896	46.96	13.04	20	89
hhage2	Age of the household head squared	Continuous	896	2374.6	1294.4	400	7921
hhhedu0	Household head followed no or lower primary education	0 = no 1 = yes	896	0.21	0.41	0	1
hhhedu4	Household head followed college or university education	0 = no 1 = yes	896	0.06	0.24	0	1
hhsedu0	Spouse followed no or lower primary education	0 = no 1 = yes	896	0.29	0.46	0	1
hhsedu4	Spouse followed college or university education	0 = no 1 = yes	896	0.02	0.15	0	1
exper	Number of years a household has farmed	Continuous	896	15.41	10.29	0	55
htrain	Whether household has received training for crop production	0 = no 1 = yes	896	0.23	0.42	0	1
numhhme	Number of household members	Continuous	896	6.90	2.88	1	20
deprat	Dependency ratio; the number of under 14 or above 65 on the total number of hh members	Percentage	896	38.84	22.61	0	100
central	Household is located in Central Province	0 = no 1 = yes	896	0.21	0.41	0	1
copperb	Household is located in the Copperbelt	0 = no 1 = yes	896	0.29	0.45	0	1
southern	Household is located in the Southern Province	0 = no 1 = yes	896	0.35	0.48	0	1
sizeown	Size of traditional land owned in ha	Continuous	896	7.74	15.30	0	139
sizedeed	Size of private land owned in ha	Continuous	896	3.76	16.72	0	200
sizrent	Size of the land rented in ha	Continuous	896	0.13	0.96	0	20
well2000	Household was able to meet needs by own efforts and making some extra to save or invest in 2000	0 = no 1 = yes	894	0.19	0.39	0	1
ok2000	Household was able to meet needs but with nothing extra to save or invest in 2000	0 = no 1 = yes	894	0.44	0.50	0	1
strg2000	Household was able to meet needs by Depleting productive assets and/or	0 = no 1 = yes	894	0.29	0.46	0	1

	sometimes by receiving help						
unab2000	Household was dependent on support from community in 2000	0 = no 1 = yes	894	0.07	0.26	0	1
tom2005a	Area planted with tomatoes in 2005	Continuous	777	0.10	0.19	0	1.5
cab2005a	Area planted with cabbage in 2005 in	Continuous	819	0.04	0.12	0	1.5
imp2005a	Area planted with impwa in 2005 in	Continuous	879	0.02	0.09	0	1.2
rap2005a	Area planted with rape in 2005 in ha	Continuous	775	0.09	0.19	0	1
pap2005a	Area planted with paprika in 2005 in	Continuous	888	0.01	0.05	0	0.5
gmz2005a	Area planted with green maize	Continuous	848	0.05	0.20	0	3
oni2005a	Area planted with onion in 2005 in	Continuous	868	0.02	0.08	0	1
mel2005a	Area planted with watermelon in	Continuous	887	0.01	0.07	0	1.2
okr2005a	Area planted with okra in 2005 in ha	Continuous	884	0.01	0.06	0	0.75
projarea	household is located in IDE area	0 = no 1 = yes	896	0.74	0.44	0	1
hhsex	Sex of the household head	0 = male 1 = female	896	0.14	0.35	0	1
farmgr	Whether household is member of a farmer group	0 = no 1 = yes	896	0.75	0.43	0	1
off-farm	Most important source of income between 2000 and 2003 was not crop production	0 = no 1 = yes	881	0.13	0.34	0	1

Appendix C. Multinomial logit

Table C.1 Marginal effects of adoption (t-values in brackets)

	No irrigation	Buckets	Treadle pump	Motorized pump
Management skills				
Age	0.00 (0.71)	-0.03 (-2.86)***	0.03 (2.73)***	-0.02 (-0.46)
Age2	-0.00 (-0.56)	0.00 (2.80)***	-0.00 (-0.67)***	0.00 (0.31)
No education head	0.00 (0.10)	0.04 (0.76)	-0.02 (-0.46)	-0.02 (-1.12)
High education head	0.04 (1.02)	-0.12 (-1.25)	0.19 (0.19)	0.07 (1.27)
No education spouse	-0.01 (-1.31)	0.01 (0.14)	0.01 (0.17)	0.00 (0.04)
High education spouse	0.02 (0.49)	0.13 (0.85)	-0.17 (-1.36)	0.03 (0.51)
Experience in years	-0.00 (-0.79)	-0.01 (-0.57)	0.01 (0.40)	0.01 (1.12)
Followed crop training	-0.00 (-0.08)	-0.00 (-0.05)	0.02 (0.47)	-0.02 (-1.50)
Size of household	-0.00 (-0.96)	0.01 (0.83)	-0.01 (-0.88)	0.00 (1.18)
Dependency rate	-0.00 (-0.83)	-0.02 (-1.70)*	0.02 (1.86)*	0.00 (0.15)
Farm potential				
Central Province	-0.05 (-3.98)***	0.02 (0.28)	-0.02(-0.25)	0.05 (1.44)
Copperbelt	0.00 (0.32)	0.05 (0.82)	-0.04 (-0.57)	-0.02 (-1.19)
Southern Province	-0.13 (-5.61)***	-0.05 (-0.79)	0.17 (2.82)***	0.01 (0.34)
Size of traditional land	-0.01 (-1.5)	-0.01 (-0.83)	0.01 (0.86)	0.01 (2.66)***
Size of private land	-0.02 (-2.08)**	0.00 (0.14)	0.02 (1.80)*	-0.00 (-0.33)
Size of rented land	0.06 (1.30)	0.28 (0.92)	-0.47 (-1.41)	0.12 (2.61)***
Irrigation potential				
Welfare high 2000	-0.00 (-0.39)	-0.04 (-0.70)	0.03 (0.63)	0.01 (0.46)
Welfare low 2000	-0.01 (-1.18)	-0.15 (-3.39)***	0.15 (3.40)***	0.01 (0.54)
Welfare very low 2000	0.02 (0.76)	0.00 (0.00)	-0.02 (-0.32)	0.00 (0.17)
Living in IDE area	-0.12 (-3.78)***	-0.18 (-3.97)***	0.29 (7.33)***	0.02 (1.27)
Risk				
Household head sex	0.01 (0.75)	0.11 (1.91)*	-0.11 (-1.86)*	-0.02 (-1.01)
Membe r farmer group	-0.07 (-2.56)***	-0.12 (-2.40)**	0.18 (3.81)***	0.01 (0.380
Off-farm income	0.03 (1.37)	-0.06 (-1.08)	-0.05 (-0.85)	0.09 (2.37)**

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

Appendix D. Effect treadle pump

Table D.1 OLS estimates of income and self-assessed welfare (with t-values)

	Income in $	**Self-assessed welfare** (1= unable to 4= well-off)
Irrigation method		
Bucket	66 (0.41)	-0.01 (-0.12)
Treadle	229 (1.63)	0.17 (2.51)***
Mechanic	1252 (1.69)*	0.25 (2.09)**
Management skills		
Age	-87 (-2.70)***	-0.12 (-4.55)***
No education head	-97 (-1.02)	-0.04 (-0.48)
High education head	87 (0.39)	0.17 (1.12)
No education spouse	136 (1.04)	0.06 (0.83)
High education spouse	461 (0.83)	0.30 (1.61)
Experience in years	-8 (-0.23)	0.03 (0.82)
Followed crop training	-75(-0.89)	0.03 (0.36)
Size of household	101 (0.41)	0.06 (0.51)
Farm potential		
Central Province	152 (1.30)	0.46 (5.43)***
Copperbelt	152 (1.42)	0.38 (5.18)***
Living in IDE area	130 (1.67)*	0.10 (1.36)
Crops		
Tomatoes in ha	1027 (1.91)**	-0.08 (-0.47)
Cabbage in ha	277 (0.71)	0.43 (1.47)
Impwa in ha	-724 (-1.07)	0.18 (0.65)
Rape in ha	-2 (-0.01)	0.01 (0.03)
Paprika in ha	-1092 (-0.65)	1.37 (2.42)**
Green maize in ha	257 (0.98)	0.31 (2.69)***
Onion in ha	-587 (-0.71)	0.66 (2.43)**
Melon in ha	156 (0.22)	-0.20 (-0.40)
Okra in ha	4585 (1.56)	-0.75 (-1.44)
Risk		
Household head sex	-14 (-0.17)	-0.13 (-1.43)
Member farmer group	-99 (-1.32)	0.08 (1.04)
Constant	*231*	*2.52*
R-squared	*0.19*	*0.18*
Number of observations	*643*	*685*

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

Table D.2 Number of observations per block (testing for balancing proporty)

Inferior of block of pscore	Treadle		Total
	0	1	
0	58	1	59
.1	72	13	85
.2	130	61	191
.4	157	179	336
.6	55	91	146
.8	2	7	9
Total	474	352	826

Table D.3 PPS estimates for adoption of the treadle pump

	PPS for adoption of the treadle pump
Management skills	
Age	0.72 (2.73)***
Age2	-0.00 (-2.76)***
No education head	-0.06 (-0.50)
High education head	-0.03 (-0.13)
No education spouse	-0.06 (-0.52)
High education spouse	-0.47 (-1.28)
Experience in years	0.05 (0.84)
Size of household	-0.11(-0.60)
Dependency rate	0.05 (2.23)**
Farm potential	
Central Province	-0.32 (-2.45)**
Copperbelt	-0.51 (-4.07)***
Size of traditional land	0.01 (1.56)
Size of private land	0.01 (1.89)*
Size of rented land	0.09 (-1.11)
Irrigation potential	
Welfare high 2000	0.04 (0.31)
Welfare low 2000	0.42 (3.76)
Welfare very low 2000	-0.05 (-0.25)
Living in IDE area	0.78 (6.53)***
Risk	
Household head sex	-0.40 (-2.65)***
Member farmer group	0.51 (4.16)***
Constant	-2.91
R-squared	0.1216

***Significantly at 1%
**Significantly at 5%
*Significantly at 10%

Appendix E. Further research

This appendix summarizes some issues that were noticed, but not further analyzed during the field work and at the IDE main office. These issues are not at all scientifically established, but could be interesting for further research.

A. Ownership
A big constraint on the effect of the treadle pump is the large number of broken or faulty pumps. There seem to be much more broken pumps around than necessary. It would be interesting to analyze this; why are there so many broken pumps and what are the reasons that the household does not repair them? A possible answer could be that as long as the pump is broken they have a reason not to repay their debt. A related issue here is the ownership; are broken pumps more common amongst households that did not repay their pump.

B. Pumps
IDE is constantly trying to develop and import cheaper and more efficient pumps. The modern pumps are lighter in use and can therefore be used by more family members. However, during field trips all 'first generation pumps' seemed to still be in use, while the modern pumps were often broken. It could be the case that the older, less efficient, pumps are more easily to maintain. It would be interesting to look at the technical features of the pump and to link these to the outcomes of this research.

C. Field officers
Although this issue is far out of the field of this thesis, it would be very interesting to establish the work load of the field officers. There are three areas in Zambia where two field officers work. They perform all the executive tasks from the Lusaka office. They have to establish farmergroups and demo-sites, and visit these groups (around 20 groups per area) every fortnight to give training. On top of this they have to guide the many visitors from the main office and from oversees. These field-officers are provided with motor bikes, a limited budget for fuel and a laptop, but do not have access to internet. In contrast the main office has 4 employees for monitoring and evaluation alone. It would be very interesting to look into the task description of IDE Zambia. Very likely the work would benefit greatly from more field officers and a higher budget for these officers.

D. Credit
This research did not focus on credit. However it is an intrinsic part of distributing any technology and could not be left out the analysis all together. Although credit is an important issue, it does not seem to be clear what different schemes have been used by IDE in the last ten years. This is a complicated issue as many/ most of the credit schemes were not given by IDE, but by a partner. It would be very interesting to inventory these different schemes and try to find out which ones were and which ones were not successful (e.g. rate of repayment). The general feeling is they all failed, but there must be differences between the different schemes. This information is interesting for the future schemes that are now being developed as it takes into account the typical situation of Zambia and the typical aspects of the treadle pump..

E. Motorized pump
This aspect was mentioned by the Country Director of IDE Zambia; more knowledge needs to be collected on users of motorized pumps. The PRISM dataset lacked the variables to do this,

but further research could focus on the owners of motorized pumps. It would be interesting to see how many of hem used to have a treadle pump. Are there possibilities to grow from treadle pump to motorized pump? According to this dataset the users of a motorized pump do not irrigate a larger area than the users of a treadle pump, but they do have a much higher income. Is this due to a higher yield, or are these households in a better bargaining position for instance.

F. Data collection

In a future survey for monitoring and evaluation the following variables should be included.

1. Total revenue or income from other sources than agriculture; off-farm and non-farm activities.
2. Consumption and household-assets to proxy for welfare.
3. Distance to asphalt/ gravel road.
4. Kind of treadle pump (e.g. first pump, plastic pump).
5. Number of cropping cycles.
6. Source of water also for those households not using irrigation + the technical attributes (e.g. depth of well and months of water availability).
7. Reason why owners of a treadle pump do not use their pump.
8. If the credit was the means to buy the pump; the part repaid or how long it took to repay.