Economics of Indigenous Fruit Tree Crops in Zimbabwe

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Abstract

Poverty is a common problem in the rural areas of Sub-Saharan Africa. Rural households frequently rely on indigenous fruits (IF) and other wild food resources during times of food and income shortages in order to supplement their nutrition and income. However, the availability of indigenous fruit tree products is declining as a result of deforestation. In order to conserve biodiversity, the Domestication of Indigenous Fruit Trees Programme of the World Agroforestry Centre (ICRAF, formerly the International Centre for Research in Agroforestry) aims to increase farm household income through farmer-led indigenous fruit tree planting. Lack of quantitative data hampers the progress of the programme insofar as the role of indigenous fruit tree products in the rural household economy is not clear.

This study is part of ICRAF's 'Domestication Programme'. Its objective is to fill in some of the knowledge gaps. Specifically, this study assesses the contribution of indigenous fruit trees towards rural incomes and reduction of (seasonal) vulnerability to poverty. It further assesses the degree to which indigenous fruit trees have to be improved or the natural resource base has to decline so that on-farm planting is rendered economically attractive.

Data were collected by means of farm household surveys in two locations of Zimbabwe from August 1999 to September 2000. Data collection consisted of monthly household monitoring of income, expenditure and labour data of 39 households and a random sample of 303 households to determine factors that are related to indigenous fruit use. Additionally, farmer workshops were conducted to gather general information and biophysical data of the indigenous fruit tree species. Surveys targeted the three most popular indigenous fruit tree species as previously determined by ICRAF.

Results indicate that the majority of rural households benefit from consumption and sale of IF, although the extent varies amongst households. Within the household, children are the main consumers of the fruits. Marketing of IF is carried out by women, who use the receipts to purchase household goods. While *Uapaca kirkiana* fruits are more important in generating cash income than others, fruits of *Parinari*

curatellifolia are more important for home consumption during food shortages. The gross margins from collection of IF are lower than from livestock and crop production. However, returns to labour from collection and use of IFT products are considerably greater than from other activities including gardening and livestock-rearing, indicating that collection of IF is an efficient labour allocation strategy.

Vulnerability to poverty is assessed by means of a stochastic simulation model of monthly household income in the course of the year. Results show that vulnerability to income poverty is very high amongst rural households and is subject to seasonal fluctuations. Vulnerability is highest during the critical period of the year, i. e. between August and January, when IF are available. The income surplus that is carried over from the previous cropping season and also the degree to which indigenous fruits are used/are available for income smoothing determine vulnerability to poverty. As expected, the higher the availability of IF, the lower the vulnerability to income poverty. During August to January, the critical period of the year, indigenous fruits can reduce the probability of falling below the income threshold by up to 30%, depending on their availability. Although indigenous fruits contribute to reduction of vulnerability, other sources of income show higher influence on the household income. The highest influence stems from production of agricultural crops, which contribute a major share towards rural incomes. Overall, collection of IF constitutes an income source that can easily be accessed in times of need in order to bridge income and food shortages.

Planting of domesticated indigenous fruit trees (IFT) is characterised by uncertainty, irreversibility and flexibility. Thus, timing of investment is crucial for maximising household net income. The critical value of an investment in planting IFT is derived using the real options approach to investment analysis. The risk-adjusted rate of return is endogenously determined via the Capital Asset Pricing Model. Its estimation is based on the portfolio of the different sources of farm household income. Results show that currently, collecting fruits and other products of IFT from the commons is more profitable than planting the trees. A combination of technical change and decreasing resource abundance provides scope for farmer-led planting of domesticated IFT and thus biodiversity conservation. However, breeding progress

must be significant for investment in farmer-led tree planting to be economically attractive and thus contribute to on-farm preservation of the IFT.

The key conclusions for policy advice and further research are to assess whether tree improvements that are necessary to initiate investment are technically feasible. Furthermore, the alternative to on-farm planting, indigenous fruit tree conservation in their natural habitat, needs to be economically assessed. Finally, further research that takes into account spatial aspects of indigenous fruit tree abundance should be conducted. Based on this information, most promising areas for farmer-led tree planting could be identified. This especially refers to other countries of the region, e.g. Malawi, where deforestation is more pronounced.

Keywords: indigenous fruits, rural incomes, poverty, investment, uncertainty, Zimbabwe

Zusammenfassung

In Simbabwe wie auch in zahlreichen weiteren Ländern in Afrika südlich der Sahara sind Armut und die unsichere Versorgung mit Nahrungsmitteln zentrale Entwicklungsprobleme. Die ländliche Bevölkerung ist von dieser Situation besonders betroffen. Um dieses Problem zu mindern, greifen ländliche Haushalte vielmals auf heimische Wildfrüchte und andere eßbare natürliche Ressourcen zurück. Diese Früchte stellen ein Allmendegut dar und werden für den Eigenverzehr und den Verkauf genutzt. Zur Minderung dieses Problems führt das World Agroforestry Centre (ICRAF, vormals International Centre for Research in Agroforestry) ein Programm aus mit dem Ziel einheimische Baumfrüchte zu domestizieren. Das Domestizierungsprogramm zielt darauf, die Bäume züchterisch zu verbessern, um so Anreize für deren gezieltes Anpflanzen durch die ländlichen Kleinbauern zu setzen. Damit soll ein positiver Beitrag zur Steigerung ländlicher Einkommen erzielt und gleichzeitig ein Beitrag zum Erhalt dieser Fruchtbäume geleistet werden.

Quantitative Informationen zur wirtschaftlichen Bedeutung der Wildfruchtbäume sind momentan nicht vorhanden und so kann der Bedarf und der potentielle Erfolg des Programms schwer geschätzt werden. Diese Lücke soll durch die vorliegende Arbeit gefüllt werden. Insbesondere analysiert diese Arbeit den gegenwärtigen Stand der Fruchtnutzung und die wirtschaftliche Bedeutung der Früchte in den ländlichen Gebieten. Weiterhin wird der Beitrag der Früchte zur Vermeidung von Armut und der Verminderung des Risikos unter die Armutsgrenze zu sinken analysiert. Letztlich werden Investitionsrechnungen mit dem Realoptionsansatz durchgeführt, um das Niveau der züchterischen Verbesserungen, das notwendig ist, um sofortige Investition in das Anpflanzen der Bäume durch die ländlichen Haushalte zu erreichen, zu bestimmen.

Die Studie wurde in zwei Gebieten in Zimbabwe durchgeführt. Eine Zufallsstichprobe von 303 Haushalten dient zur Analyse von Faktoren, die mit der Fruchtnutzung verbunden ist. Weiterhin wurden 39 Haushalten auf monatlicher Ebene zu Einkommen, Ausgaben und Arbeitsflüssen befragt, um den Beitrag der Früchte zum Haushaltseinkommen und deren Arbeitsproduktivität abzuschätzen.

Die Studie zeigt, daß alle ländlichen Haushalte die Früchte für den eigenen Verzehr und vielmals auch für den Verkauf nutzen, um so monetäres Einkommen zu erwirtschaften. Die Früchte sind besonders für Kinder eine wichtige Nahrungsquelle. Sammeln der Früchte ist eine saisonale, attraktive Aktivität mit relativ hoher Arbeitsproduktivität. Besonders Haushalte, die weniger hohe monetäre Transferzahlungen von Familienmitgliedern, die in der Stadt im formellen Sektor tätig sind, erhalten, verkaufen häufiger heimische Früchte. Ebenfalls häufigerer Verkauf ist zu beobachten bei Haushalten, die in relativer Nähe zum Markt wohnen.

Um den Beitrag der Früchte zur Reduktion von Armut zu analysieren, wurde basierend auf monatlichen Einkommensdaten ein stochastisches Simulationsmodell, welches das Haushaltseinkommen auf monatlicher Ebene abbildet, erstellt. Die Ergebnisse zeigen, daß die Früchte das Risiko unter die Armutsschwelle zu fallen senken können. Dieses Risiko unterliegt wie das Einkommen saisonalen Schwankungen und ist während der kritischen Periode von August bis Januar besonders hoch. Je mehr Wildfrüchte den Minimumnahrungsbedarf substituieren können, desto mehr wird dieses Risiko vermindert. Trotzdem haben andere Einkommensquellen wie z.B. das Einkommen aus der Landwirtschaft einen höheren Einfluß auf die Reduktion des Armutsrisikos. Insgesamt kann durch die Wildfruchtnutzung das Risiko unter die Armutsschwelle zu fallen um 5% bis 30% reduziert werden, in Abhängigkeit davon in welchem Ausmaß Früchte zu Verfügung stehen.

Die Investition in das Anpflanzen der domestizierten Wildfruchtbäume wird mit Hilfe des Realoptionsansatzes analysiert. Beruhend auf dem Capital Asset Pricing Model und den Aktivitäten des Farmhaushaltsportfolios wird die Risikoprämie bezüglich einer Investition in die Pflanzung von heimischen Fruchtbäumen kalkuliert. Diese fließt in die Investitionsbewertung ein. Es wird gezeigt, daß beträchtliche Verbesserungen der Bäume notwendig sind, um eine sofortige Investition auszulösen. Solche Verbesserungen können auf vorgezogene Fruchtproduktion, erhöhten Ertrag bzw. verbesserte Fruchtqualität abzielen. Alternativ würde unter den getroffenen Annahmen auch eine geringere Häufigkeit der Bäume und somit gestiegene Sammelkosten das Anpflanzen auslösen.

Aus der vorliegenden Arbeit werden folgende Schlußfolgerungen gezogen und Empfehlungen ausgesprochen. Die Ergebnisse der Investitionsanalyse geben Hinweise in weit die Bäume verbessert werden müßten. Diese sollten überprüft werden, ob sie im Bereich der züchterischen Möglichkeiten liegen. Weiterhin könnte die Alternative zum Anpflanzen der Bäume, d.h. deren Erhalt in ihrem natürlichen Bestand, unter wirtschaftlichen Gesichtspunkten untersucht werden. Schließlich sollten räumliche Informationen bezüglich der Abundanz der Bäume mit in weitere Analysen einfließen, um so die relative Verfügbarkeit der Früchte und die Kosten des Sammelns abzuschätzen. So könnte besonders in anderen Ländern der Region, z.B. in Malawi, mit geringer hohen züchterischen Verbesserungen der Früchte die sofortige Investition ausgelöst werden, da die Früchte dort relativ knapper sind.

Schlagwörter: heimische Früchte, Armut, ländliche Einkommen, Investition, Unsicherheit, Simbabwe.

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Acronyms

acc.	according to
AEQ	adult equivalent
agric.	agricultural
bkt.	20 l bucket
c.p.	ceteris paribus
EF	exotic fruit(s)
EFT	exotic fruit tree(s)
F	F-value
FAO	Food and Agriculture Organization of the United Nations
Df	degrees of freedom
DS	dry season
DT	domesticated trees
GBM	geometric Brownian motion
GDP	gross domestic product
GM	gross margin
ha	hectare
HH	household
ICRAF	World Agroforestry Centre
IF	indigenous fruit(s)
IFT	indigenous fruit tree(s)
MFR	minimum food requirements
N	sample size
NPV	net present value
PPP	purchasing power parity

R&D	research and development
SD	standard deviation
SE	standard error
WS	wet season
ZWD	Zimbabwe Dollar (1 US Dollar = 38 ZWD, December 1999)

Notation

α growth rate

a, k activities of the market portfolio

β positive solution to Equation (9)

b_t vector of benefits derived from planting of indigenous fruit trees

B shift parameter (equation (13))

c_t vector of costs related to planting of indigenous fruit trees

C cash and in-kind variable costs

Co household consumption

δ convenience yield

dz increment of the standard Wiener process

D opportunity costs of land

E expectations operator

$\mathrm{E}[r_a]$ expected rate of return on activity *a*

Ex household cash expenditure

F(V,t) value of the option to invest

g age of indigenous fruit trees in years (productive period)

G gain in value of livestock

GM gross margin

Hi household income (sum over gross margins plus informal loans & surplus from previous period)

I initial irreversible investment cost

IC additional cash available, e.g. informal loans

K Marshallian trigger

λ market price of risk

L person-days

LC cost of hiring labour and work parties

μ risk-adjusted discount rate

m time period (season, poverty model)

N farmers of the sample; n, ...N

$NPV_{C\infty}$ net present value of collecting the fruits from the Communal Areas (= V_C)

O gross income, cash and in-kind

PL poverty line

r risk-free rate of return

r_a rate of return on activity a

r_m market rate of return

r_V rate of return on V

R_T residual value in T

σ variance rate of the geometric Browning motion

S loss in value of livestock

SF school fees

t time horizon (years, investment analysis)

T optimal life span of the orchard

υ, ζ,, κ coefficients of the Hoerl function

u fruit yield in kg

V incremental benefit of planting domesticated indigenous fruit trees

V_C present value of collecting indigenous fruits from the wild

V_{DT1} present-value of planting indigenous fruit trees for the first rotation

Vu vulnerability

V^* trigger value

ω_a weight of activity a in the market portfolio

x units purchased of the replicating portfolio

1 Introduction

1.1 Background

The majority of the African population lives in rural areas, where poverty is a major factor hampering development (World Bank, 2001). Rural people experience periods of food shortages caused by climatic conditions, political instability, poor infrastructure and other factors. On the other hand, people of rural areas have access to a wide range of products from their natural environment. For example, a variety of edible wild fruits are a popular natural resource (Maghembe et al., 1998). They are extensively used by the local population and, apart from own consumption, they are increasingly sold in markets (Cavendish, 1998; Maghembe et al., 1998; Maghembe et al., 1994). Thus, the indigenous fruit tree products are a source of food and a means of generating cash income essential for purchasing the required household goods in rural areas (Campbell et al., 2002). The fruits are available at times of drought, thus helping to sustain food security (Rukuni et al., 1998). Also, Zimbabwean farmers appreciate the nutritional value of these fruits (Rukuni et al., 1998). Demand for fruits in urban centres and areas where they are not available as well as limited alternative economic options in the rural areas are driving rural people to increased commercialisation of indigenous fruits. Consumers prefer the indigenous fruits and show high willingness to pay for the fruits (Ramadhani, 2002). The market system of indigenous fruits is imperfectly competitive, and so far, no fruit product differentiation takes place. The fruits themselves are a public good, although increased competition for the fruits has caused shortages and rivalry (ibid.). Due to increasing population pressure and other factors[1], deforestation continues at an annual rate of 1.5% (FAO, 2001). Although according to traditional rules indigenous fruit trees have to be preserved when clearing woodland in favour of agricultural

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[1] E.g. agricultural policies (Chipika & Kowero, 2000). Physio-geographic factors may also contribute towards deforestation as shown by Deininger & Minten (2002) for Mexico.

production, nowadays, indigenous fruit trees are sometimes also being felled (Rukuni et al., 1998).

In 1997, the World Agroforestry Centre (formerly the International Centre for Research in Agroforestry (ICRAF)) initiated a programme of domestication of indigenous fruit trees (IFT) of Southern Africa to halt the loss of biodiversity in IFT due to deforestation and to enhance rural incomes through on-farm planting of these trees (ICRAF, 2001; ICRAF, 1996)[2]. Maghembe (1998) conducted a priority-setting exercise in which farmers identified the most popular indigenous fruit tree species, which include *Uapaca kirkiana*, *Strychnos cocculoides* and *Parinari curatellifolia* as the top three species in Zimbabwe. Criteria for ranking those species were their role in food security, potential for commercialisation, suitability for processing and conservation, taste and abundance (Kadzere, 1998). Differences exist among indigenous fruit tree species in terms of value; for example, *Uapaca kirkiana* is valued for the commercialisation potential of its fruits (Rukuni et al., 1998), whereas *Parinari curatellifolia* is valued as a food source for survival (Nyoka & Rukuni, 2000). The priority-setting study also included questions regarding characteristics that should be improved. According to farmers' viewpoint, traits to be improved include fruit quality, fruiting precocity[3], fruit size and morphological characteristics like thorniness, fruit yield, tree size and resistance to pests (Kadzere, 1998).

Domestication work so far has concentrated on selecting seeds of different locations in order to select superior genotypes and also on developing successful vegetative propagation methods. In the long run, the domestication programme aims at encouraging the planting of indigenous fruit trees with improved fruit quality and higher yields and thus enhancing farmers' income as well as the conservation of biodiversity (ICRAF, 2001; ICRAF, 1996). This programme can be seen as part of an on-going debate on the future direction of rural development efforts. Some

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[2] Also, "getting the prices right" may contribute to reducing deforestation and biodiversity loss, as Benhin & Barbier (2004) show for Ghana. In this case, removal of subsidies on agricultural inputs combined with increased output prices due to the Structural Adjustment Programme reduced the reliance on crops that depended on inputs from forests, causing loss of biodiversity.

[3] Precocity refers to early maturity, i.e. first fruit production.

approaches favour biotechnology and an expansion of the green revolution; others prefer to diversify the basket of crops available (Leakey et al., 2004). The domestication programme is part of the latter strategy. The untapped potential of wild plants is seen as a means to benefit the economies of tropical countries, to motivate improved conservation of the wild areas that supply these crops (Evans & Sengdala, 2002) and to enhance the productivity and sustainability of agroforestry systems (Simons, 1996).

1.2 Research problem and objectives

Target species of this study are the three most popular species of the priority-setting exercise, namely *Uapaca kirkiana*, *Strychnos cocculoides* and *Parinari curatellifolia*. At this point, little information on the economic value and the role of indigenous fruit tree products within the farming system in comparison to income alternatives is available. The lack of information on the economics of IFT use hampers the domestication programme, as it is not quite clear what the need for IFT and their products in rural areas is. Also, the interrelation among indigenous fruit tree use and other small-scale farm household activities is lacking. In recent years, a number of studies on the economics of non-timber forest products have been published (Neumann & Hirsch, 2000 provide a review). For the Southern African region, livelihood analyses have been conducted and data on income from woodland use in general have been analysed (Campbell et al., 2002; Shackleton et al., 2002; Cavendish, 2000; Cavendish, 1997). Except for that of Ayuk et al. (1999), the studies concentrated on a variety of fruit tree species and woodland products in general and not exclusively on indigenous fruits. Data on returns to labour from the use of IFT are not available. Collection of wild fruits has been identified as a risk-coping strategy, especially in drought years, to supplement consumption. According to Dercon (2000), poor households are more likely to get involved in the collection of IF, as the entry barriers to fruit collection are low. However, the degree to which indigenous fruit contribute to rural incomes and thus reduce poverty is not known.

Until now, farmers have rarely planted IFT, but collect the fruits from the Communal Areas (Campbell, 1996b). Planting of domesticated indigenous fruit trees from the small-scale farmer's point of view is an investment. A necessary but not sufficient condition for adoption of tree planting at farm level for a profit-maximizing farmer is economic gain. Profitability of enhanced production through planting of indigenous fruit trees, even of domesticated, i.e. improved species, has not been estimated. The influence of the improvement process on investment profitability has not been assessed. Additionally, there is a need to clarify incentives to and constraints on planting activities.

On the farm level, indigenous fruit tree planting competes with collection of indigenous fruits from the wild, i.e. the natural environment, and also with other production activities for scarce resources. Farmers take into consideration alternative uses of their farm's resources and also the opportunity to wait until they invest in planting of domesticated species. They can gain further information and reduce uncertainty over returns to investment by waiting. Farmers adopt cultivation of indigenous trees more rapidly and to a greater extent if their contribution towards the household's income is substantial or if these trees can play other important roles such as overcoming food shortages in times of scarcity and if returns on investment are less uncertain.

The overall objective of the study is threefold. First, a baseline study is conducted that provides an assessment of the economics of indigenous fruit collection, use and sale. Here, an important indicator will be returns to labour from the collection and use of IFT products in comparison to those from other enterprises such as agriculture, horticulture, livestock and off-farm activities. In order to assess the status quo of indigenous fruit use further, the following questions are addressed: (a) who are the beneficiaries of IF use within the household, (b) what factors other than economic considerations influence the sale of IF, (c) what is the contribution of IF to household income, (d) are there complementary or competing inter-linkages between IF collection and use and other production activities and (e) is IF collection an efficient labour allocation activity?

The second objective is to quantify the contribution of indigenous fruit trees towards reducing vulnerability to poverty of rural households in Zimbabwe. This is determined by (a) assessing seasonal fluctuations of the income and expenditure flows in the course of the year and (b) analysing the contribution of indigenous fruit tree products towards reduction of vulnerability.

The third research objective is to conduct an economic analysis of planting indigenous fruit trees from the point of view of the household. Specifically, the investment analysis tackles the problem of (a) the risk-adjusted discount rate, (b) the level of improvement that is required to trigger on-farm investment in *U. kirkiana* and (c) the rise in the level of costs of collecting the fruits from the natural environment that induces investment.

It is expected that the study can clarify the prospects of ICRAF's domestication programme of increasing the likelihood that farmers incorporate planting of indigenous fruit trees in their portfolio of income-generating activities. Thus, this study contributes to ex ante impact assessment of technologies by an international research centre under the Consultative Group of International Agricultural Research (CGIAR).

This study is part of a joint PhD programme; this part concentrates on the economic aspects of indigenous fruit production, whereas the marketing aspects are dealt with in the study of Ramadhani (2002). The German Ministry for Economic Cooperation and Development (BMZ) funded both studies through ICRAF's domestication of indigenous fruit trees programme.

1.3 Organisation of the thesis

The thesis is organised as follows. The second chapter describes the economic environment of rural households in Zimbabwe. It further gives an extended overview of information available on indigenous fruit tree use and the institutional framework. The third chapter outlines the economic background. This includes the concept of household income, the concept of poverty and vulnerability to poverty and the real option approach to investment analysis. At the end of the third chapter, the research hypotheses are spelled out. The fourth chapter provides an overview of the research locations and an outline of the data collection process.

Chapters five, six and seven present the results on the research questions. Each chapter is preceded by a description of the application of theoretical concepts to the research problems. Results on the status quo of indigenous fruit tree use and factors that influence the sale of the fruits are presented in the fifth chapter. Chapter six deals with assessment of poverty and the contribution of indigenous fruit trees towards reduction of vulnerability to poverty. The seventh chapter answers research questions with respect to the domestication programme and presents results of the investment analysis, i.e. the level of tree improvement that renders tree planting economical.

Finally, in chapter eight conclusions from the findings of this study are drawn and their implications for the domestication programme are outlined. The chapter closes with recommendations for further research on the domestication programme in order to enhance the success in inducing farmer-led on-farm IFT planting for improved household incomes and on-farm tree conservation.

2 Indigenous fruit trees of the Miombo woodlands in Southern Africa

This chapter presents details of the farming system, land tenure and environmental conditions. The role of woodland resources and the institutional arrangements for woodland use are described. Finally, domestication is defined and explained in the context of indigenous fruit tree biodiversity[4] of the Southern African Region.

2.1 Ecology of the Miombo woodlands

The Miombo woodlands, sometimes also referred to as Miombo eco-zone, stretch over parts of seven countries in Central and Southern Africa, ranging from Angola and northern Namibia in the West across northern Botswana and northern South Africa, Zimbabwe, Zambia, the South of the Democratic Republic of Congo and Malawi to Tanzania and Mozambique in the East (Chidumayo, 1997). The leading tree species of the Miombo woodlands are *Brachystegia*, *Isoberlinia* and *Julbernardia*. They form a closed deciduous non-spinescent woodland with a shrub layer variable in density and composition (Campbell, 1996b). Variety of species is high; the woody plant flora is estimated to consist of 650 species (Fanshawe, 1971, cited in Chidumayo, 1997) including a high number of indigenous fruit tree species (Maghembe et al., 1998).

Three seasons based on temperature and rainfall can be distinguished. The hot dry season lasts from September to November, the hot wet season from November/ December to March and the cool dry season from April to August. The average annual rainfall varies between 600 and 1000 mm in the dry Miombo woodlands that are found in Zimbabwe (Chidumayo, 1997; Campbell, 1996b). Generally, soils of the Miombo are poor, with low concentration of organic matter and macro-nutrients.

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[4] Biodiversity is the variability among living organisms from all sources. It includes diversity within species, between species and the ecosystem (Glowka et al., 1994 cited in Benhin & Barbier, 2004).

Land uses in the Miombo zone include cultivation of sorghum, millet, maize and pulses in rain-fed agricultural production (Campbell, 1996b). Cattle in communal lands are kept as an input to other production components, e.g. draught power, and are seldom an objective per se (Gambiza et al., 2000).

Local use patterns and many of the changes in Miombo woodlands have been driven by macro-level phenomena, e.g. tsetse eradication programmes, villagisation, politically-led resettlement and pricing policies, etc. (Misana et al., 1996). Much of the Miombo woodlands have been cleared in favour of expansion of agricultural areas due to the growing population. The population growth rate in Southern Central Africa exceeds economic growth. This leads to expansion of the cultivated area and puts a lot of pressure on the remaining natural resource base (Scholes, 1996). The population growth was at 2% annually for the period 1998 to 2000; in comparison annual growth of GDP was at 3% in 1998 and then declined to -1%, -5% and -8% for 1999, 2000 and 2001 respectively (World Bank, 2001). Today, dry and open savannahs with grain and tobacco cultivation, grasslands, and cultivation of exotic fruits trees with only patches of Miombo woodlands left have replaced the formerly dense woodlands in the densely populated districts (SADCC Energy Sector, 1987). Gains in production in the region have largely been due to expansion of cultivated land area rather than to intensification since economic policies have provided few incentives for intensification (Misana et al., 1996).

Land ownership

The majority of people live on communal lands (Mudimu et al., 1995). In the Communal Areas land is held under traditional freehold tenure[5] with rights to sub-divide by family members, to bequeath and inherit without further reference to the state (Rukuni et al., 1994). Thus the state owns the land, but usufruct rights are granted to the families living there. Currently, some confusion exists over the administrative procedures in the Communal Areas. Officially, elected Village

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[5] After a person has leased land for some time for production including investments on this plot, the state normally awards the user with a freehold title (Rukuni et al., 1994).

Development and Ward[6] Development Committees are responsible for land and resource ownership matters, but current practise is to refer these issues to the traditional leaders, who hold the trust of the people (Rukuni et al., 1994).

In other regions of Zimbabwe, people were resettled after independence on farms, which used to belong to the colonial settlers. Land in the Resettlement Areas is owned by the state, although use of the land is free (Rukuni et al., 1994). The land cannot be bequeathed from father to children; thus, land then officially falls back to the state. Usually, inhabitants of the Resettlement Areas have access to a larger piece of land than farmers of the Communal Areas. People of the Resettlement Areas elect a Village Development Committee and a Village Chairman, who are responsible for putting rules on natural resource use into place. The District Councils also establish rules on resource use. The Resettlement Areas are experiencing the most rapid rates of woodland clearance (McNamara, 1993). Settlers are being encouraged to destump their fields; woodland clearance is aggravated by the fact that no management policies on natural resource use were put into place (Grundy, 1995, cited in Misana et al., 1996). Generally, as natural resources are deemed to belong to everyone in the Resettlement Area, everyone is supposed to benefit from each of the natural resources (Marasha & Chikomba, 2000).

Land tenure is an important factor since land tenure insecurity may hamper the decision to invest, e.g. to plant trees. On the other hand, households from a variety of tenurial arrangements have planted trees as not only private property regimes achieve sufficient security as an incentive to tree growing. Tree growing seems to be mostly affected by the existence or absence of rights of exclusion, particularly the exclusion of livestock from the household’s fallow fields. Once farmers have control over planted trees, economic factors are of more influence than characteristics of tenure (Arnold & Dewees, 1999), although in some cases tenure or control restrictions affect tree growing, e.g. in cases where the state is empowered to appropriate forest or woodland areas.

[6] A ward is an administrative unit below the district level.

2.2 Indigenous fruit trees and other woodland resources

Woodlands provide the last safety net for poor rural households during drought or periods of economic depression and high urban unemployment (Luckert et al., 2000). Woodland resources constitute assets that can be used during difficult times as a means of diversifying crop production and income and as buffer stocks of food, browse and fodder during times of drought (Campbell et al., 2002; Dewees, 1994). Currently, a rapid rise in the number of people marketing woodcarvings, basketry and other gathered products (Mopane caterpillars, wild fruits such as *Strychnos* sp., fuelwood and thatching grass) is observed in western Zimbabwe (Braedt & Gunda, 1988; Matose et al., 1997; Hobane, 1995; and Hobane, 1994 cited in Luckert et al., 2000). Expansion of cultivation areas, increasing population pressure and also privatisation of land have diminished access to tree resources for many people (Misana et al., 1996). Especially poor households rely heavily on woodland resources, although natural resource use does not lift them out of poverty (Campbell et al., 2002).

In the Miombo woodlands, a wide variety of edible indigenous fruit trees has been identified (Maghembe et al., 1998; Clarke et al., 1996). Mainly children consume wild fruits, but they also contribute to adults' diets, providing a supplement for vitamins and other nutrients. Starchy staple diets are frequently deficient in nicotinic acid, vitamin C, calcium and riboflavin, protein and caloric values; thus, indigenous fruits can help to overcome this deficiency (Saka, 1994).

Local use of edible wild fruits is influenced by species distribution, abundance, flavour and tradition (Chidumayo, 1997). They are mostly consumed during the hot dry season and the early rainy season before agricultural crops are harvested (Clarke et al., 1996). Some of them, like *U. kirkiana*, are widely traded (Maghembe et al., 1998). Thus, indigenous fruit trees contribute to the cash and non-cash income of the local household. The benefit derived from indigenous fruits varies between years, since yearly variability of yield is high (Chidumayo, 1997).

Collection of wild foods is considered a risk-coping strategy; that is, in years with income shocks, wild foods are collected for consumption smoothing (Dercon, 2000). Since entry barriers to wild food collection are low, poor households are equally able to be involved as wealthy households. In contrast, poor households face constraints in entering high-return activities with high entry barriers (Dercon & Krishnan, 1996). Gender issues in the field of natural resource use show that mostly women are involved in non-timber forest product use, since these activities often yield low returns to labour and can easily be combined with other women's tasks (Neumann & Hirsch, 2000). When new labour-saving techniques are introduced, e.g. for processing of non-timber forest products, or returns to labour rise due to other factors, men often take over this activity. According to the literature, differences in men's and women's harvesting practises exist, with women harvesting natural resources as joint activity and closer to the homestead, whereas men tend to go on 'collection trips' further afield (Neumann & Hirsch, 2000; Campbell et al., 1997).

2.2.1 The most popular indigenous fruit tree species: *Uapaca kirkiana*, *Strychnos* sp. and *Parinari curatellifolia*

Surveys conducted by ICRAF in Zimbabwe, Zambia, Tanzania and Malawi showed that *Uapaca kirkiana*, *Strychnos cocculoides* and *Parinari curatellifolia* are the three most popular indigenous fruit tree species. They are indigenous throughout the Miombo zone (Maghembe et al., 1998). *U. kirkiana* and *P. curatellifolia* are evergreen trees. *Strychnos* sp. sheds leaves during the dry season and produces new flush just before the rainy season. All three species are multipurpose trees; fruits are the main product, but other products, like leaves and wood, are also used. They start fruiting during the dry season, *Strychnos* sp. in August, *U. kirkiana* in October/November and *P. curatellifolia* in November. Fruiting finishes for *Strychnos* sp. in October, whereas the other two species continue to produce fruits until January.

U. kirkiana is an evergreen, deciduous tree of small to medium size, up to 13 m high, with many branches and a dense rounded crown. The pulp of ripe fruits is edible, with the fruits up to 3.3 cm in diameter (FAO, 1983) and containing between two and six seeds (Ngulube et al., 1997) (Figure 1 and Figure 2). *U. kirkiana* trees bear fruit of different colour, i.e. red, brown or cream. Fruit load varies significantly with tree size and colour of the fruit. Trees with cream-coloured fruits produce the highest yield (Mwamba, 1996). *U. kirkiana* shows yearly variations in fruiting, varying from 5 - 19% of all trees fruiting (Chidumayo, 1993). Differences in fruit size for *U. kirkiana* range from 4 - 50 g and the amount of pulp per fruit ranges from 0.2 - 30 g (Kwesiga et al., 2000). Larger trees seem to be more productive than smaller ones, even when fruit loads are related to tree size (Mwamba, 1994). Fruiting of *U. kirkiana* seems to be biannual[7], and is not affected by thinning treatments (Mwamba, 1996).

Figure 1. *Uapaca kirkiana* fruits.

[7] This phenomenon is referred to as alternate fruit production. It is a well-known phenomenon in fruit production and fruit tree management (Mwamba, 1996). Thinning treatments in apple production in Europe, which is also affected by the problem of alternating yields, lead to more even apple production over the years.

Figure 2. Marketing of *Uapaca kirkiana* fruits.

Strychnos sp. is a shrub or a small tree 3 - 8 m high. Ripe fruits are harvested from the tree or collected from the ground. Also, green fruits can be picked and stored for ripening (FAO, 1983) (Figure 3).

Figure 3. Children picking fruits of *Strychnos* sp.

P. curatellifolia is a tall evergreen tree up to 15 m high with a rounded crown. Fruits are between 3 - 5 cm long and are collected from the ground. The fruit pulp is edible and the kernel has high oil content. The wood is very hard and is used for construction (FAO, 1983).

2.2.2 Policies on fruit use

Forest legislation in Southern Africa generally restricts the rights of households to benefit from woodland management for anything other than subsistence purposes (Dewees, 1994).

In Zimbabwe, the Communal Land Areas Forest Produce Act does not rule out any trade in indigenous fruits. If someone wants to trade, officially a permit from the Rural District Council is required. The Rural District Council itself requires a permit from the Forestry Commission. The objectives of the regulations are to conserve the natural resource and to ensure benefit sharing. Presently, the rules regarding the trade of indigenous fruits are not enforced, although the Forestry Commission is supposed to enforce the rules to some degree. However, enforcement is difficult by any national institution because of the large number of people involved. The Forestry Commission now attempts to delegate to the village level. Resource Management Committees have just been established. Their biggest constraint on enforcement currently is the small number of staff, which consists of only one officer per district. At the moment, all revenues are shared between collectors, traders and sellers. The producer community does not benefit if its members are not trading themselves. Thus, the policy itself does not pose a constraint, but rather, the entitlement of the people who live with the resources does (Moyo, 2000).

The review of non-timber forest products use by Neumann & Hirsch (2000) also shows that in a situation with expanding markets, rising prices and growing importance of natural resources for the national economy, the economic situation of rural households does not necessarily improve. Especially when they lack secure property rights, as they then do not have the means to exclude outsiders. In Zimbabwe, returns to labour from natural resource use might drop to unacceptable levels if fiscal measures were put into place (Campbell et al., 2002, based on Breadt, 2002 and Standa-Gunda et al., 2002). Entitlement to fruits from trees that have been deliberately planted has not specifically been addressed; this is covered by means of by-laws on plantations (Moyo, 2000).

During the rainy season, while crops are in the fields, tree products from trees within the fields belong to the owner of the field. During the dry season, these trees and their products revert back to being common property (Campbell et al., 1997). Generally, access to fruits is controlled (Sithole, 1996). A study conducted in three regions of Zimbabwe by Rukuni et al. (1998) shows that the local chief controls indigenous fruit trees in the forest to varying degrees; the field owner controls trees in the field and the owner of a homestead controls trees within the homestead. The degree of control by the traditional leaders or other official bodies depends on their relative power and interest in resource conservation.

Anyone is allowed to harvest as much fruit as he/she can eat from private property without asking for permission, but when fruits are available abundantly, people are supposed to collect fruits from the commons, not from private lands. Collecting fruits from private areas in years with sufficient food supply is deemed suspicious, harvesting "too much" fruit is not acceptable, harvesting during the night or in the early hours is regarded as theft and trespassing (Sithole, 1996, p. 128). Farmers who try to restrict access to fruit trees still report problems with other people stealing fruits from their trees. Once the resource is opened up for use, a sequence of other people comes and harvests the fruits, starting with relatives, friends, then friends of friends. Then the fruit tree is back under a common property regime (ibid.). According to Ramadhani (2002), increased competition for the fruits and the unclear regulations regarding their use have changed their status from being a common property to an open access resource.

2.2.3 Commercialisation of indigenous fruits

Fruits of *Uapaca kirkiana*, which are mostly collected from the commons, are especially widely traded in Zimbabwe. The market chain links collectors to traders, wholesalers and retailers, although only few actors are involved at the wholesale stage. No sophisticated product differentiation takes place; consumers show rather high willingness to pay for the fruits (Ramadhani, 2002). Fruits and other goods from the Miombo woodlands are mostly traded in the informal sector and thus do not appear in national statistics (Brigham et al., 1996). Trading often constitutes a livelihood strategy to meet specific cash needs, a contingency in case of crop failure or simply an opportunity in itself (Campbell et al., 2002).

The emergence of markets for woodland products is complex. It is related to many factors, e.g. the process of specialisation and exchange, thataccompany the expansion of the wage labour economy, the emergence of markets in urban areas and alterations in market access due to infrastructural development or other factors (Brigham et al., 1996). The level of indigenous fruits marketing differs depending on availability, shelf life, control over the resource, demand patterns and access to markets, sale price and the effectiveness of social controls regulating the sale of these products (Gumbo et al., 1990). The level of marketing varies between regions in Zimbabwe, which is partly due to varying availability of indigenous fruits (Brigham et al., 1996). Indigenous fruits fetch lower prices in the rural than in the urban areas due to high supply, high competition amongst sellers and low demand (Brigham, 1996; Gumbo et al., 1990). Also, transport costs from the rural areas where the fruits are collected to urban markets contribute to this fact.

Growth in markets for edible Miombo woodlands products like indigenous fruits occurs due to the products' cultural importance and the increasing urbanisation. As regards the latter, urban migrants can only access the goods through the market (Falconer, 1990 cited in Brigham et al., 1996). Trading takes place seasonally, year-round or occasionally depending on cash needs, the type of the source and characteristics of the household (Arnold, 1996). He claims that frequent involvement of women in trade of non-wood forest products is an indicator of easy resource access and low thresholds of skill and capital to enter trading activities. Packham (1993) argues that access to markets and availability of transport are key factors in determining the commercialisation of produce.

Generally, agrarian change and growth in market transactions may shift household production from predominantly subsistence to more market-oriented production. Local markets emerge due to the need for specialisation and exchange, while urban or industrialised markets are likely to emerge in areas closer to commodity markets. Producers will sell when they have surplus or when the opportunity cost of selling is advantageous. However, policies may constrain farmers from participating in these markets (Arnold & Dewees, 1999).

2.2.4 Factors influencing indigenous fruit tree management

The following paragraphs give a general overview of factors that influence tree management and tree planting, followed by evidence from Zimbabwe. Farm households use indigenous fruits and other natural resources in order to pursue a strategy of livelihood security including several objectives like food sufficiency, social security, risk management and income generation. Once resource availability, objectives and socio-economic household characteristics change over time, costs and benefits that accrue to farmers will change, and the household will change its strategy.

As pointed out by Arnold & Dewees (1999), increased tree management and planting is a function of a change in the frame conditions, such as:

- to maintain supplies of tree products as production from off-farm tree stocks declines due to deforestation or loss of access;
- to meet growing demands for tree products as populations grow, as new uses for tree outputs emerge or as external markets develop;
- to help maintain agricultural productivity in the face of declining soil productivity or increasing damage from exposure to sun, wind or water runoff;
- to contribute to risk reduction in the face of needs to secure rights of land tenure and use, to even out peaks and troughs in the seasonal flow of produce and income and in seasonal labour demand, or to provide a reserve of biomass products and capital available for use as a buffer in times of stress or emergency.

A decline in availability of tree products may influence the decision to plant trees. However, a decline in trees that constitute a common property off-farm resource does not necessarily lead to on-farm planting. Other factors besides resource scarcity are also influential. Reduction of market constraints with respect to sale of tree products seems to constitute a higher incentive for tree growing than actual incentives to plant trees. Agricultural and land use policies may influence tree-growing activities, e.g. price policies for agricultural crops may favour their production, leading to less tree-growing activities. The same effect may be caused by policies supporting adoption of new agricultural technologies (Arnold & Dewees, 1998). With the opening up of rural areas and development of labour markets, opportunity cost of labour of rural people rises. Thus, formerly time-intensive collection activities of indigenous fruits may turn unprofitable because of now comparably low returns. This may be an incentive to cultivate indigenous fruit trees closer to home in order to reduce collection time. However, sometimes, rather than an increased tendency to cultivate indigenous fruit trees on-farm, production shifts away from using the product occur (Arnold, 1996).

Factor availability, i.e. availability of land, labour and capital, and allocation of these factors may limit tree cultivation. According to Arnold & Dewees (1999), tree cultivation often requires less labour and capital input than most other crops; thus, planting of trees is a favourable option if opportunity costs of labour are high, problems with hiring in labour and supervision exist and/or a smaller labour force is available, i.e. households with predominantly elderly people. However, seasonal labour peaks of agricultural production may compete with tree management tasks and thus hamper enhanced fruit tree cultivation.

Tree cultivation may be a feasible option if income is sufficient and the need to intensively produce additional income is small, land quality is low and would require high labour input for intensive production and/or the household wants to maintain control over surplus land. Increased wealth, or improved functioning of land, labour and capital markets that enables farmers to respond to imbalances in factor availability could reverse some of the shifts towards more tree cover that are occurring at the present (Arnold & Dewees, 1999).

Patterns of planted trees vary. Trees can be maintained on non-arable or fallow land, which is more likely to occur in more extensive farming and grazing systems. Trees that are grown around the house are often fruit and other valued species. Here, higher protection against livestock damage is given (Arnold & Dewees, 1995, cited in Arnold & Dewees, 1999). For example, in a ranking exercise in Zimbabwe, households put the highest value on benefits from fuelwood, building material and tree-derived inputs for crop production, although farmers indicated a higher interest in planting trees for fruit production (Campbell et al., 1991). This may be due to the fact that a higher number of substitutes exist for the former three types of tree products than for fruit trees.

If trees need to be separated from crops, they are grown along boundaries. This is also the case when trees are used for boundary demarcation or when they serve as windbreaks and for other protective purposes. Inter-cropping on arable land takes place where trees provide benefits to agricultural crops through shade, shelter or soil improvement or if the inter-cropping is mutually beneficial. Mono-cropping of trees on arable land in form of woodlots occurs near market areas in order to produce cash crops. However, trees are grown for a combination of purposes, and the decision to grow is influenced by a variety of factors such as characteristics of the individual household (Arnold & Dewees, 1999).

In Zimbabwe, households use indigenous fruit trees primarily in their natural habitat (Cavendish, 1998; Campbell, 1996b). This means the practice of planting indigenous fruit trees is uncommon; trees mostly regenerate by themselves (Minae et al., 1994). Brigham (1994) and Campbell et al. (1993; both cited in Campbell, 1996a) and Price & Campbell (1998) found within rural communities that only between 1% and 10% of households had planted indigenous fruit trees. More commonly, farmers nurture young saplings found on their land (Price & Campbell, 1998).

Some studies show that when land areas are cleared in favour of agricultural activities, indigenous fruit trees are conserved in the crop fields (Clarke, 1996). Indigenous fruit trees account for the majority of trees that remain standing in agricultural areas (Price & Campbell, 1998; Brigham, 1996). It has been observed that tree planting and tree conservation activities around the homestead are responsible for replacing indigenous non-fruit trees with exotic and indigenous fruit trees (Price & Campbell, 1998). Trees that remain in the fields are managed by pruning, lopping and pollarding, thus providing increased compatibility with crops and providing firewood and building materials to the household (Clarke et al., 1996; Minae et al., 1994). However, the study of Rukuni et al. (1998) shows that the continuing deforestation process also affects indigenous fruit trees. This process is limited to varying extent by the traditional leaders, who put in place rules on indigenous fruit tree cutting and also enforce those rules.

Two driving forces push towards more and more active management of trees. The first is growing scarcity, i.e. on-farm resources have grown more valuable (McGregor, 1991), and the second is commercialisation and the potential income that can be derived from planting (Brigham, 1996; McGregor, 1991)[8]. As the case of wild coffee in Ethiopia shows, market access can be an incentive to collect coffee from protected areas (Abebaw & Virchow, 2003). Deforestation status has no influence on the planting of exotic fruit trees (Musvoto & Campbell, 1995; McGregor, 1991; and Du Toit et al., 1984). On the other hand, Wilson (1990) states that “the extent to which fruit trees are planted is linked to the extent to which wild fruit trees have been left in fields, and this is in turn linked to the species composition of woodlands which were cleared prior to cultivation” (cited in Dewees, 1994, chapter 4).

[8] This has also clearly been demonstrated for the case of rattan cultivation in Laos (Evans & Sengdala, 2002).

According to Musvoto & Campbell (1995), the wealth status of the household has no influence on the planting of trees. Households headed by men are likely to grow a higher number of exotic fruit trees on their farms than those headed by divorcees or widows. Similarly, households with a longer residence period have more exotic fruit trees on their farms (Price & Campbell, 1998). Among exotic fruits, mangoes are the major one. They only contribute a small share towards cash income relative to crops like maize, but they are more valued for household consumption (Musvoto & Campbell, 1995).

Exotic fruit trees are planted because they have properties that households prefer, e.g. -commercialisation potential (Brigham, 1994 cited in Campbell, 1996a). Many people believe that the indigenous fruit tree species are inferior to the exotic ones. Enhanced management of indigenous fruit trees is hampered by substitution among species, which also includes planting of exotic fruit trees (Campbell, 1996a). Exotic fruit trees are increasingly planted and utilised for construction purposes, while indigenous fruit trees more and more serve as a source of fuelwood (McGregor, 1991). In South Africa, Mander et al. (1996) identify the lack of understanding as the main obstacle to commercial cultivation of traditionally used plants.

2.3 Domestication of indigenous fruit trees

ICRAF started domestication activities in 1994, concentrating on so-called “Cinderella” species, i.e. species whose products are traditionally used by local people and thus contribute to food security and household welfare (Leakey & Tomich, 1999). The target species of this study are also part of the domestication programme. Positive external effects on the environment, e.g. soil conservation, are expected to add to the returns to domestication and enhanced planting effort, although these benefits do not necessarily accrue to the farmers (ibid.). However, market reaction to increased supply of indigenous fruits has so far not been analysed in order to value domestication effort towards enhancing fruit supply and rural incomes.

Indigenous trees are better adapted to climatic conditions of Africa than many exotic species; thus, improvement of the indigenous ones could be more profitable than working on adapting exotics to the climatic conditions (Mizrahi & Nerd, 1996). Moreover, wild fruit trees are highly adapted to variable climatic conditions, in particular to drought, and as a result, it can be expected that fruits have an extremely important function in times of drought-induced nutritional stress, although there is little information on the yields obtainable from wild fruit trees (Packham, 1993). Therefore, although yields may be relatively low compared to exotic fruits, the ability of indigenous trees to withstand harsh conditions is probably of overriding importance, resulting in protection by farmers (ibid.). The potential contribution of indigenous fruit trees to raising incomes of rural household provides the rationale for ICRAF's domestication programme (Leakey & Tomich, 1999).

Domestication and commercialisation of tree products aim at improving the livelihood of rural people, which covers improvements of production systems, in terms of income-generating opportunities and nutritional well-being (Mwamba et al., 1996). Domestication follows extractivism, i.e. resource collection from the wild, when markets expand beyond forests' ability to supply products or when the resource is overexploited and thus market demand cannot be met (Leakey & Isaac, 1996; Homma, 1996 and Homma, 1994 cited in Leakey & Tomich, 1999). Generally, domestication is an iterative process involving accelerated and human-induced evolution to bring species into wider cultivation through farmer-driven and often market-led process (ICRAF, 1997). Domestication is also interpreted as a change in human-plant interaction (Wiersum, 1996), which then also covers the stimulation of the production of a certain product, e.g. pruning methods to enhance fruit size and quality.

The most effective strategy of domestication has often been vegetative propagation of rare genotypes with superior characteristics, which were found either in nature or resulted by chance from breeding programmes (Leakey & Tomich, 1999). Grafting of fruit trees results in early fruiting. For example, with *Sclerocarya birrea*, an indigenous fruit tree of the drier regions in Southern Africa, fruiting in the wild occurs at between 10 and 12 years. However, grafted cultivars of *Sclerocarya birrea* fruited after three to four years (Mateke, 2000).

The rationale for public investment like ICRAF's investment in tree domestication is that private firms tend to under-invest from society's point of view in products that produce positive external effects like food security, poverty alleviation and environmental conservation. Technical knowledge is a public good characterised by low rivalry and exclusivity. Thus, incentives for a private firm to do research on the generation of new technical knowledge are low, since the firm cannot appropriate the benefits of its research. Also, risk associated with failure to meet research objectives is fairly high, so that farmers cannot be expected to take it willingly (Upton, 1996). Private firms also tend to keep investment in tree domestication low since the breeding process takes a long time to generate benefits (Leakey & Tomich, 1999). For example, the time from cross-pollination between the ideal parents until the release of a new cultivar is more than 20 years (Thompson, 1993). In Botswana, an agroforestry trial was established in 1995 by Veld Products Research on intercropping of indigenous fruit trees, *Sclerocarya birrea*, *Strychnos* sp. and *Vangueria infausta*, with agricultural crops (sorghum and cowpeas); ten years of data are expected to be required in order to evaluate this agroforestry system (Taylor et al., 1996).

Box 1. Excursus: The example of kiwifruit domestication.

The kiwifruit is one of the most recent crops to undergo domestication, which was accomplished over a period of 70 years during the last century. In 1904, the first plants came from China to New Zealand, where most of the domestication work and initial production took place. The material was first sent to Europe and the United States between 1898 and 1915. From 1920 on, grafted material of known sex (Kiwifruit is a dioecious plant) became available. In the early 1930s, the first orchard was producing good crops; production continued at about the same level until, in 1970, production increased to meet export market demands. The success of Kiwifruit production is mostly the success of one superior cultivar that was selected in 1930 in New Zealand. Very little deliberate selection was carried out, although the natural gene pool is very variable (Ferguson, 1995).

Regarding the time frame of domestication of other fruits, few specifics are known, inasmuch as the first use of avocado, mango and citrus dates back centuries. The first stages of domestication are unknown (Smartt & Simmonds, 1995).

Another constraint faced by private R&D in fruit tree domestication is that vegetative propagation, which is viable for most tree species, allows farmers to multiply their own planting material, which will lower returns to the breeder (Leakey & Tomich, 1999). In West Africa, farmers take part in the domestication process by selecting preferred indigenous fruit genotypes (Leakey et al., 2004).

2.3.1 The domestication process

Breeding of a woody species is a long-term task, as is the shift of such a product into commercial production. The lag period between market acceptance of a new selection and full production is estimated at about 10 years (Seager, 1998). The genetic gain increases with increasing genetic selection (Leakey & Tomich, 1999). Indigenous fruit trees show high genetic variability. The resulting large variation between individual trees makes identification and selection of superior individual trees, e.g. trees with better tasting, larger fruits, easy. Since most trees can be easily propagated vegetatively during their juvenile state, multiplication of superior species is possible in large numbers once the most suitable vegetative propagation method has been identified. Thus, the first major breakthrough in the domestication process can be expected to be the establishment of vegetative propagation methods, e.g. through cuttings or grafting. Then the domestication level is determined by the pace of the identification of superior species from the natural woodlands. The upper limit from this part of domestication will be the degree to which superior individual trees exist. From then on, further improvements are only possible through generative propagation in traditional breeding processes. Here, more time will pass until characteristics of the new cultivars can be established (Leakey & Tomich, 1999).

2.3.2 Domestication and biodiversity

The value of biodiversity can be found in its stabilising or insurance function (Weitzman, 2000). Biodiversity also constitutes a potential source of innovation in the R&D sector (Goeschl & Swanson, 2002). The value of diversity between species arises from the support it extends to ecosystem services like watershed protection (Benhin & Barbier, 2004). Private resource valuation, i.e. by private patents, often underestimate social values due to existing externalities (Goeschl & Swanson, 2002).

Selection of specific traits in the domestication process may carry some opportunity cost in terms of reduced genetic diversity[9]; however, these two aspects are considered part of a "wise risk-averse strategy of domestication" (Leakey (1991) cited in Leakey & Tomich, 1999, p. 328). Benefits of tree improvements seem to outweigh costs in terms of genetic loss in this discussion. At least, Leakey & Tomich (1999) continue to summarise gains of past domestication exercises in terms of yield increase without outlining the loss of genetic diversity that may have accompanied this process. However, without domestication the resource in question could have been entirely lost.

Under common property regimes, commercialisation as a means to conservation of genetic resources is questionable because of potential overexploitation. The effects of commercialisation on the resource differ depending on tenurial, institutional and socio-political context (Neumann & Hirsch, 2000). Increased market access and increased rural development may also lead to decreased biodiversity (Wale & Virchow, 2003; Taylor et al., 1996).

2.4 Summary

The Miombo woodlands cover a vast part of Southern Africa. Due to a growing population and other factors such as institutional failures in common property regimes, much of the woodlands have been cleared in favour of agricultural production. Households of the Miombo zone rely mostly on rain-fed agriculture, livestock keeping, vegetable production and a variety of off-farm activities. Land tenure is either under communal ownership or resettlement schemes; the former allows bequest of the land to children, while the latter does not have this provision. Woodland resources are a safety net in times of need. Indigenous fruits, which are collected from Communal Areas and trees preserved in farmers' fields, are part of the safety net. *Uapaca kirkiana*, *Strychnos* sp. and *Parinari curatellifolia* are the most popular species. Sale of some of the fruits has increased over the past years. Fruits are a common property resource. Control over the resource varies, depending on the

[9] On the other hand it has been show that farmer-led domestication even resulted in increased genetic diversity (Leakey et al., 2004).

location of the tree and abundance of the fruits. The homestead owner controls trees in homesteads, trees in farmers' field are private property during the dry and common property during the wet season, and the local chief controls trees in the forest. Increased competition for the resource has enhanced rivalry. The fruit trees are predominantly preserved in farmers' fields and are less often planted. Once trees are planted, they and their products constitute private property under the Plantation Act.

The rationale for public investment in indigenous fruit tree domestication is that it is expected to generate positive externalities like poverty alleviation and environmental conservation. The domestication of a woody plant is a long-term process. Establishing appropriate vegetative propagation methods is the first major breakthrough in this process. Aspects of interaction between domestication and biodiversity, i.e. whether domestication contributes to conserving or diminishing biodiversity, are not taken up further in the present study. Rather, the emphasis is on the role of IF in poverty alleviation and the farmers' perspective of IFT on-farm planting, which is one of the major aims of the domestication programme.

3 Theoretical background

Small-scale farm households pursue a diverse portfolio of farm, off-farm and household activities with the aim of maximising utility. Indigenous fruit trees have been identified as an important source of cash and non-cash income in times of need; therefore, they are important in the context of poverty and vulnerability to poverty, one of the major problems in the rural areas. The planting of indigenous fruit trees constitutes an additional income-generating activity and can be interpreted as an investment decision.

This section is organised as follows. First, the small-scale farm household is described within the context of farm household theory. Factors that determine household utility are identified and placed into context regarding indigenous fruit tree use. Second, the framework for the analysis of income poverty and vulnerability to income poverty is set up and the role of IFT in this framework is highlighted. Third, the investment problem in the context of rural small-scale farm households is analysed. In doing so, sunk cost, flexible timing of investment and uncertain returns to investment are taken into account.

3.1 The small-scale farm household

Household theory provides the basis for analysing production and consumption decisions of semi-subsistent farm households in rural Africa. Households combine time, goods produced at home, and market goods with the aim to maximise utility. Furthermore, consumption and production decisions are interdependent (Nakajima 1986; Becker, 1982). Livelihood strategies encompass multiple objectives in maximisation of utility, like secure provision of food and subsistence goods, cash for purchase of goods and services and savings for future needs (Scherr, 1995). Generally, rural households compose their livelihood strategies from a range of assets, income sources and product and labour markets (Campbell et al., 2002; Bebbington, 1999). For example, rural livelihoods sometimes encompass migration strategies to accumulate wealth, e.g. some family members enter higher paid labour markets in urban areas and send remittances home. They participate in rural industries and rural and periurban commerce (Bebbington, 1999). The latter encompasses fruit and clothes trading activities in Zimbabwe in addition to agricultural production. Households choose the portfolio of activities that contributes the most towards their multiple objectives and yields the greatest utility. Households are efficient; the degree to which each activity is pursued depends on its marginal value product and the prevailing wage rate, the opportunity cost of labour. If differences in the wage rate of different household members, e.g. men and women, exist, labour allocation shows gender-specific differences between production activities (Ellis, 1993).

In the unitary household model, the household is assumed to act as one decision-making unit, i.e. with one utility function, whereas collective models account for the fact that differences between household members' utility functions may exist (Ellis, 1993) and accordingly influence resource allocation and production decisions[10]. However, additional household income is not necessarily pooled and distributed equally amongst all household members as the unitary household model assumes. For example, extra income from women's activities has proved to be beneficial for children's well-being, whereas men tend to spend a higher proportion of their income on personal use (Alderman et al., 1995; Ellis, 1993).

Climatic and market risk, which characterise the environment of small-scale farm households, cause uncertainty[11] about the success of production enterprises from year to year and even within one year. Consequently, variability in income, food supply and labour requirements is high. If utility is defined in terms of the absolute amount of income and variance, e.g. the mean variance criterion, households are then assumed to maximise utility by minimising variance for a given income level or maximising income for a given level of variance (Brandes & Odening, 1992; Hazell & Norton, 1986). Both strategies influence the choice of the efficient portfolio of income-generating activities that maximises utility. The portfolio choice of a household is an indicator of the household's optimal portfolio under the constraints of this household.

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10 Differences in the opportunity cost of household members and labour allocation are analysed in Low's (1986) household model (cited in Ellis, 1993).

11 In the literature, risk refers to a situation with known probabilities for a state of nature or uncertain consequences of an action. Uncertainty refers to absence of known probabilities or

Production activities vary in their demand for land, labour and capital inputs; thus the farm household's choices are limited by its resource endowments. Land refers to natural resources that are used by the household (Upton, 1996). Land availability often is not a constraint in Africa; however, low soil fertility and/or erratic rainfall may still limit agricultural production. Labour consists of family labour, work parties, i.e. reciprocal labour exchange between villagers, and hired labour. According to Upton (1987), labour rather than land is the limiting factor in agricultural production in African rural areas since agricultural activities are highly seasonal and many tasks like planting have to take place within a very short period of time in order to ensure the success of production[12]. Thus, labour productivity is an important criterion for evaluating performance of production activities. Capital refers to everything else in production "that is not a gift of nature, but which has been produced in the past" (Upton, 1996, p. 19).

Figure 2 summarises the linkages between resource endowments and households' production choices, whereby environmental and institutional factors constitute the framework in which households operate. In the case of Zimbabwean small-scale farmers, farm, off-farm and household activities are interrelated components of the household system and IFT use constitutes one of them. Leaves are a valuable input into agricultural and horticultural production, acting as fertiliser and also improving soil structure. Also, the leaves and fruits are feed for livestock and the timber is used for construction and firewood. Most importantly, the fruits are consumed at home either fresh or processed and are also frequently sold. Mostly labour for collection of the fruits and land if trees are preserved on farmers' fields are inputs into IFT use. Since the fruits are a common property resource (Ramadhani, 2002; Sithole, 1996), households compete for the use of them. External factors like the climate, socio-cultural norms and gender roles, the national economy and other factors provide the background against which households decide on their income portfolio.

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incomplete information (Hardaker et al., 1997).

12 This fact is aggravated by the high HIV/AIDS rates in the region.

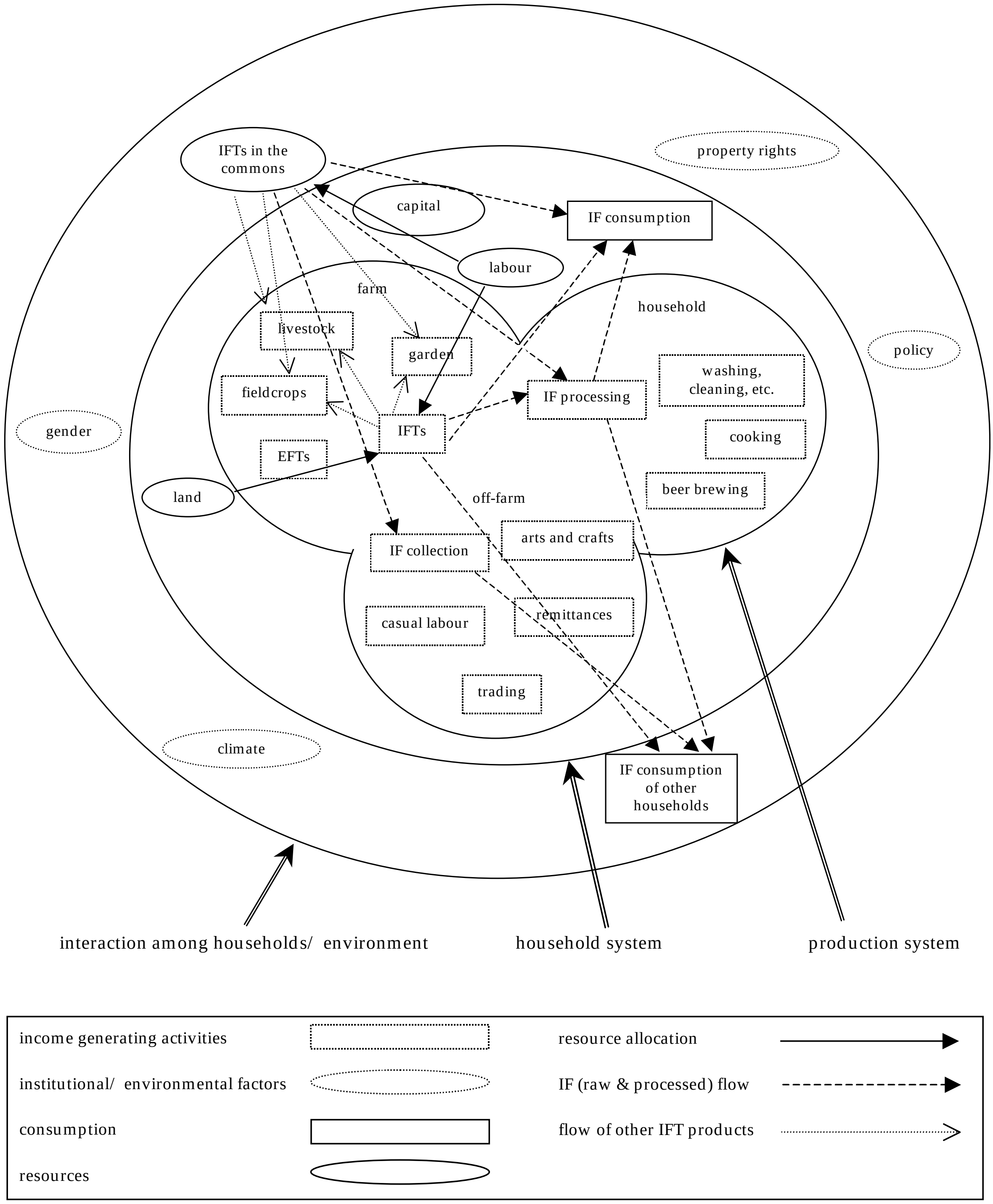

Figure 2: Indigenous fruit trees within the farm household system.

Source: Own formulation.

This study values the costs and benefits of use and sale of IFT products from farmers' perspective via calculation of gross margins because farmers take the private costs and benefits of collection of the respective tree products as a yardstick when evaluating the efficiency of IF collection compared to alternatives for income generation. Farmers also value the non-market services and cultural values that the trees provide (Campbell et al., 1997). The gross margins computed for this study exclude these aspects and thus underestimate the total benefit derived from IFT, as these services are not accounted for.

In short, three aspects can be highlighted: (1) farmers assess production activities on the basis of their contribution towards maximising utility, (2) distribution of income within a household influences each member's well-being, and (3) labour can be a limiting factor of production, so that labour productivity is a factor considered when taking up production activities.

3.2 Food security, poverty and vulnerability

According to the FAO, food security is defined as "physical, social and economic access to sufficient, safe and nutritious food that meets dietary needs and food preferences for an active and healthy life for all people at all times". Household food security is the application of this concept at the family level, with individuals within households as the focus of concern. In contrast, food insecurity refers to a situation when people are undernourished and their food intake falls below the minimum requirements (FIVIMS, 2003).

Poverty is a broader concept. It is defined as "pronounced deprivation in well-being" (World Bank, 2001, p.15). Deprivation restricts someone's capability to lead the kind of life he or she values (Sen, 1999). Poverty in this sense encompasses several dimensions: (a) material deprivation, (b) lack of education and health, (c) exposure to vulnerability, (d) exposure to risk, (e) voicelessness and (f) powerlessness (World Bank, 2001). Usually, monetary income or consumption expenditure is used to measure poverty. Both indicators carry their own problems, i.e. variance in survey design and data collection between countries and over time. Also, if data are collected on a household level, intra-household food distribution is neglected. A frequently used benchmark for assessing poverty is the so-called poverty line, under which a household (individual) is considered to be poor (World Bank, 2001).

Poverty is a static concept. It can be classified according to the degree of persistence in transient poverty and persistent poverty. Transitory (stochastic) poverty refers to households that are sometimes below, sometimes above the poverty line (wherever this is set). Chronic (persistent) poverty refers to a household always below the poverty line. This means that for stochastically poor households, current consumption < poverty line < household's permanent income. For chronically poor households it holds that permanent income < poverty line as well as that current consumption < poverty line (Morduch, 1994). Gaiha and Deolalikar find that most households are poor for some time (1993, cited in Dercon, 2000). If households forego higher returns for more stable consumption in order to cope with high income risk, chronic poverty may be one of the consequences (ibid.). Transient poverty is caused by fluctuations in consumption, whereas chronic poverty is caused by high income-risk in general (Dercon, 2000). Three factors have been identified to contribute to poverty in poor countries, i.e. (i) climatic and price variability, (ii) poorly developed financial institutions and (iii) weak social insurance institutions (Morduch, 1994).

Vulnerability in the context of the food security discussion is caused by a variety of factors, and as a consequence puts people at the risk of becoming food insecure. In contrast to poverty, vulnerability is a dynamic concept that captures the response to changes over time (World Bank, 2001; Webb & Harinarayan, 1999). An individual's or household's exposure to risk factors and their ability to cope with them determine the degree of vulnerability (FIVIMS, 2003). Vulnerability in the context of poverty is the risk that an individual or household will face a period of poverty over time (World Bank, 2001), in other words, the probability of falling below the poverty threshold (Pritchett et al., 2000). Income risk and the failure to cope with it result in household consumption fluctuations. They also affect nutritional, health and educational status as well as contributing to inefficient and unequal intra-household allocations (Dercon, 2000).

Counteracting vulnerability

Risk-management and risk-coping strategies are employed in order to reduce vulnerability to poverty (Dercon, 2000). Risk-management strategies aim at income smoothing from an ex ante perspective, e.g. via diversification by combining activities with low positive covariances and income skewing, that is, taking up low risk activities with low returns. Risk-coping strategies include self-insurance such as precautionary savings, i.e. building up of assets and group-based risk-sharing. They deal with risk from an ex post perspective and aim at consumption smoothing. Attempts to earn extra income are also part of risk-coping strategies; collection of wild foods is such a source of extra income (Dercon, 2000). Wild foods are natural food resources collected from the natural environment, e.g. Communal Areas, roadsides, etc. Risk-coping strategies are of course limited depending on the type of risk the household or the community faces.

Income diversification is often limited by entry constraints. Also, the effectiveness of income portfolios depends on its relation to the asset portfolio and other options available and the covariance between them. A risky, specialised portfolio may be associated with lower consumption risk than a diversified portfolio, depending on the asset position, i.e. depending on the extent to which the assets can serve as a buffer against consumption fluctuations (Dercon, 2000).

The effectiveness of risk-management and risk-coping strategies depends on the type of risk a household faces. When faced by common risk, i.e. risk that affects everyone in the community, assistance from outside the community is required. For idiosyncratic risk, i.e. risk that affects individuals in the community only, a wider range of management and coping strategies within the community may be sufficient. Idiosyncratic risk contributes a large part to income risk. Holding assets does not necessarily protect against income and consumption fluctuations, as sometimes suggested. This is due to covariance of asset values and income after common shocks and lumpiness of relatively safe and profitable assets, e.g. livestock (Dercon, 2000).

Lastly, small but frequent shocks are easier to deal with than large, infrequent shocks. Consumption smoothing is more difficult to achieve with successive shocks than with single shocks (Alderman, 1996, cited in Dercon, 2000).

Measurement of poverty and vulnerability

The World Bank, based on Chen & Ravallion (2000) and Ravallion & Chen (1997), defines the international poverty line as consumption poverty, i.e. households that consume (“live on”) less than 1 dollar per day measured by consumption expenditure per capita. It was first calculated in 1990. To this end, national poverty lines for 33 countries were converted into 1985 purchasing power parity (PPP) prices, and the most typical line among the low-income counties for which a national poverty line was available was selected. In 1999, the same national poverty lines were converted by using 1993 PPP prices, and the new international poverty line was determined as the median of the ten lowest poverty lines[13] (World Bank, 2001). For the establishment of poverty lines, consumption expenditure is either directly estimated from expenditure surveys or, when only income surveys are available, income is adjusted by the national savings rate to arrive at the expenditure figures. Whenever data on mean consumption are available, this information is used to replace income means (Chen & Ravallion, 2000). Consumption levels are updated either by new survey information, or, if this is not available, by estimation of growth rates of private consumption from national statistics. The international poverty line can be used as an indicator for global comparison. On a national level, national poverty lines, which reflect "what it means to be poor in each country's situation", are more appropriate (World Bank, 2001, p. 17).

Contrary to the World Bank method, Sala-i-Martin (2002) estimates income poverty rates based on PPP-adjusted GDP data. He claims that income is the better measure of poverty, since using the national savings rate to adjust income to consumption implies that all households, even those below or near the poverty line, save the same percentage of income, which may not hold (Sala-i-Martin, 2002)[14].

Overall, both approaches result in similar figures on the global poverty rate as well as on the poverty rate in Africa for 1998 (Figure 4). However, for preceding years figures differ; estimates of the poverty rate in Zimbabwe also differ. The Zimbabwean consumption poverty rate is based on expenditure surveys (Alwang et al., 2002). The latter include additional information on poverty rates for rural and urban areas in Zimbabwe (in 1995 48% and 8% respectively).

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[13] The 1999 poverty line is equivalent to USD 1.08 per person per day in 1993 PPP terms (World Bank, 2001).

[14] GDP, on the other hand, includes savings that do not contribute towards personal income and government expenditure, which may not reach everyone in a country (Fukuda-Parr, 2002).

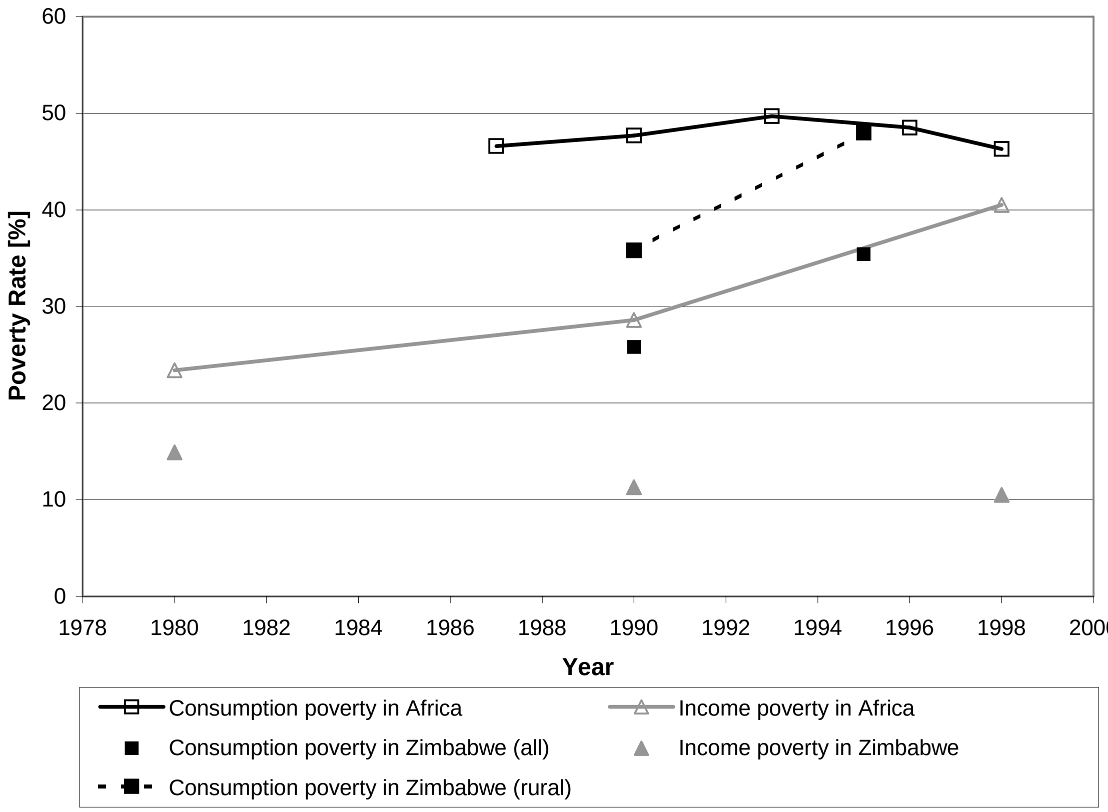

Figure 4. Income and consumption poverty in Sub-Saharan Africa and Zimbabwe.

Source: Income poverty: Sala-i-Martin (2002); consumption poverty, Africa: World Bank (2001); and consumption poverty, Zimbabwe: Alwang et al. (2002).

Alwang et al. (2002), based on data from the Central Statistical Office, Zimbabwe, give a national minimum food needs poverty line of about ZWD 30 per person per month for 1990. Extrapolating this figure to 1999-2000 using the average annual growth rate of the food price index of 34% (World Bank, 2003) yields an average poverty line of 9.2 ZWD per person per day. The international poverty line of USD 1 per person per day at the PPP conversion factor provided by the World Bank is within a similar range. It is at 6.3 and 9.6 ZWD per person and day for 1999 and 2000, respectively.

By using income rather than consumption as a measure of living standard, it is accepted that income constitutes the capability to consume, and "consumption functioning" can be understood as the outcome of the exercise of that capability (Duclos, 2002, p. 5).

In order to appropriately assess vulnerability, data are required on household assets, on formal and informal safety nets, and on the functioning of markets and economic policies, which determine the opportunity set and range of activities one household can pursue. Vulnerability measures based on either assets or income only may not reflect households' overall exposure to risk since the total determines the capacity of a household to counteract risk (World Bank, 2001). Moreover, vulnerability is a dynamic process of cumulative conditions. Significance of causal factors and their combination change over time and place (Webb & Harinarayan, 1999). These fluctuations result from changes in causal factors, but also from coping mechanisms available (ibid.; Campbell et al., 2002). Vulnerability results from poverty, but at the same time can reinforce income processes and lead to poverty (Morduch, 1994).

Morduch (1994) suggests treating vulnerability as a component of poverty, so that poverty could be measured either as mean and variance of consumption[15] over time or in terms of certainty-equivalent consumption, i.e. the trade-off a household accepts between certain and uncertain -- though higher -- consumption levels.

Based on the outline above, one can draw the following conclusions:

- Many activities contribute to farm household income and influence poverty and vulnerability to poverty.
- Vulnerability is a dynamic concept and changes over years and seasons depending on household's asset base, risk exposure, social risk-management and other smoothing mechanisms available.
- Collection of indigenous fruit constitutes a risk-coping strategy, whereas indigenous fruit tree planting constitutes a risk-management strategy in the sense of portfolio diversification by the taking up of this new activity[16].
- A large contribution of indigenous fruits collection towards rural incomes does not necessarily justify promotion of on-farm planting, since entry constraints between collection and on-farm planting differ.

The analysis concentrates on the assessment of indigenous fruit collection from the Communal Areas as a risk-coping strategy. This approach does not allow assessment

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15 However, by using variance of consumption as an indicator of vulnerability, upside and downside risk are given equal weights (Kamanou & Morduch, 2002).

16 If tree planting contributes towards minimising the variance of farmers' portfolios.

of the contribution of indigenous fruits to food security using a caloric intake concept, but rather an access-based concept ('trade entitlements' concept), accounting for the fact that households can exchange income generated by indigenous fruit trade for food and other income types and even health and education.

3.3 Technology adoption, investment and the farm household

It is the expectation of the ICRAF domestication programme that farmers are going to adopt indigenous fruit tree planting once the trees have been domesticated. Several factors and their interaction have been discussed in the context of technology adoption. Some of them refer to characteristics of the technology itself, e.g. profitability and uncertainty of returns. Others concern the decision-making environment, e.g. policy and market conditions, while the third group refers to the characteristics of the adopter and his resource base, e.g. risk aversion, size of land holding, labour availability, wealth status, credit availability, age[17], education and land tenure (Feder et al., 1985; Feder & Umali, 1993; Marra et al., 2003 provide reviews). Generally, profitability and uncertainty of returns on new technologies are major factors in the adoption decision. Studies have shown that the higher the profitability, the faster the rate of adoption. On the other hand, uncertainty about profitability induces potential adopters to delay adoption in order to gather new information. In a Bayesian framework, the new information is used to update prior beliefs concerning the profitability. If the expected gain becomes sufficiently large, adoption takes place; if not, adoption is further delayed or does not take place at all (Jensen, 1982). It is difficult to predict the time dimension, i.e. timing and speed, of an adoption process in an ex ante assessment. Furthermore, adoption processes are very complex and influenced not only by economic, but also by social and institutional factors (Rogers, 1995). Adoption of a new technology can be interpreted as an investment decision and profitability can be estimated from an ex ante perspective[18].

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[17] This could implicitly stand for the individual time preference.

[18] Many innovations that have been analysed in the field of agriculture carry the characteristics of an investment, i.e. current income is foregone in favour of enhanced future income, especially in the case of irrigation technologies or other technological packages. Even innovations that do not

Also, timing of adoption, i.e. whether to invest today or later, can be assessed from an ex ante perspective, as will be shown below.

Investment problems include pure investment aspects,[19] but also hedging aspects, i.e. reducing risks that are related to normal business operations or to investments (Luenberger, 1998; Brandes & Odening, 1992). Decisions about which investment alternative to choose are not only influenced by the initial outlays and future income streams, i.e. their absolute amount, variance and distribution, but also by consumption decisions and requirements of the household in question. Thus, the investment problem constitutes a "portfolio selection problem, since the real issue is to determine where to invest available capital" (Luenberger, 1998, p. 8).

Recent developments in investment theory have stressed shortfalls of the traditional net present value (NPV) criterion (Odening, 2000; Trigeorgis, 1998; Beißinger & Möller, 1994; Chavas, 1994; Dixit & Pindyck, 1994). The traditional NPV investment rule to 'invest if the sum of discounted net benefits exceeds zero' has several implicit assumptions: (1) It ignores sunk cost, thus assuming that the investment is reversible. If market conditions turn out to be worse than anticipated, the traditional NPV model implies that the investment can be undone and expenses can be recovered (Dixit & Pindyck, 1994). (2) The NPV criterion does not consider that investments can be delayed, which may have a value in itself. It uses a "now or never" point of view (Dixit & Pindyck, 1994, p. 6). (3) The traditional NPV approach often works with a scenario of expected values, that is, it does not account for uncertain events of the future (Trigeorgis, 1998; Beißinger & Möller, 1994).

Although the latter shortfall can be overcome through application of stochastic simulation (Hertz, 1964) or decision tree analysis (Trigeorgis, 1998; Hardaker et al., 1997; Brandes & Odening, 1992), which analyses various future scenarios an investment could follow, some problems persist. Both approaches suffer from the

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involve investment in new machinery may include major upfront costs in terms of farmers' time spent gathering information. The question is the time lag between initial outlay and expected returns and the size of costs and benefits involved.

[19] Pure investment refers to the motivation to increase future return for present allocation of capital (Luenberger, 1998).

problem of determining the appropriate discount rate. Stochastic simulation approaches result in probability distributions of the evaluation criterion, e.g. the net present value (Hertz, 1964). Different investment alternatives can then be compared according to the criterion of stochastic dominance (Hardaker et al., 1997; Brandes & Odening, 1992). Proponents of the stochastic simulation approach welcome the fact that the probability distributions of the net present value will provide information on the riskiness of the new venture. However, it is not necessarily the overall variance of returns of the investment that is of interest, but the contribution of the investment towards the variance of the farm households' portfolio. The total risk of an investment can partly be diversified away, i.e. the unsystematic risk, so it is only the systematic risk that matters. The systematic risk of one title is captured by the correlation of its returns with the market portfolio (Lewellen & Long, 1976).

The investment decision poses an option to the decision maker similar to a financial call option that has not yet been exercised. That is, the decision maker has the right, but not the obligation to realise the investment,[20] and flexibility has a value in itself (Lund, 1991; Trigeorgis, 1998). This opens up a new set of models and tools taken from financial options theory to evaluate investment opportunities (Trigeorgis, 1998; Dixit & Pindyck, 1994). This approach is commonly referred to as the real options approach or new investment theory.

The real option approach is relevant for investment opportunities characterised by irreversibility, flexibility and uncertainty. Thus, there exists a positive value of waiting to invest, and it has been demonstrated that deferring investment may be a profit-maximising strategy for these three conditions independent of the risk attitude of the decision maker (Dixit & Pindyck, 1994).

Hence, "the correct calculation to value an investment involves comparing the value of investing today with the (present) value of investing at all possible times in the future" (McDonald & Siegel, 1986, p. 707). Only if gains of new information by postponing an investment are smaller than cash flows foregone by deferring it should the investment be realised right away (Musshoff, 2000). Thus, it has been suggested

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20 This right, which is a result of the option owner's flexibility, is similar to the quasi-option value developed earlier by Arrow & Fisher (1974).

that the NPV criterion has to be extended to include the value of the option of waiting to invest (Trigeorgis, 1998; Dixit & Pindyck, 1994). Other real option values include the option to abandon, of sequential investment, to expand or contract, to temporarily shut down, to switch outputs or inputs. They also create additional flexibility for the decision maker and provide values in themselves (Trigeorgis, 1998).

The value of the option to postpone the investment grows with enhanced variability of input and output prices, which has been demonstrated in many applications of the real option approach to agricultural investments decision (Isik et al., 2003; Odening & Musshoff, 2001; Price & Wetzstein, 1999; Winter-Nelson & Amegbeto, 1998; Purvis et al., 1995). The value of the option to wait is also large if expected improvements of the new technology are large (Bessen, 1999)[21].

The real option value can be identified either by dynamic programming or contingent claims analysis. The dynamic programming approach requires the knowledge of risk and time preference of the decision maker, whereas an application of the contingent claims analysis is independent of these individual preferences. The contingent claims approach establishes the discount rate and the value of the option to invest via an underlying, or so-called spanning asset (Dixit and Pindyck, 1994). Most empirical applications using the dynamic programming approach assume the discount rate and test the results of their real option value analysis via sensitivity analysis with respect to changes of the discount rate.

The following section is based chiefly on Dixit & Pindyck (1994) and shows by using the contingent claims approach that under uncertainty, there exists a positive value of waiting to invest.

The investment model

This model analyses the investment on the household level. Benefits to the local and global community, i.e. external benefits due to option and existence values or further environmental benefits, are not accounted for. Gender issues involved in the decision

[21] "Standard analysis says, 'buy the better mousetrap'. Yet there are clear risks to such a policy when mousetraps continue to improve and when the competitors may equip themselves better. No firm wants to be saddled with equipment that is soon to be obsolete." (Bessen, 1999, p. 16).

to plant domesticated indigenous fruit trees as well as effects of the investment on intra-household resource allocation are neglected due to unavailability of data in this ex ante assessment scenario.

A small-scale farmer's decision to plant indigenous fruit trees as well as the decision when to uproot the trees is determined by several factors. Expected returns from planting depend on the number and the value of products the trees produce. They are also determined by physical factors, i.e. growth and yield functions, which follow functions with decreasing marginal rates (Haworth & Vincent, 1977). Alternatives to allocating land and labour exist, such as extending agricultural production; hence planting of trees has some opportunity cost.

The net present value, NPV_{DT}, of profits from an orchard of domesticated indigenous fruit trees, DT, providing multiple products planted at t=0 is given by equation (1):

$$NPV_{DT1} = V_{DT1} - I = R_T \cdot e^{-\mu T} + \int_{t=0}^{T} (b_t - c_t) e^{-\mu t} dt - I \,. \tag{1}$$

V_{DT1} is the present value of planting indigenous fruit tree for the first rotation, where the subscript indicates the number of rotations. In year t=0, costs include initial irreversible investment cost, I. In year T, the end of the optimal life span of the orchard, the costs of uprooting the plantation and benefits from harvest of timber are included via R. During the lifetime of the orchard, costs occur due to management of the orchard and in harvesting the fruits. Opportunity cost of land can be included in c_t, if alternative land uses are possible. Benefits from the multiple tree products are accounted for in b_t. Costs and benefits are discounted by the risk-adjusted discount rate, μ. If opportunity costs of land are lower than expected returns from the orchard, the farmer can be expected to continuously replant the orchard. The net present value over an infinite sequence of orchard rotations is given by (Perman et al., 1999):

$$NPV_{\infty} = \frac{V_{DT1} - I}{1 - e^{-\mu T}} \,. \tag{2}$$

The net present value of the infinite sequence is found where the marginal benefit of the plantation left growing for an additional period equals the marginal opportunity cost of this choice, i.e. site value and capital tied up (Perman et al., 1999; Hartman, 1976). In the following, the subscript ∞ is omitted and NPV always indicates the maximum net present value of an infinite investment sequence in domesticated indigenous fruit trees. The incremental benefit of an investment in planting domesticated indigenous fruit trees is given by $V = (NPV + I)_{DT\infty} - (NPV_{C\infty})$, where $NPV_{C\infty} = V_C$ constitutes the net present value of collecting the fruits from the Communal Areas[22].

While the costs and benefits of the investment can be observed on the market, the discount rate cannot. If one assumes that the option to invest is owned by well-diversified investors who hold efficient portfolios, then they need only to be compensated for the systematic component of the risk of the option to invest. According to the Capital Asset Pricing Model (CAPM), the expected risk premium in a competitive market varies in direct proportion to the market risk, that is, the non-diversifiable (systematic) risk. The price for the non-diversifiable risk of the title V is the risk-adjusted discount rate (= total expected rate of return), μ (Brealey & Myers, 2000).

$$\mu = r + \lambda Cov\left[r_m r_V\right]. \tag{3}$$

μ is determined by the risk-free rate of return, r, the market price of risk, $\lambda = \frac{E[r_m] - r}{Var[r_m]}$[23], the market rate of return, r_m, and the rate of return of V, r_V.

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[22] Collection of indigenous fruit tree products from the wild, e.g. the Communal Areas or roadsides, constitutes an alternative to planting the trees, so that costs of collection have to be deducted as opportunity cost of planting.

[23] The market price of risk is a measure of the trade-offs investors make between risk and return (Hull, 2003). It gives the expected return in excess of the risk-free return per percentage change

The optimal timing of investment aims to maximise the value of the option to invest $F(V,t)$. $F(V,t)$ can be derived by replicating the costs and benefits under uncertainty using traded assets (= spanning assets) since the farmer can buy the products of a domesticated indigenous fruit tree at the market instead of producing the products by planting the tree, as is demonstrated in the following.

The farmer can buy x units of bundles of the products from one tree xV, the so-called spanning asset, and invests 1 dollar in the riskless asset, i.e. a savings account. Thus, the (replicating) portfolio costs $1+xV$ dollars. All the values of the portfolio are known. If this portfolio is held for a short interval dt, it will generate the following return: the riskless asset will pay interest of rdt and the return on the spanning asset will be given by the gain from owning products of the tree, the convenience yield $x\delta Vdt$, and the random capital gain $x\alpha Vdt+x\sigma Vdz$, which are assumed to follow a geometric Brownian motion of the form $dV = \alpha Vdt + \sigma Vdz$ [24]. α constitutes the growth rate (or drift rate), e.g. from price appreciation or technical progress, σ is the variance rate of the geometric Brownian motion, and dz is the increment of the standard Wiener process. The relationship between growth rate, risk-adjusted rate of return and convenience yield, δ, is given through $\delta = \mu - \alpha$. The convenience yield is equivalent to the dividend in financial economics; it is a benefit that accrues just from holding the project, e.g. an income flow derived from the project (Dixit & Pindyck, 1994)[25].

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of the variance of the market portfolio.

[24] The geometric Brownian motion is a stochastic process for which changes in the natural logarithm of the variable V are normally distributed. It is a specialised case of the Wiener process (also called Brownian motion). A Wiener process is a continuous time stochastic process with three properties: (1) probability distributions of future values depend on the current value only (Markov property), (2) it grows at independent increments and, (3) changes are normally distributed (Dixit & Pindyck, 1994).

[25] In Dixit & Pindyck's words, "δ is an opportunity cost of delaying construction of the project, and instead keeping the option to invest alive. If δ were zero, there would be no opportunity cost to keeping the option alive, and one would never invest, no matter how high the NPV of the project." (Dixit & Pindyck, 1994, p. 149).

The total return from holding the portfolio over the short time interval for each dollar invested is (Dixit & Pindyck, 1994):

$$\frac{1}{1+xV}\cdot(rdt+x\delta Vdt+x\alpha Vdt+x\sigma Vdz) = \frac{r+x(\alpha+\delta)V}{1+xV}dt+\frac{\sigma xV}{1+xV}dz\,. \tag{4}$$

The return can be split up into the risk-free return, which is the first term on the right hand side of equation (4), and the return that is stochastically influenced, the second term on the right hand side of equation (4).

Instead of holding the portfolio, the farmer can buy the right to plant trees and produce the products herself to generate *V* for the same short interval *dt*. If she produces the products herself, she has to spend *F(V,t)*, the market value of the trees that entitles her to the future profits from the trees. Over the short time period *dt*, this value will change by *dF*. The change is uncertain. The random capital gains *dF* can be calculated using Ito's Lemma (Dixit & Pindyck, 1994)[26] [27]:

$$dF=\left[F_t(V,t)+\alpha VF_V(V,t)+\frac{1}{2}\sigma^2V^2F_{VV}(V,t)\right]dt+\sigma VF_V(V,t)dz\,. \tag{5}$$

The total return per dollar invested in this option is given by equation (6):

$$\frac{F_t(V,t)+\alpha VF_V(V,t)+\frac{1}{2}\sigma^2V^2F_{VV}(V,t)}{F(V,t)}dt+\frac{\sigma VF_V(V,t)}{F(V,t)}dz\,. \tag{6}$$

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26 With respect to a stock option, the option's price is a function of the underlying stock's price and time. This generally holds for all derivatives (Hull, 2003). In this study it is the value of the option to invest $F(V,t)$ and the output V, respectively.

27 The subscripts denote the partial derivatives; thus $F_{VV}(V,t)$ denotes the second partial derivative of F with respect to V.

Similarly to returns on the replicating portfolio, returns on holding the option to invest are also separated into risk-free and stochastic returns, which are the first and the second term of equation (6), respectively. Since the replicating portfolio (consisting of one dollar's worth of the riskless asset and x units of the spanning asset, V) has to replicate the risk and return of owning the option to invest and also has to avoid arbitrage opportunities, the following conditions must be met (Dixit & Pindyck, 1994):

$$xV/(1+xV) = VF_V(V,t)/F(V,t)\,. \tag{7}$$

and

$$\frac{F_t(V,t) + \alpha V F_V(V,t) + \frac{1}{2}\sigma^2 V^2 F_{VV}(V,t)}{F(V,t)} = \frac{r + x(\alpha+\delta)V}{1+xV}\,. \tag{8}$$

Equation (7) ensures that both assets are of equal risk (the *dz*-terms must equal each other), and as they are of the same risk, they also must yield the same return, which leads to equation (8).

After some transformation, the return for holding the option to invest can be expressed as a partial differential equation (9)[28]:

$$\frac{1}{2}\sigma^2 V^2 F_{VV}(V,t) + (r-\delta)VF_V(V,t) + F_t(V,t) - rF(V,t) = 0\,. \tag{9}$$

$F(V)$ must fulfil the following conditions: When $V = 0$, the value of the option to invest is also 0 (equation 10). The value-matching condition determines that when the investor carries out investment, she will receive V^*-I, where V^* is the return received at the optimal time of investment (equation 11). The last condition, given in equation

[28] Note that with an infinite time horizon, the partial differential equation (9) becomes independent of time and only depends on V (Dixit & Pindyck, 1994).

12, ensures that at the critical return, V^*, $F(V^*)$ has to be continuous and smooth (smooth pasting condition, Dixit & Pindyck, 1994):

$$F(0) = 0, \tag{10}$$

$$F(V^*) = V^* - I, \tag{11}$$

$$F'(V^*) = 1. \tag{12}$$

After solving equation (9) according to the conditions in equations (10) - (12), the function for the value of the option to invest is given by (Dixit & Pindyck, 1994; Dixit, 1992):

$$F(V) = \begin{cases} BV^{\beta} & \text{for } V \leq V^* \\ V - I & \text{for } V \geq V^* \end{cases} \tag{13}$$

The upper function gives the value of waiting to invest and the lower part gives the value of immediate investment (compare with Figure 5).

with

$$B = (V^* - I)/(V^*)^{\beta} = (\beta - 1)^{\beta - 1}/(\beta^{\beta} I^{\beta - 1}), \tag{14}$$

and

$$\beta = \frac{1}{2} - (r - \delta)/\sigma^2 + \sqrt{\left[(r - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2r/\sigma^2}\ . \tag{15}$$

B is a shift parameter, and β is the positive solution to Equation (9) used to establish the trigger value, V^*, i.e. the critical level of returns that will induce investment (Dixit & Pindyck, 1994):

$$V^* = \frac{\beta}{\beta - 1} I \,. \tag{16}$$

Equation 16 states that the value of immediate investment, *V*, should be at least as high as *V**. If the current level of *V* is less than *V**, it is worthwhile to postpone investment.

Figure 5 illustrates the value of the option to invest in an old and a new technology. The bold curve describes the value of the option to invest, which is determined by the value of waiting, BV^{β}, for $V < V^*$ and by the value of immediate investment, *V-I*, for $V > V^*$. The value of waiting and the value of immediate investment equal each other at $V = V^*$. Point *K* is the Marshallian trigger, at which $V\text{-}I = 0$. According to the *NPV*-rule, investment would be profitable for all $V > K$ (then $NPV > 0$). However, according to the modified rule, investment would commence for $V > V^*$. The present value of investment has to exceed initial investment cost by the factor $\beta/(\beta\text{-}1)$, the so-called hurdle rate. For the old technology, the present value exceeds the trigger value and investment is triggered. With respect to the new technology, the value of waiting shifts from BV^{β}_{old} to BV^{β}_{new} and the trigger and present values also shift. In the case illustrated below, the trigger value exceeds the present value for the new technology and waiting to invest commences.

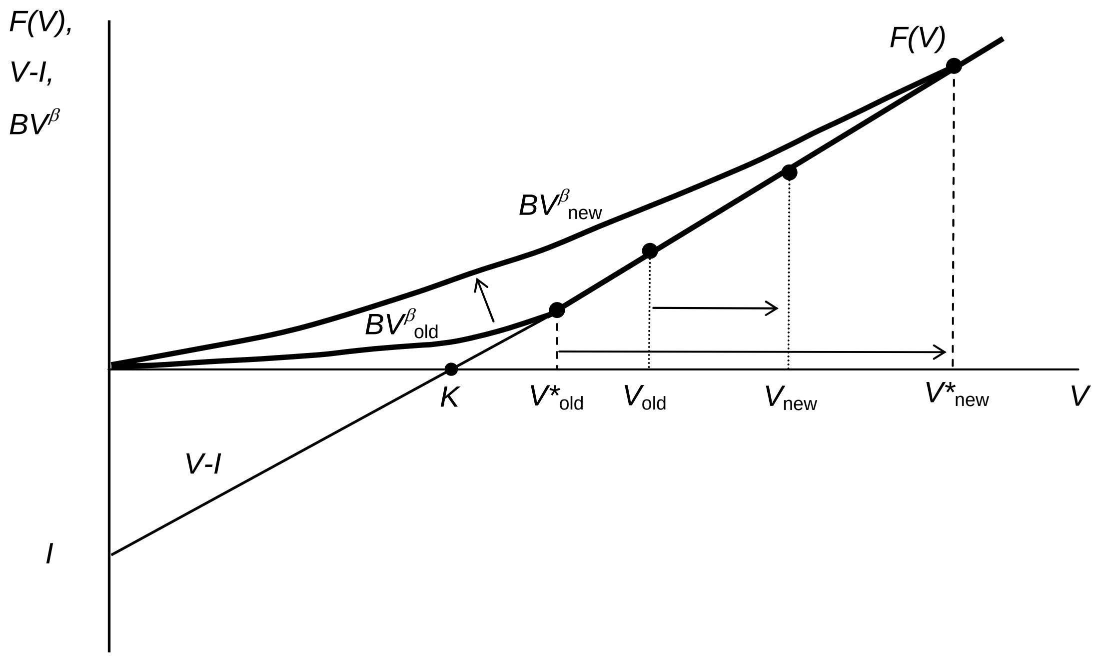

Figure 5. The value of the option to invest.

Source: Own formulation based on Purvis et al. (1995), Dixit & Pindyck (1994) and Dixit (1992).

Several factors characterise the optimal investment rule (Table 1). Changes in some of the parameters induce an increase in the value of waiting, while changes in others induce a decrease. For example, an increase in the variance of returns enhances the value of the option to invest and the value of waiting, since it enhances the maximum possible gain while the maximum possible loss remains unchanged (McDonald & Siegel, 1986). An increasing growth rate promises higher returns on investment due to price appreciation or technical progress and makes waiting for this improvement attractive[29]. However, one has to consider interdependencies amongst the parameters (Dixit & Pindyck, 1994). For example, increases in the risk-free rate of return may influence the risk-adjusted rate of return; the same holds true for the variance. Consequently, one has to assess the influence of changing parameters and interdependencies on the optimal timing of investment separately for each project.

[29]This case refers to the "mousetrap problem" described by (Bessen, 1999, p. 16, footnote 20).

Table 1. Comparative statics and the optimal investment rule.

Parameter change[1)]					Result		Strategy
r	σ	μ	α	$\delta=\mu-\alpha$	$F(V)$	V^*	
-	↑	-	-	-	↑	↑	⇒ Value of investment opportunities grows. ⇒ WAIT
-	-	-	↓	↑	↓	↓	⇒ The expected appreciation of the option to invest declines. ⇒ INVEST
-	-	-	↑	↓	↑	↑	⇒ The expected appreciation of the option to invest increases. ⇒ WAIT
↑	-	-	-	-	↑	↑	⇒ A low interest rate increases the opportunity cost of immediate investment. ⇒ WAIT

1) - = constant, ↑ = increase, ↓ = decrease.

Source: Own formulation based on Dixit & Pindyck (1994).

Summing up the theoretical considerations with respect to the investment problem, the planting of indigenous fruit trees needs to be economically competitive to ensure adoption. Non-stationary prices and uncertainty about market demand for indigenous fruits contribute to the risk of the investment. In this case, β decreases and the hurdle rate increases, which may cause farmers to postpone the investment until they have better information on the future development of improved species and their marketing potential. Also, expected improvements of IFT via the domestication programme serve to increase the value of waiting to invest and of the hurdle rate. Both effects cause farmers to require returns on investment to exceed the conventional investment threshold of 'discounted net benefits of investment equal initial investment cost'.

3.4 Research hypotheses

Based on the theoretical considerations and the three objectives of this study, the following research hypotheses are identified: (1) collection of IFT products is an efficient labour allocation strategy; (2) collection of IFT products reduces vulnerability to income poverty; and (3) under conditions of uncertain returns to planting indigenous fruit trees and potential improvements of the trees via the domestication programme, the value of waiting to plant indigenous fruit trees is positive and exceeds the value of immediate investment given the current level of returns to collecting the fruits from the natural environment.

4 Methodology of data collection

This chapter presents the data collection procedure followed. The first section explains the selection of the research sites, the data requirements and the survey design. The second section describes the data collection methodology that facilitates establishment of the current status of indigenous fruit use and the factors that influence their use. The last two sections outline the data collection procedure and specify data sources used in analysing labour productivity of indigenous fruit collection and of other activities. They also describe data sources for analysis of vulnerability to poverty and modelling the investment problem.

4.1 Selection of research sites, data requirements and survey design

The study was conducted in Ward 16 of the Mangwende Communal Area in Murehwa District and Takawira Resettlement Area near Mvuma in Chirumanzu District, Zimbabwe (Figure 6).

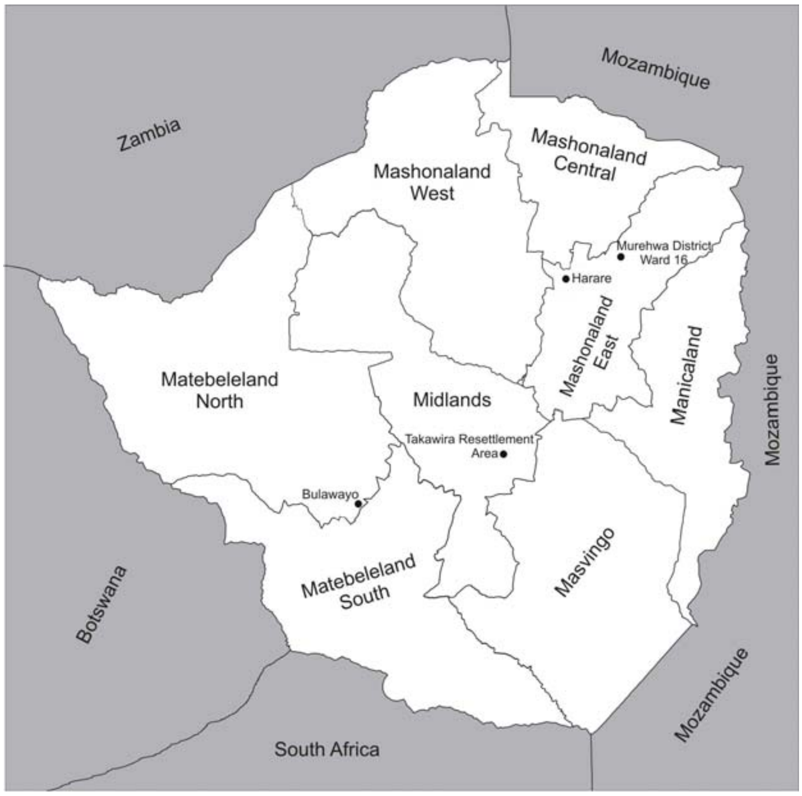

Figure 6. Map of Zimbabwe showing the research sites.

Ward 16, Murehwa District is located along the road to Mozambique and Malawi, about 80 km east of Harare and close to the growth point[30] of Murehwa Centre. Murehwa Centre has a thriving market and also a big bus stop, which is frequented by buses travelling to the neighbouring countries to the east. Households settled in Murehwa between 1940 and 1960.

Takawira Resettlement Area is situated along the road leading to Masvingo and further on to South Africa about 200 km south of Harare. The nearest centre is Fairfield market, which also is a bus stop. Fairfield market is much smaller than Murehwa Centre; only local agricultural and horticultural produce is available. Mvuma is about 10 km from the Resettlement Area. It is bigger than Fairfield market and has shops and a supermarket but is yet smaller than Murehwa Centre. Takawira Resettlement Area was resettled between 1982 and 1983.

Murehwa District is classified as sub-humid to semi-arid, whereas Takawira Resettlement Area is semi-arid. The two sites were selected based on the abundance, production and marketing potential of *U. kirkiana*, *S. cocculoides* and *P. curatellifolia*. *U. kirkiana* is highly abundant in Murehwa and is frequently sold, whereas *S. cocculoides* and *P. curatellifolia* are highly abundant in the Resettlement Area. The three species were identified as priority species for domestication by local farmers (Maghembe et al., 1998) and were also confirmed as target species in a first survey in October 1999 (Baseline Survey 1999). Avocado, mango, orange, peach and guava were identified by farmers as the most popular exotic fruit tree species during the same survey.

In the beginning, data collection was facilitated by the governmental agricultural extension service, AGRITEX, which has extension officers stationed across all centres of the rural areas. Local school leavers who lived at the research sites were employed as research assistants and trained in data collection methods. Throughout the study, a unitary household model approach was applied, i.e. data were both collected and analysed on a household basis.

At the beginning of the main data collection process, village meetings and a baseline survey were conducted. The initial village meetings were held in September 1999 in

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30 In Zimbabwe, growth points are urban centres of medium size.

four villages of each area, with two villages close to the market and two villages further away from the market. In these meetings, the objectives of the survey and survey instruments were explained and indigenous fruit use practises were discussed. During these meetings, households that had preserved, managed or planted indigenous fruit trees as well as households that sold the fruits were identified.

Out of these households, 50 households were selected on a voluntary basis in each research site. They were interviewed during the baseline survey in October 1999 verifying the information gathered during the initial village meetings on use and management practises relating to indigenous fruit trees in general and the target species specifically.

Table 2 gives an overview of the data requirements and the methodology of data collection. Each method is described in more detail in the following sections.

Table 2. Data requirements, sources and collection methods.

Objective	Data collected	Methodology
Socio-economic survey		
• income sources • status quo of indigenous fruit use within the household system • factors related to indigenous fruit use	• fruit use quantities, cash income & expenditure • income, expenditure of other income-generating activities • socio-economic household characteristics	• random sampling • single visit • standardised questionnaire • sample size: 303 households
Household monitoring		
• interaction between income-generating activities • labour productivity of income-generating activities	• fruit use quantities, cash income and expenditure • income, expenditure, other income-generating activities • socio-economic household characteristics • labour flows	• purposive sampling • multiple visits • monitoring sheets, participatory observation and interviews • sample size: 39 households
Farmer workshop		
• age-yield function	• IFT age at maturity • IFT growth parameters • IFT fruit production	• open discussion using guidelines and visual methods
• general information	• land ownership, development of the areas	
Tree inventories		
• age-yield function	• IFT age at maturity • IFT growth parameters • IFT fruit production	• measurements and interviews during household monitoring
Expert interviews		
• age-yield function	• IFT age at maturity • IFT growth parameters • IFT fruit production	• questionnaire and informal discussions

Source: Own formulation.

4.2 The socio-economic survey

The socio-economic survey was carried out in order to draw a representative picture for both research sites regarding the use of indigenous fruit trees and factors that determine their use as well as their role within the household system. Table 3 gives information on the demographic characteristics of the study areas on which the sample selection was based.

Table 3. Demographic characteristics of the study areas.

	Murehwa	Takawira
Number of villages	16	17
Number of HH	2304	596
Number of HH in the smallest village	46	14
Number of HH in the largest village	496	96
Villages in the vicinity of the market(s)	7	9
Villages at greater distance from the market(s)	9	8
HH living in villages in the vicinity of the market(s)	1302	321
HH living in villages at greater distance from the market(s)	1002	275

Source: Own compilation, update based on AGRITEX data.

Household census data were available at both sites from the local AGRITEX extension services and were updated by cross checks with the respective village heads. Villages were stratified in two groups, i.e. villages in the vicinity and villages further away from the market. Stratification was conducted based on assessment of local informants, i.e. the AGRITEX extension officers and key informants from the villages. In each stratum, households were drawn randomly according to the villages' proportion of the total population within the strata. The sample for Murehwa consisted of 221 and the sample for Mvuma consisted of 82 households. These households were interviewed once by standardised questionnaire. Socio-economic characteristics were identified and data on household resources as well as on income and expenditure of production activities from all income-generating activities, including indigenous and exotic fruit tree use, were collected. Additionally, one section of the questionnaire dealt with planting of indigenous and exotic fruit trees. Another section analysed use of indigenous fruits in years with insufficient food supply (see Table 2). The socio-economic survey was conducted from February until April 2000, covering the period March 1999 to March 2000. Results from this survey are referred to as 'socio-economic survey'.

4.3 Household monitoring

Monitoring of case study households on a monthly basis allowed detailed data collection on income, expenditure and labour flows, as the recall period was short. For this purpose, 20 farmers from each research site were selected from the sample of the baseline survey to take part in the household monitoring survey. Of the 20 households, ten were located in two villages in the vicinity of the market (five households per village), the other ten were located in two villages further distant to the market (five households per village). The households were selected based on their interest in IFT issues, use of the trees and willingness to participate in the monitoring. All 20 households remained in the monitoring programme in Takawira Resettlement Area, but one household had to be dropped in Murehwa.

The first monitoring round was conducted in October and covered all activities back to the middle of August. From then on, monitoring rounds were carried out on a monthly basis. Thus, the monitored period covered all activities from August 1999 to August 2000. For Murehwa District nine monitoring rounds were completed and for Takawira Resettlement Area eight were completed. In September 2000, each household was interviewed using a brief questionnaire summarising the previous visits and findings. At each research site, two enumerators were responsible for monitoring ten households each. Income, expenditure and labour data were monitored with respect to the use of indigenous and of exotic fruit trees, cultivation of horticultural and agricultural crops and keeping of livestock. Also, income, expenditure and labour flows related to receipt of remittances were recorded, as were off-farm activities like casual labour and various home industry activities. For all these activities, cash income and income in-kind were monitored. Socio-economic data on number, gender and education of household members were gathered during the first monitoring round. Results from this survey are referred to as 'household monitoring'.

4.4 Farmer workshop, tree inventories and expert interviews

A pre-requisite for analysis of investment in indigenous fruit tree planting are the respective age-yield functions. Data on growth and yield characteristics of indigenous fruit trees are not available from trials and proved difficult to collect. Therefore, different means of data collection were employed. Initially, a large sample of naturally grown IFT was located within the forests of the Communal Areas. For the trees of this sample, size of the stem at breast height and overall tree height were measured and the yield was estimated. However, due to wild animals and harvesting of premature fruits, the yield estimates were much smaller than the estimates provided by the farmers for naturally grown trees of similar size that they had preserved in their fields (this is referred to as 'tree inventories', see below). Additionally, the sample taken from farmers' fields has the benefit of including data from trees growing under conditions similar to those of planted trees. Furthermore, data from farmers' trees seem to be more reliable, as the observations are more frequent. Also, it proved impossible to estimate age or production period for trees within the forests and the Communal Areas due to non-existent observations. Data on growth and yield parameters were collected for two of the target species, i.e. *U. kirkiana* and *S. cocculoides*[31].

4.4.1 Farmer workshop

In September 2000, one farmer workshop was conducted in each research site. Throughout the workshop, a discussion guideline was used and visual methods were applied where appropriate. The workshop participants were purposely selected to reduce information biases: two men and two women, for each gender one of them between 25 and 30 years old and the other between 45 and 60. The enumerators were responsible for translating throughout the discussion. During the workshop, age at maturity, the yield level, the shape of the age-yield function as well as the influence of management practises on the yield, i.e. application of manure, were discussed. The workshop was located at a farm where many indigenous fruit trees had been preserved on the farmer's fields, so that the workshop participants could compare tree sizes and yield.

Additionally, general information on the research sites and developments in the area was discussed. This included land ownership issues and developments over the years

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31 Tree inventories and information from case study households proved to be the most informative tool for establishing the age-yield relationship. Information that could be gathered from the farmers is a function of their knowledge of and experience with the trees, i.e. the trees' relative abundance in their fields. Since none of the farmers had *P. curatellifolia* trees preserved in their field, no information could be gathered for this species.

in the use and commercialisation of various indigenous and exotic fruit tree products. The time when exotic fruit trees were first introduced in the area was established. Further topics were price developments of the indigenous and exotic fruit tree products over the years and labour flow calendars in the course of the year.

4.4.2 Tree inventories

In addition to the information gathered during the farmer workshop on the age-yield function of the target species, naturally grown indigenous fruit trees that had been preserved by the farmers participating in the household monitoring in their fields were recorded in tree inventories (September 2000). The height of the trees was estimated and the girth at breast height was measured. The farm owners provided estimates on the minimum, the maximum and modal yield the trees produced per year and gave information on the age at which the trees had reached maturity, i.e. had produced fruit for the first time. For *U. kirkiana,* 38 trees were included in the inventory, and for *S. cocculoides,* 43 trees were included.

4.4.3 Expert interviews

In January 2000, a questionnaire for consulting experts on the age-yield relationship of *U. kirkiana* and *S. cocculoides* was designed and sent off to 27 experts in the field. These were researchers who had been involved with natural resource use projects in the Southern African region and were known from their publications. Even though two follow-up letters accompanied the initial survey, the response to this survey was very low. Additional information from only three experts could be gathered. This was then supplemented by informal interviews and discussions with ICRAF staff members working for the Domestication of Indigenous Fruit Trees Programme on the research stations in Malawi, Zimbabwe and Zambia.

5 The role of indigenous fruit trees in the rural household economy

The purpose of this chapter is to analyse the status of indigenous fruit tree use and factors that determine IF sale. First, household income is defined and data analysis is explained in more detail. The chapter then describes the households of the two study sites and their resource base in terms of labour force and land holding. Household income, its components and their relative importance are analysed and labour productivity is calculated. Income figures are based on actual cash income and cash expenditure as stated by survey households or, in order to value in-kind income and expenditures, on average prices of the period August 1999 – August 2000[32]. Data were collected individually for each crop and each livestock activity, but then aggregated for analysis to allow better comparison between each enterprise of the household economy, i.e. agriculture, horticulture, livestock, exotic and indigenous fruit trees, off-farm activities and remittances. This was done because the intensity across enterprises, especially agriculture and horticulture, differs in terms of resources used and also the season for engaging in relevant activities. In this chapter, data collected from both samples, the household monitoring and the socio-economic survey, are used for analysis. The former provides information on income figures, whereas the latter is used to assess the resource base of rural households as well as patterns of indigenous fruit consumption and sale[33].

5.1 Definition of household income and household welfare

Production activities are differentiated according to the following enterprises: (1) agriculture refers to production of field crops, (2) horticulture to production of vegetables (all crops that are produced in so-called "gardens", which are plots in the vicinity of water sources, allowing for intensive cultivation throughout the year), (3)

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32 For comparison, the exchange rate is 1 USD to ZWD 38 (December 1999).

33 This chapter partly draws on results that were previously published in Mithöfer & Waibel (2003).

livestock, (4) exotic fruit trees (EFT), (5) indigenous fruit trees (sub-differentiated into a) *P. curatellifolia* and *Strychnos* sp. and b) *U. kirkiana* for better comparison between the species), (6) receipt of remittances from relatives and (7) all other activities. The last enterprise includes mostly off-farm activities like wage labour, but also various home industry (household) activities such as arts and crafts production, brick moulding, broom making and beer brewing. All of these activities are summarised in the following and are referred to as 'off-farm'.

In order to determine the contribution of different farm and household activities to household income, all produce was valued at the average farm gate price over the period August 1999 – August 2000[34]. This may overestimate the benefits of the fruits as the marginal benefit may decline with increasing consumption. The average farm gate price of *U. kirkiana* fruits is 4.3 ZWD per kg and for *Strychnos* sp. 1.5 ZWD per fruit. *Parinari curatellifolia* fruits are not traded, so they are valued at 60% of the farm gate price of *U. kirkiana* fruits. Other valuable products of trees such as wood and leaves are also valued. Wood is valued based on market prices of firewood and timber. Miombo tree leaf litter contains 0.66% nitrogen on a dry weight basis (Chidumayo, 1997). Tree leaves, which are used as a source of nutrients in crop and vegetable production, are priced via the surrogate value of their nitrogen content at the farm gate prices for nitrogen. The farm gate price per kg of nitrogen is ZWD 28 in Murehwa and ZWD 39 in Takawira Resettlement Area based on the farm gate prices of a 50 kg bag of ammonium nitrate. Putting a value on the non-market goods allows a more realistic assessment of the benefit of indigenous trees relative to other income-generating activities with mostly marketable output.

Products of agricultural and horticultural crops include produce harvested green (e.g. maize cobs) and ripe products. All produce used for home consumption, sale and as production input into other activities (e.g. maize for beer brewing or poultry feed) is accounted for. By-products like maize stalks, which are used as cattle feed, are excluded due to the difficulty of determining their economic value, as maize stalk is not traded and adequate marketable substitutes do not exist. All other products are

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[34] August 1999 serves as starting point since data collection commenced then; it also is a convenient starting point insofar as agricultural activities are at their lowest level.

traded, thus market prices are used for valuation[35]. Operational costs include expenses for seeds, fertilizers, manure, pesticides, draught power, transport and labour. The latter includes cash and in-kind payments for hired workers and work parties.

The contribution of each production activity towards the household income is established via gross margin calculation (equation 1 and 2) for each production activity, taking cash and in-kind figures into account. The gross margin is defined as gross income, *O*, net of direct variable cost, *C*, (FAO, 1985) and labour costs of hiring labour and work parties, *LC,* which are considered direct variable costs. Equation 17 refers to the gross margins of all activities except livestock keeping, and equation 18 refers to the gross margin for livestock keeping, which takes into account changes in the value of stock, *G-S*.

$$GM_{crops\&trees} = O - C - LC\ . \tag{17}$$

$$GM_{livestock} = (G - S) + O - C - LC\ . \tag{18}$$

G is a gain in value, e.g. animals born over the year; the loss in value of stock, *S*, is caused by death, theft and slaughtering of animals. Livestock sale and purchase is accounted for to establish cash and in-kind income. It is assumed that money or other goods exchanged or gifts received in return for an animal are of equal value. With respect to gifts, one can assume that return payments of some other type are made at some point of time. Products from livestock keeping include milk, eggs, meat, manure, and draught and transport power, depending on the livestock species. In-kind income from slaughtering an animal is equal to the price of the animal. It is accounted for via the revenue generated, but also through the loss in value of the stock. Draught power from donkeys and cattle is valued at the prevailing market

[35] Cavendish (2000) also found reliable price information for most goods, even environmental products, used by rural households.

prices and added to the gross margin from livestock. Manure is priced via its nitrogen content, which is 1.04% on a dry matter basis in the Communal Areas in Zimbabwe (Steinfeld, 1988). For all other products, market prices are used for gross margin calculations. Direct variable costs of livestock keeping include expenses for medical treatments, feed and hired labour.

Opportunity costs of capital are assumed to equal the risk-free interest rate, i.e. the rate that can be obtained by incurring no risk, that is, zero. The risk-free alternative to investing cash in production activities would be to put the money into a savings club. Savings clubs consist of a group of households that contribute cash or storable goods in-kind to the club at regular intervals. At pre-defined dates the items are distributed amongst the members. Either the whole stock is transferred to one member of the savings club according to a rotation principle, or each member receives back what she paid in. As club members receive back their deposits and product prices rise according to the rate of inflation, i.e. 59% in 2000 (World Bank, 2003)[36], the savings club protects members from inflation. Group pressure ensures that members pay in regularly and that no member will take out the 'savings' before the date agreed upon by the group. Further, rules exist in order to deal with members who fail to adhere to the rules. This arrangement can be interpreted using the following examples. First, Hagmann (1997) found that farmers preferred investments that generated lower net revenues but paid out in several small amounts over a longer time-period to investments that generated higher net revenue as a lump-sum payment. This is due to the cultural circumstance in Zimbabwe that requires farmers to share the revenue with needy relatives and to the fact that large sums invite more requests than small sums (Hagmann, 1997). Thus, the savings club 'protects' the savings from being consumed by relatives. It can be interpreted as a joint storage system where safekeeping at one member's house ensures that the 'savings' cannot be withdrawn prematurely without consent of the group[37]. Second, these savings clubs could be interpreted as informal loans that are handed out and received on a rotating principle.

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[36] The real interest rate on a savings account was negative due to high inflation in 1999 – 2000.

[37] This type of savings club is referred to for establishment of the risk-free rate of return, as described in the theoretical background referring to the investment problem.

Other studies show that on most informal loans no interest is charged and that they are part of informal risk-sharing arrangements (see Fafchamps & Lund, 2002 for a discussion of this issue). Third, the savings club described above is similar to the rotating savings described and analysed by Besley et al. (1993). The authors of this study show that rotating savings are a means to cover lumpy expenditures in the absence of credit markets and lead to a higher welfare level of contributors. In their opinion, these lumpy expenditures are related to idiosyncratic life-cycle events rather than being a buffer against risk. The rotating savings keep money in circulation as shown by Ardener (1964 cited in Besley et al., 1993). Overall, the literature agrees that these savings clubs hand out loans without charging interest. However, these systems are not for free, e.g. members delay consumption. Overall, the benefit via membership of such a savings club can be expected to exceed costs of foregone immediate consumption due to the reasons described above, although these benefits would be difficult to quantify. Hence, assuming a risk-free interest rate of zero is a lower bound.

Opportunity costs of land are also zero, as land can be borrowed from neighbours or additional land is allocated from the village chief free of charge. Returns to labour are derived from gross margin data and family labour flows for each income enterprise. Farmers often not only collect IF, but also pursue other activities on the same trip. Whenever this was the case, 40% of the time spent was attributed to fruit collection.

In this study household welfare is estimated by household income, which in this chapter is defined as the sum of gross margins of all production activities and is denoted by total gross margin. Fixed costs of production are minimal, as most tools are already written off and can thus be neglected for income calculation and no other fixed assets are used for production. Similar to Cavendish (2000), household income refers to total rather than full income (Becker, 1982). The latter also includes production of elementary goods, so-called z-goods like childcare, which is difficult to measure and value and not accounted for in the presented analysis. The thus-defined household income underestimates total household welfare, especially if household production constitutes a large part of the full income. However, most studies do not include production of elementary goods in their income estimation. Additionally, as the study of Cavendish (2000) shows, households use a far greater variety of environmental goods than the three IFT species selected in this study.

Thus, income figures from this survey underestimate total household welfare due to the fact that (a) household production is excluded from analysis, (b) households use a higher variety of natural resources than the three indigenous fruit tree species under consideration, and (c) households assign positive values to services natural resources provide that are not incorporated into the analyses.

Commercialisation of the fruits has increased over the past years. However, in order to address policy issues of commercialisation, there is a need to identify household characteristics that are related to selling activities. Thus, the association between the sale of IF and socio-economic household characteristics including receipt of remittances is investigated by means of non-parametric tests.

5.2 The resource base of rural households

This section describes households' resource base in terms of labour force, knowledge and access to loans. The labour force determines the degree to which production activities can be pursued. Knowledge, i.e. formal or informal agricultural training, determines the success of production activities, and education influences the potential off-farm activities, whereas access to loans is a means to ensure liquidity.

Households in Takawira are bigger than households of Murehwa (Table 4). In Takawira, more adult children had remained at the homestead due to the lack of economic alternatives and also the fact that land in the Resettlement Areas cannot be divided amongst children. Some families responded to this by unofficially dividing land amongst the children. If this resulted in separate production from the initial household, these adult children were considered as separate households. If adult children produced for the same store as their parents, they were counted as part of the parents' household. Some of the adult children had children of their own, contributing to the higher number of children in the households of Takawira.

Table 4. Demographic household characteristics.

	Number of HH members[1)]	
Location	Murehwa	Takawira
Sample size	N= 221	N = 82
Household	6.0 (4.1)	7.8 (5.7)
Adults (18 years or older)	2.8 (2.7)	3.6 (3.6)
Children (younger than 18 years)	2.9 (1.4)	4.2 (2.1)
Men	1.2 (1.2)	1.8 (1.7)
Women	1.6 (1.5)	1.9 (1.8)
Boys	1.5 (0.7)	2.0 (1.1)
Girls	1.4 (0.7)	2.2 (1.1)

1) Figures give average number of household members; figures in parentheses state average adult equivalent units per household for each age group. Conversion factors per household member to adult equivalent units (AEQ) are set according to Ströbel et al. (1973): household members above 65 years = 0.75 AEQ; 18–65 years = 1.0 AEQ; 14–18 years = 0.75 AEQ; 7–14 years = 0.5 AEQ, below 7 years = 0.25 AEQ.

Source: Socio-economic survey.

The highest educational level held by one household member is adult classes or secondary level for Takawira (Table 5). For Murehwa, the highest level reached by most households is primary school and secondary school level. If only the educational level of the head of household is considered, the absolute figures are slightly lower, but the ranking between different levels of education remains the same. The position of one household member within the household may influence the success in income-generating activities due to the degree of decision-making powers. For example, if the head of household holds the highest level of education and training, he may more strongly influence the scope and intensity of possible activities than do the children.

Households of Takawira have a higher exposure to agricultural training than households in Murehwa. Informal agricultural training, i.e. master classes, are relevant to a higher share of households than formal training, which refers to agricultural courses at school. According to Kinsey et al. (1998), Resettlement Areas tend to have better access to services than Communal Areas, which may contribute to the relatively higher frequency of informal agricultural training in Takawira than in Murehwa.

Table 5. Schooling and agricultural training of households of Murehwa and Takawira.

	Schooling and agricultural training[1)] [%]	
Location	Murehwa	Takawira
Sample size	N= 221	N = 82
No education	11.8	2.4
Primary school	39.8	24.4
Secondary school	26.2	34.1
Higher education	4.1	0.0
Adult classes	17.2	39.0
No agricultural training	67.0	37.8
Formal agricultural training	10.9	3.7
Informal agricultural training	21.7	58.5

1) The percentages do not add up to 100% due to a few households that failed to answer this question.

Source: Socio-economic survey.

The length of the resettlement period influences the gross margin of production activities like the growing of exotic fruit trees, which take some years to start producing fruits and to reach the maximum production level. On average, households settled earlier in the Communal Area; the length of the settlement period also shows a higher variance than in the Resettlement Area (Table 6). This is to be expected since resettlement commenced at a discrete point in time for each large commercial farm that was bought for resettlement after independence.

The area and quality of land determine the degree to which a household takes up production of agricultural and horticultural crops. Area refers to the size of land a household has access to. Quality in this case refers to the proximity to irrigation water. Plots for horticultural, i.e. vegetable production, the so-called gardens, are usually in the vicinity of water sources, and thus manual irrigation using watering pots is feasible. Agricultural production refers to field crops like maize, sorghum and rapoko (finger millet) under rain-fed conditions. Gardens are larger on average in Murehwa, whereas fields for agricultural production are larger in Takawira. The more highly developed market at Murehwa growth point and the proximity to Harare explain the difference in the size of the gardens better than access to water does. The ground water table in the Resettlement Area would allow extension of the gardens. The differentiation between rain-fed agricultural and vegetable production is important because the latter reaches a peak at a different time of the year and also contributes a higher share of cash income, which will be shown later in more detail. Generally, households of Resettlement Area have larger plots of arable land than families of the Communal Areas (Kinsey et al., 1998). Livestock is kept under communal grazing in both areas.

Table 6. Mean period of residence and area of privately owned land of households in Murehwa and Takawira.

Location Sample size	Murehwa N= 221	Takawira N = 82
Length of residence period [years][1)]	26.2 (16.8)	16.6 (2.5)
Area for agricultural production [ha][1)]	2.1 (1.0)	3.8 (1.4)
Area for vegetable production [ha][1)]	0.25 (0.30)	0.13 (0.18)

1) Figures in parentheses give standard deviation.

Source: Socio-economic survey.

Access to credit, loans and further sources of cash is provided through a variety of channels (Table 7). One special form of conserving cash resources is the savings clubs that are described in the preceding section. Many households own savings accounts at local banks in order to receive cash transfers from relatives in the urban areas. Informal loans refer to money that can be borrowed from neighbours and friends; formal credits are loans that can be taken out from formal institutions. The higher availability of formal credits in Takawira also underlines the fact that households of the Resettlement Areas have better access to services (Kinsey et al., 1998). In conclusion, most households do not face a cash constraint, as they own/have access to a savings account and/or informal loans as the most prevalent means to maintain liquidity. Of course, the amount that can be accessed varies among households, an aspect that will be taken up in more detail in chapter 7.

Table 7. Share of households having access to various sources of additional cash income [%].

	Murehwa N= 221	Takawira N = 82
Membership in a savings club	16.3	18.3
Ownership of a savings account	63.8	65.9
Access to informal loans	53.4	84.1
Access to formal credits	11.8	24.4

Source: Socio-economic survey.

Labour is a major production input and often poses a constraint to the expansion of production activities. Thus, households were asked whether they have the means to increase their labour force in times of labour shortages, e.g. via additional family labour, hired labour and reciprocal labour exchange amongst villagers, so-called work parties. Due to seasonal fluctuations in production activities, labour availability is assessed for the agricultural peak, i.e. from the end of October to July, and off-season, i.e. August to September.

Comparing availability of additional labour to access to additional cash, results show that the latter is less a constraint than the former. Over both seasons and locations, less than 40% of the sample have access to additional labour; this underscores the constraint on this production input. As expected, hiring of additional labour is less of a constraint during the agricultural off-season than during the peak. Also, the labour market in Murehwa is better developed than in Takawira, which shows in the higher access to additional labour (Table 8).

Table 8. Share of households having access to additional labour during the peak and off-season of agricultural production [%].

Location Sample size	Murehwa N= 221	Takawira N = 82
Access to additional labour during agricultural off-season	38.9	21.9
Access to additional labour during agricultural peak season	28.1	17.1

Source: Socio-economic survey.

The average daily wage rate over all types of additional labour and both seasons is ZWD 43.1 and 68.7 in Murehwa and Takawira, respectively (socio-economic survey). People who are employed are provided with food during lunchtime in addition to the cash payments. In order to derive the total daily wage rate, these payments also have to be accounted for. A meal consists of tea with sugar and a dish from maize meal (called "Sadza") with vegetables and meat. The meal is valued at 15 ZWD per person, which is 75% of the price of a meal in the small restaurants at the growth points. Thus, the average daily wage rate over the year amounts to ZWD 58 in Murehwa and ZWD 84 in Takawira (Table 9).

Table 9. Average wage rate of the agricultural peak and off-season over various types of labour[1)] in Murehwa and Takawira [ZWD day^{-1}].

	Family labour		Non-family labour		Hired labour		Mean	
Location[2)]	M	TRA	M	TRA	M	TRA	M	TRA
Peak season	12.8	0.0	26.5	141.8	81.0	186.7	40.1	109.5
Off-season	7.9	0.0	42.8	44.4	87.4	39.3	46.0	27.9
Average across seasons	-	-	-	-	-	-	43.1	68.7

1) Non-family labour refers to help from neighbours and other villagers (= 'work parties'), whereas hired labour refers to more formal relationships.

2) M = Murehwa, N = 221; TRA = Takawira, N = 82.

Source: Socio-economic survey.

5.3 Sources of income

Households pursue a wide range of farm, off-farm and household activities. The major farming activities are maize production, intercropped with cowpeas, beans or different pumpkin varieties. Other agricultural crops are finger millet and sorghum. Frequently grown garden crops are tomatoes and kales. Cattle are mostly kept for transport and draught power. Poultry is kept for cash income generation. Poultry types are local varieties, broilers for meat and layers, which are kept for egg production.

Comparing between the two surveys shows that the socio-economic survey yields lower income figures than the household monitoring for Murehwa, whereas it is the other way around for Takawira. Cash income figures are more similar between both surveys than gross income figures, except for agricultural income. This difference can be attributed to the timing of the socio-economic survey, which took place in March 2000. During this period, the maize harvest had just started and farmers were asked how much they were going to sell, whereas data from the monitoring survey observed amounts actually sold[38].

Both surveys show that households of Takawira Resettlement Area receive fewer remittances than households of Murehwa District (Figure 7). Also, a higher share of Murehwa households receives remittances as compared to Takawira, i.e. 83% versus 65% of households. The mean amount of remittances received over these households is ZWD 9400 for Murehwa and ZWD 5500 for Takawira (socio-economic survey).

Off-farm income contributes a higher amount to the income of Murehwa households, which may be due to the higher access to markets and trading activities at the better-developed growth point. On average, households in Murehwa used ZWD 1100 per month for household expenditures including school fees. In Takawira, households incurred average monthly expenditures including school fees of ZWD 1000 on average (socio-economic survey).

Exotic and indigenous fruits are frequently consumed as a small meal in between. Eliciting this type of in-kind income with long recall periods is difficult. Furthermore, tracking in-kind expenditure, especially changes in stock from livestock production and in-kind input to crop production, proved unreliable. Further analysis of household income and its components is based on income figures derived from household monitoring since it is considered more reliable due to the shorter recall periods. In contrast, the analysis of structural patterns is based on the socio-economic survey.

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[38] Maize is produced for subsistence, but is also a cash crop. Usually, yield is sold if in excess of subsistence needs or if cash is in short supply.

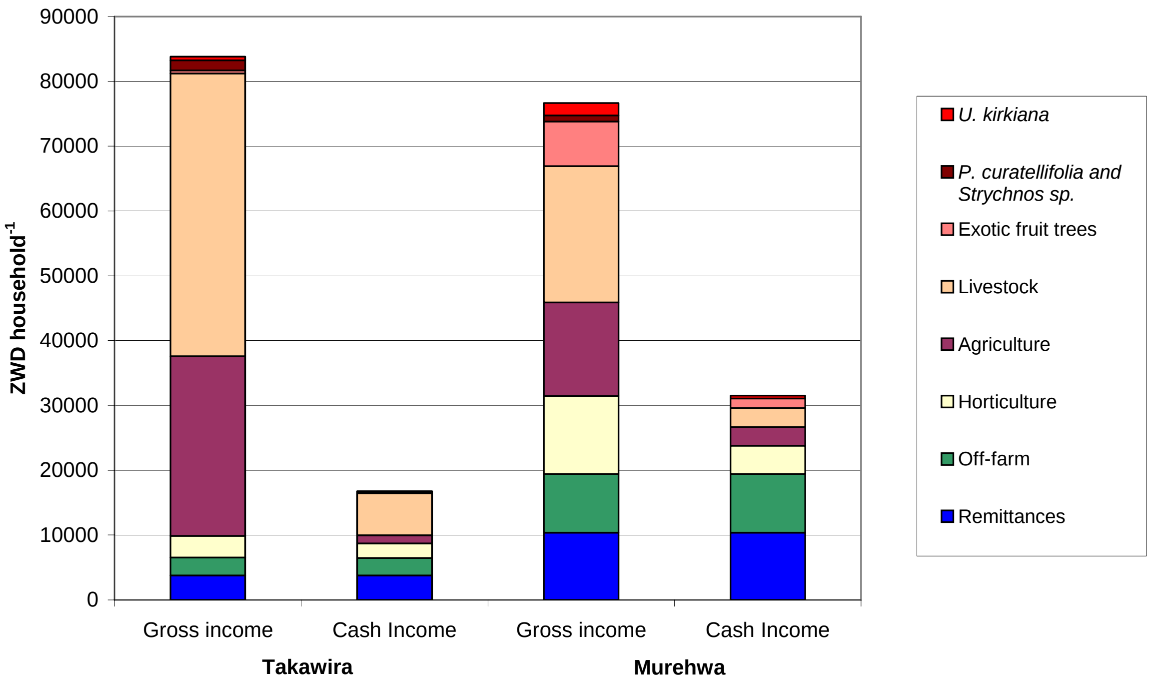

Figure 7. Average gross and cash income per household by enterprise in Murehwa and Takawira.

Based on average prices August 1999 – August 2000; 1 USD = 38 ZWD in December 1999.
Source: Household monitoring.

Labour allocation and income flows differ among the fruit tree species and the research sites, which is probably due to the difference in their abundance. *U. kirkiana* is more abundant in Murehwa, whereas the other two species are more abundant in Takawira Resettlement Area. Gross margins from the use of IFT are higher than from EFT for Takawira and lower for Murehwa (Table 10).

Income from indigenous fruit trees consists of income from the use of the fruits, i.e. own consumption and sale, but also of income from the use of leaves and wood. The latter two types of use are more important for *Strychnos* sp. and *P. curatellifolia*. *P. curatellifolia* in particular provides leaves, which are a very popular source of fertiliser for vegetable production; its wood is very durable and therefore used for construction purposes, e.g. for cattle kraals. Gross income of indigenous fruit trees use corresponds with gross margin figures as the fruits are collected and no inputs are used except for family labour and no costs in cash accrue.

Table 10. Household labour allocation and gross margins by enterprise in Murehwa and Takawira.

Enterprise[1)]	Takawira		Murehwa	
	Gross margin [ZWD HH^{-1}]	Labour[2)] [person-day HH^{-1}]	Gross margin [ZWD HH^{-1}]	Labour [person-day HH^{-1}]
Remittances	3765 (5122)	-	10359 (15233)	-
Off-farm	2690 (3253)	32 (48)	7925 (11777)	70 (73)
Horticulture	2559 (3073)	31 (24)	10063 (15036)	75 (52)
Agriculture	16886 (16791)	111 (74)	8524 (9231)	75 (51)
Livestock	15585 (12333)	165 (88)	6380 (7049)	212 (129)
Exotic fruit trees	433 (586)	8 (10)	6758 (7204)	27 (33)
P. curatellifolia and *Strychnos* sp.	1564 (549)	12 (11)	945 (766)	3 (4)
U. kirkiana	531 (321)	3 (4)	1910 (1389)	12 (8)
Total	44014 (21153)	362 (94)	52864 (32389)	474 (222)

1) Data are averages of the sample and refer to the period September 1999 to August 2000. Figures in parentheses give standard deviations. Takawira: N = 20; Murehwa: N = 19.

2) One person-day refers to a workday of 8 hours of an adult household member equalling one adult equivalent.

Source: Household monitoring.

The following references serve as a basis of comparison for the findings presented. Shackleton et al. (2002) attribute a mean gross value of USD 74 per household per year to consumption of wild fruits in three regions of South Africa in 1998, which, at the 1999 exchange rate, is equivalent to about ZWD 2800. The mean annual value of production of *Dacryodes edulis* fruits in Cameroon is calculated at USD 15 and 132 per grower in two regions having low and high market accessibility, respectively (Ayuk et al. 1999). This corresponds to ZWD 570 and ZWD 5016 at the 1999 exchange rate. The production values can be compared to the gross income and gross margins of this survey, except for the fact that the figures above include all tree products. The gross margin for all products of *U. kirkiana* in Murehwa is similar to the income figures of the study by Shackleton et al. (2002). However, the study of Shackleton et al. (2002) includes income from a higher variety of indigenous fruits. The gross margin from *U. kirkiana* trees in Murehwa includes cash income from sale also, whereas IF are not traded in South Africa; Shackleton et al. (2002) thus report the value of consumption only.

The higher gross margin for livestock activities in Takawira is due to the intensive use of cattle manure and draught power for agricultural activities. Gardening in this area has lower gross margins due to the cyclone that hit the area in February 2000 and destroyed most of the crops of some of the sample households.

Most of the income figures show very high standard deviations in comparison to the mean values. A comparison across both locations and all households shows that for all branches of the household economy there are relatively more households that derive low incomes from that branch, e.g. five households of Takawira do not receive remittances, whereas other households of the household monitoring receive rather high incomes. The household with the highest receipt of remittances receives ZWD 19800 in Takawira.

Total gross margin shares give the contribution of each enterprise towards the household income. Cash income is reported, as most households required some cash every month for household expenditures (Table 11).

Table 11. Shares of labour allocation, net cash income and total gross margin by enterprise for Takawira and Murehwa [%].

Enterprise	Family labour		Net cash income		Total gross margin	
	TRA	M	TRA	M	TRA	M
Remittances	-	-	30.7	53.6	7.6	19.6
Off-farm	9.5	15.2	34.6	29.4	7.3	17.4
Horticulture	8.5	15.4	16.4	9.8	4.4	14.1
Agriculture	29.1	16.9	-12.4	-7.6	31.5	16.3
Livestock	46.1	41.7	26.0	3.1	44.3	11.5
Exotic fruit trees	2.3	6.3	4.1	9.1	1.3	14.4
P. curatellifolia and *Strychnos* sp.	3.7	0.3	0.0	0.0	2.4	2.1
U. kirkiana	0.8	3.7	0.7	2.5	1.0	4.5

Data are averages of the sample and refer to the period September 1999 to August 2000. Totals partly deviate from 100% due to rounding. TRA = Takawira: N = 20; M = Murehwa: N = 19.

Source: Household monitoring.

Grain crops are produced for subsistence, whereas vegetables and other garden crops are mostly sold. Another source of cash income is the sale of exotic fruits in Murehwa. The largest share of cash income is derived from remittances and various off-farm activities like brick moulding, beer brewing, knitting, etc. Campbell et al. (2002) also stress the importance of these off-farm activities as source of cash income. They contribute about 27% whereas remittances contribute about 46% of the net cash income in their study. Brick moulding was frequently observed in Takawira, where houses were being rebuilt after the cyclone.

The Miombo woodlands and woodlands in general provide households with a range of products in addition to timber that are often referred to 'non-timber forest products' in the literature. Sometimes, the general term also used is 'woodland products'. Based on a survey conducted in the South of Zimbabwe in a drier region than that of the present study, income from woodland resources sum up to ZWD 3784 and constitute about 16% of household income (cash and in-kind) for 1999 (Campbell et al. 2002). In their study woodland products include, amongst other products, different fruit types. A study from India shows that non-timber forest products provided about 16% of household income and about 5% of cash income of rural households (Gunatilake et al. 1993). In comparison, the three indigenous fruit tree species contributed 6.6% and 3.4% of total gross margin in Murehwa and Takawira, respectively. According to Campbell et al. (1997), wild fruits constitute about 20% of the value of total woodland resource use by local households in Zimbabwe. This includes fuelwood, birds, mushrooms, poles, handles, mortars and fruits, i.e. a larger number of fruit species than is included in the present study. Overall, findings of the present study on the contribution of indigenous fruit tree income towards the total gross margin are similar to findings of other studies.

5.4 Labour productivity

Labour productivity allows the evaluation of the comparative advantage of one activity over another if labour is a scarce factor. Returns to family labour were based on income and expenditure data for the year 1999/ 2000 (Table 12).

Table 12. Average returns to family labour by enterprise in Takawira and Murehwa.

Enterprise	Return to family labour [ZWD person-day^{-1}]	
	Takawira (N = 20)	Murehwa (N = 19)
Off-farm activities	216 (161)	144 (93)
Horticulture	90 (67)	112 (115)
Agriculture	194 (272)	140 (170)
Livestock	60 (342)	27 (30)
Exotic fruit trees	132 (242)	302 (263)
Parinari curatellifolia and *Strychnos* sp.	232 (167)	532 (466)
Uapaca kirkiana	380 (387)	222 (228)
Mean	193 (154)	213 (139)

Figures in parenthesis give standard deviations.
Source: Household monitoring.

Collection of IF and other IFT products yields high returns to labour, which can explain the widespread use of the IFT. No up-front costs are incurred to gain access to IFT products. Data on returns to labour in the use of EFT exclude the initial investment cost of planting the trees. Labour productivity of EFT use is lower for Takawira. Here, fruit production is lower because trees are younger and many exotic fruit trees had not yet reached maturity. In Murehwa, farmers incur few management costs for mature exotic fruit trees, which results in relatively high returns to labour, as yields are nevertheless fairly high.

Campbell et al. (1997) estimate production costs, i.e. costs of collecting woodland resources in general, at 75% of their market value. In comparison, the present survey indicates that collection cost of *U. kirkiana* products in terms of opportunity cost of labour priced at the average wage rate amounts to 56% and 60% of the gross margins in Takawira and Murehwa, respectively. The average combined collection cost for *P. curatellifolia* and *Strychnos* sp. comprises 71% and 28% of the gross margins in Takawira and Murehwa, respectively (compare with Table 10).

Returns to labour can be compared to the prevailing wage rate in both locations, which was at ZWD 58 and ZWD 84 for Murehwa and Takawira, respectively (Table 9). Although returns to labour varied across households, average returns were greater than the wage rate at both sites. Thus, households can be assumed to take up work outside their farm only when own production activities allow them to do so. Still, farming activities carry a higher risk in terms of incurring sunk cost than do off-farm activities, especially casual labour. Furthermore, seasonal aspects influence all production activities; this is followed up in more detail in the following chapter.

5.5 Sale of indigenous and exotic fruits

A higher proportion of Murehwa households sells indigenous as well as exotic fruits (Table 13), which may be due to the higher fruit production levels since fruit tree holdings are larger and older. Another reason may be the more developed market structure in Murehwa, which results in better-developed fruit marketing possibilities and higher availability of fruit tree seedlings. In Murehwa, planting material for exotic fruit trees is sold at the nearby growth point, whereas in Takawira, seedlings have to be ordered from towns, e.g. Gweru, at a distance of about 60 to 80 km, which constitutes a barrier to planting due to the high costs of acquisition.

Table 13. Sale of indigenous and exotic fruits in 1999/ 2000 in Murehwa and Takawira.

Fruit	Location	HH selling fruits %	Quantity of fruits sold per HH 20 l buckets (number of fruits)	Gross cash income ZWD per HH (SD)
Uapca kirkiana	M	20	20 (9200)	971 (810)
	TRA	7	3 (1380)	358 (159)
Avocado	M	18	25 (1471)	1372 (2518)
	TRA	-	-	-
Mango	M	50	38 (3420)	1040 (1337)
	TRA	24	3 (270)	376 (556)
Guava	M	28	22 (3960)	286 (616)
	TRA	22	2 (360)	189 (210)
Peach	M	-	-	-
	TRA	29	2 (368)	251 (564)

Fruits sold per household and gross cash income are averages over households selling the fruits during the period March 1999 – March 2000. TRA = Takawira: N = 82; M = Murehwa: N = 221.
Source: Socio-economic survey.

Mangoes in Murehwa and peaches in Takawira Resettlement Area are most frequently sold. Quantities sold vary among households, although the average quantities are similar for different species. *Uapaca kirkiana* is the main indigenous species for sale. Cash income from *U. kirkiana* is within the same range as that from each exotic fruit tree (EFT) species, although total cash income from the sale of EF is higher than from IF (Table 13). In Murehwa, EF are mostly sold to vendors who come straight to the farms. In the Resettlement Area, they are most frequently sold to other people in the village. All households of Takawira Resettlement Area involved in sale sell *U. kirkiana* in the nearby townships, whereas households in the Communal Area sell at the roadside market. There are also vendors who buy fruits directly at the farms. Normally, sellers walk to the marketplaces and carry the fruits; consequently, households incur few cash costs related to sale. Cash income from selling fruits is mostly spent to buy household items such as soap, food, etc. Income from the sale of *U. kirkiana* accrues at a time when inputs for agricultural production are required and is spent on these items.

Absolute amounts of cash income from fruit sale are lower than cash derived from remittances (Figure 7); however, the latter is spread out over the year, whereas fruit income is generated over a shorter period.

5.6 Socio-economic factors influencing IF sale

Complementary to the study of Ramadhani (2002), this study aims at identifying factors that are related to sale in the producer community. Many factors have been suggested as influencing the sale of IF, among them wealth of the household, gender, educational level and level of agricultural training of the head of household (Campbell 1996); consequently, these factors were tested by means of cross tabulations and Chi-Square[39].

Since Chi-Square tests do not indicate the strength of the association, further tests were performed. Cramer's V-Test was computed for nominal variables, e.g. the relationship between village of residence and selling activities. It takes on values between zero and one; values closer to one show a stronger association. For ordinal

[39] Chi-Square tests serve to establish associations between variables by evaluation of the deviation between observed and expected cell counts of cross tabulations. For this purpose, the sample size has to be large enough and evenly distributed across cells so that the minimum expected cell count is five.

variables, e.g. receipt of remittances and sale, Kendall's τ_b and τ_c[40] were calculated. In addition to information on the strength of association, these also provide the direction. They take on values between -1 and +1. The former reflects a strong negative and the latter a strong positive association between variables, whereas values close to zero show that there is no association between the variables (Janssen & Laatz, 2003).

In Murehwa, 19.6% of the sample households sell *U. kirkiana* fruits, whereas in Takawira[41] only 7.3% sell them. As an indicator of household wealth, results indicate that in Murehwa, the amount of remittances received from relatives in the urban areas is significantly related to the sale of IF (Pearson Chi-Square, $p \leq 0.05$; Table 14).

[40] Kendall's τ_b is shown for 2 by 2 tables, whereas Kendall's τ_c is shown for all other tables.

[41] Due to the small number of households that sell *U. kirkiana* fruits in Takawira, all Chi-Square tests of relationship between sale and the variables described are based on either Monte Carlo sampling or Fisher's exact test for 2 by 2 cross tabulations. If the minimum expected cell count is below five, exact tests have to be performed to generate an unbiased measure of association. Exact tests calculate the chi-square of all possible cross tables that have the same number of rows, columns and cell count sums in the rows and columns as the empirical sample. For all thus generated tables that have a test statistic larger than the empirical one, the probability of occurrence is calculated and summed up. The thus calculated probability is compared to significance levels and yields information about whether or not to accept association between variables. Exact tests require relatively high computing capacity; therefore, tests have been developed that calculate the probability of the test statistic based on Monte Carlo simulations (Janssen & Laatz, 2003).

Table 14. Households engaged in fruit-selling activities by the amount of remittances received in Murehwa.

Remittances received [ZWD]	Number of HH in each group	HH	
		Selling fruits [%]	Not selling fruits [%]
0–500	41	37**	63
501–2000	38	24	76
2001–4000	26	15	85
4001–6000	44	16	84
6001–8000	18	22	78
8001–10000	10	10	90
>10001	42	7	93

Pearson Chi-Square, $\chi^2 = 13.363$, df = 6, p = 0.038, Kendall $\tau_c = -0.201$.

** standardised residual = 2.4 ($p \leq 0.05$) (evaluation of the standardised residual and significance levels are described in Bühl & Zöfel, 1998).

Source: Socio-economic survey.

Households receiving small amounts of remittances are significantly more often involved in the sale of IF, as shown by the standardised residual > 2 (Bühl & Zöfel, 1998). Kendall's τ_c shows a weak and, as expected, negative association, i.e. higher amounts of remittances received are coupled with no sale. However, no such relationship could be established for Takawira (Pearson Chi-Square, $\chi^2 = 3.425$, df = 6, p = 0.754; minimum cell count was below 5 for 57.1% of the cells; Monte Carlo Significance based on 10,000 samples yields p = 0.816).

The results on selling activities in Murehwa support findings from Campbell et al. (2002) that show that less wealthy households depend more intensely on natural resources. Fruit-selling activities help to bridge the gap in cash supply, particularly when cash is required for farm and household activities (as also highlighted by Campbell et al., 2002). One advantage of natural resource use is the low entry barrier to this common property resource (see also Dewees, 1994).

Further tests are performed to compare selling activities across villages. Results show that in Murehwa, the village is significantly associated with selling activities (Pearson Chi-Square, $p \leq 0.01$; Cramers V = 0.391)[42]. Households of two villages, i.e. Chinake and Hanyanga, contribute significantly to this result (standardised residual 2.3 for

[42] No significant association is found for Takawira.

Chinake and 2.1 for Hanyanga). This may be due to several factors. First, these villages are closer to the market than the others; second, fruits are highly abundant in the vicinity of these villages; and third, village heads do not object to the sale of IF by villagers.

The aspect of the distance to the market was analysed further. The villages were regrouped into villages adjacent to and villages not adjacent to the market. In Murehwa, 12 villages of ward 16 are not adjacent to the market (136 households of the sample)[43] and 4 villages are directly adjacent to the market (85 sample households)[44]. The latter villages are very close to the market, i.e. the growth point in Murehwa is within close walking distance. Pearson Chi-Square shows a highly significant relationship between distance to the market and selling activities in Murehwa. Households close to the market sell fruits more often than expected and more than households far from the market (Figure 8). In Takawira, no relationship between distance to the market and sale of indigenous fruits could be established.

However, further analysis is required to single out the influence of other potential factors like the above-mentioned availability of the fruits, which is high for the four villages close to the market and only for some villages further away from the market in Murehwa. Information on the village heads' attitude towards sale is only available for some villages, e.g. the village head of Bute is indifferent to sale, whereas the village head of Ngorosha, one village further towards the market, is opposed to the sale[45]. Thus, the village head's attitude towards sale and his means of enforcing the regulations may also determine selling activities in the respective village.

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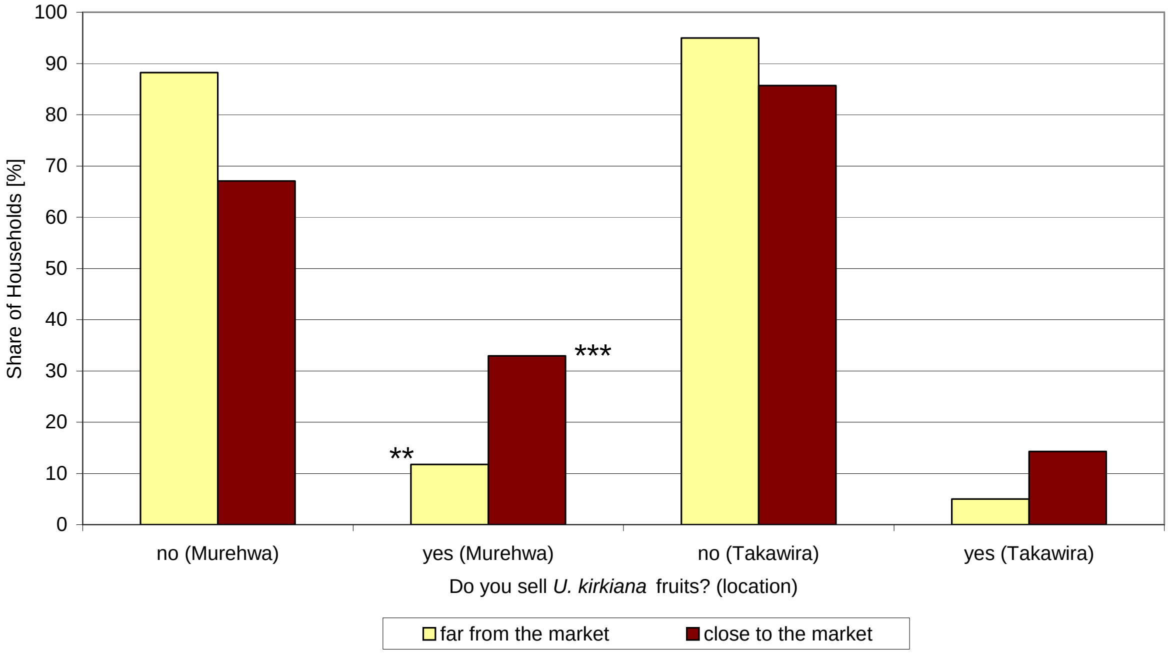
43 Chigumadzi, Chinondo, Choruwa, Hakata, Makore, Manga, Mavharume, Musakwa, Mutwandwa, Mutsvairo, Ngorosha and Zvomoya.

44 Bute, Chinake, Hanyanga and Zihute.

45 This did not prevent one household of the monitoring sample from selling fruits, although the head of that household was rather secretive about her involvement.



** standardised residual –2.1 ($p \leq 0.05$), *** standardised residual 2.7 ($p \leq 0.01$).
Murehwa: Pearson Chi-Square, $\chi^2 = 14.711$, df = 1, p = 0.000; Kendall $\tau_b = 0.258$.
Takawira: Pearson Chi-Square, $\chi^2 = 1.956$, df = 1, p = 0.331 (exact test), Kendall $\tau_b = 0.155$.

Figure 8. Relationship between sales of *U. kirkiana* fruits and distance to the market for Murehwa and Takawira.

Source: Socio-economic survey.

No significant association could be found between selling activities and gender and agricultural training of the household head in Murehwa and Takawira (Pearson Chi-Square, $p \leq 0.05$; socio-economic survey).

The household heads of 5 out of the 6 households of Takawira that sell fruits had reached secondary school education. Thus, there seems to be a relation between education of the household head and sale (Monte Carlo sampling p = 0.031; $\chi^2 = 8.794$; df = 3; Cramers' V = 0.330) in this location. In Murehwa, no significant relationship between educational level of the household head and IFT selling is established.

5.7 Consumption of fruits

The availability of indigenous fruits as measured by its collection costs from the Communal Areas as well as the benefit derived from consumption and sale are factors that influence the adoption of tree planting. If fruit supply increases due to adoption of IFT planting, the question is how the market reacts to enhanced supply and how prices will change. The study by Ramadhani (2002) assesses consumers' preferences for the indigenous fruits at two growth points and several locations in Harare. Her study shows a rather high willingness to pay for the fruits, i.e. 25% of consumers in her sample would buy *U. kirkiana* fruits at double the prevailing price. The consumers in her study were mostly urban people who buy but do not collect the fruits themselves. In rural areas, people are collectors ('producers') and also consumers of the fruits. Thus, information on consumption patterns of indigenous fruits by rural households can clarify the fruits' role in the rural economy.

In contrast to exotic fruits (EF) such as mango, avocado, citrus and guava, which ripen during the wet season, IF are available during the hot dry season and the beginning of the wet season, when food availability is rather low[46] and labour for agricultural activities reaches a peak. In Murehwa, *U. kirkiana* fruits ripen during two seasons. The peak season lasts from November to January and the off-season from May to August. In the Resettlement Area, fruits ripen during the peak season (November to January) only. Consumption patterns differ for the three indigenous fruit tree species. *U. kirkiana* fruits are consumed by all households of both locations. *P. curatellifolia* and *Strychnos* sp. are consumed by all households of Takawira Resettlement Area, but only by 49% and 68%, respectively, in Murehwa for the 1999/ 2000 season (socio-economic survey)[47]. Results from Ramadhani (2002) support the findings of this study

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[46] As shown later in chapter 6, food, or rather, income availability also depends on the household's access to a garden and the extent of horticultural activities.

[47] According to recalled consumption for the 1999/2000 season, consumption habits were similar for Takawira. However, in Murehwa, recalled consumption for this period shows a lower share of households consuming the fruits than the stated habits. Stated consumption patterns in relation to the maize harvest (Table 15) refer to "normal" behaviour over several years, whereas the socio-economic survey assessed recalled data for the years 1999 - 2000.

on the high popularity of *U. kirkiana*. In Murehwa, farmers have a higher number of exotic fruit trees on their farm. The trees are older and supply greater quantities of fruits. This can be attributed to the fact that households settled in Murehwa earlier than in Takawira. Households in Takawira have fewer avocado trees but more peach trees on their farms than households in Murehwa. Average daily consumption figures are presented in Figure 9. Across all fruit types, they show that children consume more fruits on average than adult household members.

Especially for *U. kirkiana*, the absolute numbers of fruits consumed are very high. However, the edible part of *U. kirkiana* fruits is smaller than that of exotic fruits. Whereas *U. kirkiana* consumption is popular across members of all ages in households, *P. curatellifolia* seems to be more popular among older people.

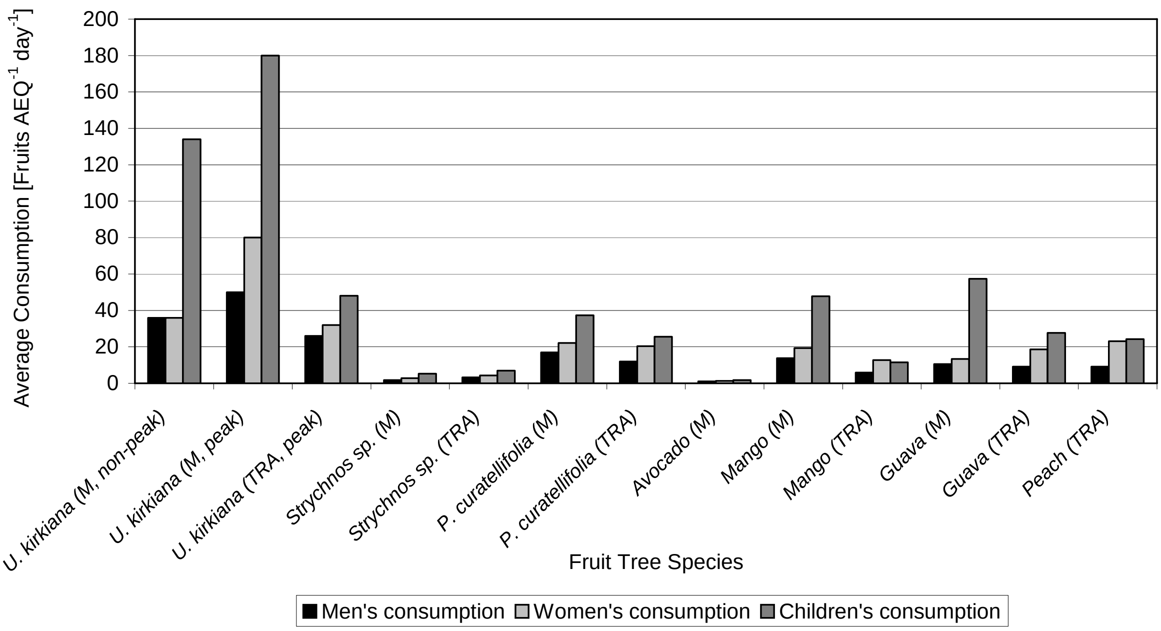

Figure 9. Average daily consumption of indigenous and exotic fruits per adult equivalent (AEQ) in Murehwa and Takawira in 1999/ 2000.

Source: Socio-economic survey.

5.8 Role of IFT species during periods of food shortages

Indigenous fruits are not a substitute for the staple food maize in Zimbabwe, but they are part of a basket of natural food resources that can supplement food supply during periods of food shortages (Shackleton & Shackleton, 2003; Shackleton et al., 2002; Shackleton & Shackleton, 2000; Campbell et al., 1997). IF are generally consumed as a snack, i.e. a small meal in between. However, in Takawira, the quantity of maize harvested has some influence on households' consumption of IF as a snack or a main meal, although consumption patterns vary among the fruit species. *Parinari curatellifolia* is more frequently used as a main meal than the other two species (Table 15).

Table 15. Percent[1)] of households consuming indigenous fruits as a snack or main meal following a normal, bumper and disaster harvest for maize.

Maize	Murehwa			Takawira		
harvest	No consumption	Main meal	Snack	No consumption	Main meal	Snack
			Uapaca kirkiana			
Normal	3.6	0.0	95.9	0.0	1.2	98.8
Bumper	1.4	0.0	98.6	0.0	1.2	98.8
Disaster	0.5	0.9	98.6	0.0	50.0	50.0
			Strychnos sp.			
Normal	22.6	0.5	76.9	0.0	0.0	100.0
Bumper	21.7	0.5	77.8	0.0	0.0	100.0
Disaster	22.2	0.9	76.9	0.0	34.1	65.9
			Parinari curatellifolia			
Normal	32.1	0.5	67.4	1.2	1.2	97.6
Bumper	31.7	0.5	67.9	2.4	1.2	96.3
Disaster	31.7	0.5	67.9	1.2	72.0	26.8

1) The percentages do not always add up to 100% due to a few households that failed to answer this question. Takawira: N = 82; Murehwa: N = 221.

Source: Socio-economic survey.

These findings support the results of Nyoka & Rukuni (2000) and highlight differences in the safety net role of IFT species during periods of food shortages. In Murehwa, none of the interviewed households change their consumption pattern of IF depending on the maize harvest. This can be due to the greater degree of support from relatives in the form of remittances and the higher amounts of off-farm income. Also, abundance of *P. curatellifolia* is lower in Murehwa than in Takawira.

5.9 Summary

Households of both research locations produce agricultural and horticultural crops. They keep cattle for draught power and chicken for meat, eggs and cash income. In Murehwa, households have a higher variety of exotic fruits trees that are also older than those of Takawira. Rain-fed agricultural production covers subsistence needs, whereas off-farm activities, home industries and remittances are important sources of cash income. Cash income is important to rural households since they depend on commercial inputs for agricultural production, especially for maize. Also, household consumption including school fees cannot be satisfied entirely by own production. Results derived from the two samples show differences that are ascribed to the varying lengths of the recall periods. Information on in-kind flows, which accrue in small quantities over a period rather than in bigger amounts at discrete points in time, seems especially difficult to recall after a longer period.

Indigenous and exotic fruits are used for home consumption and sale. All households consume *U. kirkiana*. Children consume higher amounts of exotic and indigenous fruits than do adults. Indigenous fruit sale is more prevalent in Murehwa than in Takawira and provides cash income at a time when cash is required for agricultural inputs like fertiliser. Chi-Square tests show a significant relationship between the distance to the market, receipt of remittances and sale of *U. kirkiana* fruits. Households that receive fewer remittances and households that live close to the market sell indigenous fruits more often than other households. With respect to further research, analysis of selling activities could be extended to account for the influence of other income sources, e.g. their quantity and timing.

Labour productivity of indigenous fruit tree product collection is high and higher than labour productivity of the other income-generating activities like agricultural and vegetable production. Indigenous fruits are mostly consumed as a snack. However, in years following a poor maize harvest, households of Takawira switch to consuming the fruits for a main meal, especially with regards to *P. curatellifolia*. The next chapter presents a more in-depth analysis of income flows and their impact on vulnerability to income poverty.

6 The impact of indigenous fruit trees on food security and the reduction of poverty

This chapter assesses the role of indigenous fruit trees in the reduction of poverty and vulnerability to poverty. The analysis concentrates on Takawira because survey results indicate that in times of food shortages, indigenous fruits play a more important role here than they do in Murehwa. By using data from the status quo analysis to define distributions for each income source, a model is developed that simulates distributions of the household income on an approximately monthly basis, allowing the assessment of potentially significant seasonal fluctuations in the vulnerability to income poverty that have also been found to be significant by Dercon & Krishnan (2000). By incorporating information on the volume of informal loans and savings available to the households of Takawira, the model incorporates means for consumption smoothing, if income from other sources is not sufficient to cover household consumption requirements. The role of consumption smoothing mechanisms is also analysed in the studies of Zimmerman & Carter (2003) and Fafchamps & Lund (2002).

6.1 Framework and implementation of the poverty analysis

The framework used for poverty analysis is adapted from Dercon (2001), which takes into account the interaction between assets, incomes and capabilities (Figure 10).

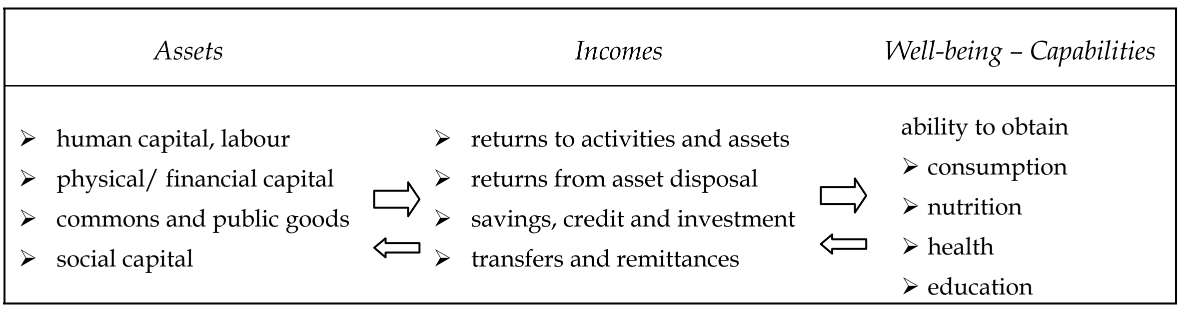

Figure 10. A framework for poverty analysis (Dercon, 2001, p. 17).

The household serves as unit for analysis; intra-household resource allocation is not incorporated. The analysis mainly concentrates on income analysis. However, it is acknowledged that income is a function of the assets listed, i.e. agricultural productivity depends on knowledge (human capital), purchase of inputs (financial capital), leaf litter from trees of the Communal Areas (common property) and sometimes also informal loans and labour exchange in times of shortages of the resource (social capital). Morduch (1994, p. 222) classifies informal loans from neighbours and relatives as "second-best arrangements that provide insurance".

On the other hand, income can be interpreted as a means of acquiring well-being in terms of consumption, nutrition, health, education and other capabilities (Duclos, 2002). By using the income required to cover minimum food needs as a benchmark for poverty measurement, this survey follows a welfarist approach, as it concentrates on the standard of living as source of welfare or utility[48].

Following Pritchett et al. (2000) vulnerability, *Vu*, is measured as the probability of falling below the poverty line, *PL*. The magnitude of vulnerability increases with the time horizon, *t*. A household, *n*, experiences a period of vulnerability if the household income, *Hi*, is less than the poverty line[49]. Over *m* periods, the vulnerability is the probability of observing at least one period of poverty within those *m* periods, which is one minus the probability of no period of poverty at any of the periods (the term in square brackets of equation (19)).

$$Vu(m, PL) = 1 - [(1 - P(Hi_t^n < PL)) * ... * (1 - P(Hi_{t+m}^n < PL))]\,. \tag{19}$$

In order to make the definition of vulnerability time-invariant, the household income has to be appropriately deflated. Thus, in combination with a constant poverty line, a constant level of welfare over time is reached (Pritchett et al., 2000).

48 See Duclos (2002) for differences between the welfarist, the basic needs and capability approach as measures of poverty.

49 Contrary to the definition above, Pritchett et al. (2000) define vulnerability based on expenditure and not on income.

Income includes production of non-market goods as well as the value of own consumption (World Bank, 1999b in World Bank, 1999a). In the context of the poverty analysis, the household income in period m is defined as the sum over gross margins, GM, of all activities, a, plus additional cash, IC, e.g. informal loans, and the surplus carried over from the previous period, m-1. The surplus from the previous period is that period's household income, Hi_{m-1}, net of household cash expenditure, Ex_{m-1}, household consumption, Co_{m-1}, and school fees, SF_{m-1}, of that period[50] (equation (20)). Household consumption is based on minimum food needs (= MFR) estimates from Alwang et al. (2002), which is ZWD 13 per AEQ and day. Income flows and vulnerability to income poverty depend on seasonal fluctuations, which are addressed by breaking the year down into several periods. The period in which income and expenditure occur is given by m; it refers to approximately monthly data[51]. Informal loans are only taken out when the household income otherwise falls below consumption plus other expenditure. They are taken out in an amount that covers consumption plus other expenditures.

$$Hi_m = Hi_{m-1} - Ex_{m-1} - Co_{m-1} - SF_{m-1} + \sum_{a=1}^{A} GM_{am} + IC_m, \tag{20}$$

with $IC = 0$, if:

$$Hi_m = Hi_{m-1} - Ex_{m-1} - Co_{m-1} - SF_{m-1} + \sum_{a=1}^{A} GM_{am} \geq Co_m + Ex_m + SF_m,$$

and $IC = Co_m + Ex_m + SF_m - \left(Hi_{m-1} - Ex_{m-1} - Co_{m-1} - SF_{m-1} + \sum_{a=1}^{A} GM_{am} \right)$, if:

$$Hi_m = Hi_{m-1} - Ex_{m-1} - Co_{m-1} - SF_{m-1} + \sum_{a=1}^{A} GM_{am} < Co_m + Ex_m + SF_m.$$

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50 Note that, due to using gross margins for household income calculations, the variable cost of production activities have already been accounted for.

51 The first period covers about four months, from August to November 1999.

Households employ several means to address the risk of the cropping enterprises, e.g. (i) participation in credit and insurance markets, (ii) receipt of transfers from other households, (iii) generation of non-farm income and (iv) sale of assets. In the case of individual risk, all strategies can be expected to work reasonably well; in the case of systematic risk, strategies i, ii and iv will be of limited use depending on the extent of the shock, i.e. the number of households and size of the area affected (Reardon et al., 1992).

The model incorporates two specific risk-coping strategies: households can access additional sources of cash and households can increase indigenous fruit collection. Households have various means of acquiring additional cash, e.g. via informal loans, membership in a savings club, ownership of a savings account and an own business. These resources are used to balance out periods when expenditure exceeds income. It is assumed that households are able to take out loans anytime; once the limit is reached, no further loans can be taken out. The informal loans are paid back at the end of the year. It is assumed that no interest is charged on these loans, as they are based on reciprocal exchange, i.e. in other periods households may extend loans themselves[52]. Additionally, whenever the model household's income falls below cash requirements and minimum food needs of the current period, households are assumed to collect more IF for home consumption and sale. Receipt of remittances and the share of off-farm activities reflect further risk-coping strategies that have been identified in the literature. Cattle and poultry are most widely owned and are the main assets sold, according to findings of Kinsey et al. (1998). This risk-coping strategy is not accounted for by using gross margins, since the sale of livestock is counterbalanced by the reduction in stock[53]. Receipt of remittances and off-farm activities are employed in the model up to the level found among the survey households.

Since all households of the research location use indigenous fruits, no comparison between indigenous fruit users and non-users can be drawn. The latter implies that no

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52 However, this information is not included in the model.

53 However, if this risk-coping strategy is to function in the long run, the sale of livestock has to occur at a lower rate than reproduction.

'without IFT' scenario can be defined. Thus, the contribution of IFT towards remaining above the poverty line is assessed by subtracting the IFT income from the household income while holding all other factors constant. Poverty and vulnerability to poverty are analysed for Takawira, which has a less developed infrastructure and is also further from the main market in Harare than Murehwa. Also, a higher share of households of this area indicates, to a higher degree, use of IF as a consumption-smoothing strategy in times of need (Table 15, p. 84).

From a risk-management perspective, since the model uses income data from observed activities, it captures the degree of income diversification in the research location.

6.2 Components and distributions of the stochastic household income

Chapter 5 described the household income and components for households of Takawira that participated in the household monitoring. The model used to assess vulnerability to poverty is based on this cross section of gross margins for each farm household enterprise, which are computed on a monthly basis. In addition to expenditure related to production activities, information on household expenditure, i.e. cash spent on household goods like cooking oil, soap, etc., is also included. School fees constitute a rather large sum of cash required at certain times of the year; hence, this information is also included. Gross margins for each period were calculated by using average prices over the period 1999 to 2000. In order to get time- invariant figures, income and expenditure of each period were deflated back to t_0, i.e. August 1999 using 50% of the implicit GDP deflator[54] (59.9%, World Bank, 2002) because gross margins are based on average price. The components of household income and expenditure as well as their descriptive statistics (valued at 1999 prices) are provided in Table 16.

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[54] The GDP deflator measures inflation by the annual growth rate of the GDP and shows the rate of price change in the economy as a whole. It is the ratio of GDP in current local currency to GDP in constant local currency (World Bank Online).

Table 16. Gross margins by household enterprise and season for Takawira.

Period		Remittances	Off-Farm	Horticulture	Agriculture	Livestock	EFT	IFT
		ZWD[1)] AEQ^{-1} Period^{-1}						
Aug –	Mean	337	221	298	-1812	840	17	147
Nov	SD	725	698	434	1464	814	24	66
Dec –	Mean	44	24	19	-30	323	31	134
Jan	SD	125	45	28	63	321	82	89
Jan –	Mean	75	35	-2	259	311	17	26
Feb	SD	143	87	11	383	339	56	22
Feb –	Mean	24	26	1	1682	141	16	15
March	SD	51	67	24	1269	229	40	26
March –	Mean	77	51	-4	2088	294	11	12
April	SD	214	92	20	2782	332	22	10
April –	Mean	54	78	5	743	458	6	9
May	SD	119	86	38	1563	395	13	10
May –	Mean	165	87	24	84	340	1	31
June	SD	339	76	41	173	260	3	33
June –	Mean	34	37	116	-127	306	0	13
July	SD	76	57	158	375	459	0	9

1) 1999 prices.

Source: Household monitoring; N = 20.

Results show that income generated by the farm household enterprises fluctuates in the course of the year. Remittances and off-farm activities generate a higher income in the period August to November and remain relatively stable thereafter on a lower level. Horticultural income increases from June onwards and then also reaches a peak in the period August to November. Indigenous fruit income starts rising in August and then decreases from January onwards. All these enterprises move anti-cyclically to agricultural activities that require expenditures for inputs in the period August to November and then generate income from February through April.

By using gross margins, one indicator captures climatic, i.e. yield fluctuations, as well as market risk, i.e. price variability. In order to pool the cross-section sample for identifying the distributions of each income and expenditure category, AEQ are used as common denominator. The results obtained from the model simulations can be interpreted as an average household of the research site.

The distributions were fitted to the data by using BestFit (Palisade, 2004). BestFit identifies a distribution that most likely produces the data sample by optimising the goodness of fit. Once the distributions are fitted, the fits are ranked using one or more fit statistics, including Chi-square, Anderson-Darling, and Komolgorov-Smirnov. For this model, the distribution with the best-fit statistic ranked by Chi-square test was employed (the distributions are shown in Appendix 2 and Appendix 3). Some of the fits show very low goodness of fit, especially those with a high number of ‘zero’ values in the data. However, fitting the distributions by using BestFit is considered superior to employing one standard distribution, although some of the distributions yield values, i.e. +/- infinity, that are not realistic. Some of the distributions with a low goodness of fit have two peaks (beta general), which reflects the data available more appropriately than, for example, a truncated normal or triangle distribution. However, under- or overestimating the tails of a distribution despite high goodness of fit may bias the modelling outcome (Hardaker et al., 1997).

The resource stock that is carried over from the previous year and is available in t_0 is assumed to be equal to the resource stock that households had accumulated by the end of the monitoring season (Table 17). All households of Takawira have access to additional sources of cash, e.g. from a savings account, with either own accumulated savings or remittances and transfers from other family members, savings clubs and informal loans. These informal loans do not require collateral or charge interest, similar to observations of other rural household surveys as also shown by Fafchamps & Lund (2002). They are informal risk-sharing arrangements that often serve purposes of consumption smoothing and are incorporated in the analysis for this reason. The volume of such additional sources of cash varies among households of Takawira (Table 17).

Table 17. Resource stock at the beginning of the agricultural cropping season and volume of informal loans available to households of Takawira.

	Resource stock carried over from previous year[1)]	Volume of informal loans and savings available
	ZWD AEQ^{-1} $year^{-1}$	
Mean	1476	561
SD	4039	719
Min	-6380	65
Max	10688	2756

1) 1999 prices.

Source: Household monitoring; N = 20.

Household expenditures on clothes, soap, paraffin, etc. and school fees vary between households and the season (Figure 11). They are higher from August to February. The standard deviations as shown by the error bars are lower than the standard deviation in income.

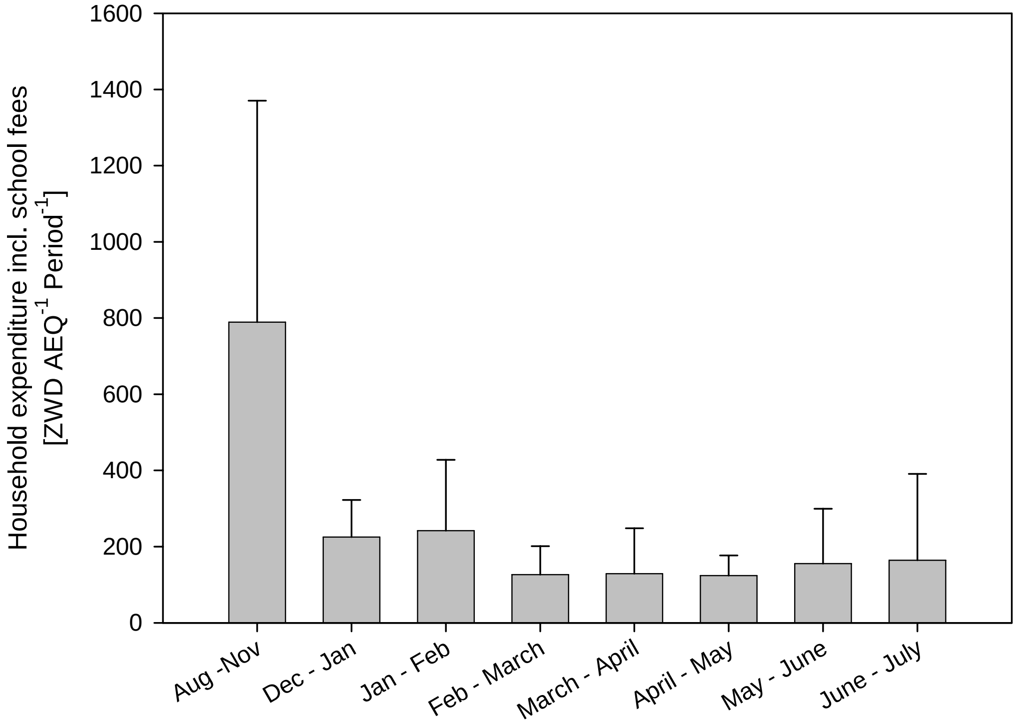

Figure 11. Mean and standard deviation of household expenditures[1)] including school fees over the year for households of Takawira.

1) 1999 prices.

Source: Household monitoring; N = 20.

Indigenous fruits are available from August to January, which corresponds to the first two periods of the survey year. During these two periods, whenever the household income falls below minimum food needs plus cash requirements for production plus household expenditure, the model household collects additional fruits from the Communal Areas. However, the extent to which the household increases fruit collection is limited. Since fruits are only one part of the natural food resource basket, households are assumed to substitute 42% of minimum food and cash requirements by indigenous fruit collection. This estimate is based on the average share of indigenous fruits in the natural food basket found in the literature (Table 18). Natural food income refers to all types of food that are not cultivated but can be collected from 'the wild', that is from the Communal Areas, along roadsides and at the margins of agricultural fields. The assumption that the household substitutes for some of the MFR through enhanced indigenous fruit consumption is justified based on results from the socio-economic survey that show that households change from consuming fruits as a snack to consuming them as a main meal in years following a bad maize harvest (chapter 5, Table 15). Since survey data capture the contribution of the three most popular species previously determined by Kadzere et al. (1998), but a much higher variety of indigenous fruit trees is available to rural Zimbabwean households, covering MFR by 42% will reflect the benefit derived from all indigenous fruits available, not just the three most popular species.

Table 18. Percentage of natural food types in total natural food income [%].

	Zimbabwe		South Africa				
Type of Food	Jinga[1)]	Matendeudze[1)]	Bushbuckridge[2)]	Ha-Gondo[3)]	Kwa-Jobe[3)]	Mogano[3)]	without location[4)]
Herbs	-	-	78	49	26	85	-
Fruits	73	97	22	39	47	6	12
Mushrooms	0	3	-	4	5	-	2
Honey	-	-	-	-	2	-	8
Insects	-	-	-	9	2	3	-
Bushmeat	27	-	-	-	-	6	77
Fish	-	-	-	-	18	-	-

1) Campbell et al., (1997)

2) Shackleton & Shackleton (2000)

3) Shackleton et al. (2002)

4) Shackleton & Shackleton (2003)

The poverty model assesses five different scenarios depending on the degree to which indigenous fruits are used to substitute MFR and the surplus that was generated in the previous year and is carried over (Table 19).

Table 19. Scenarios to assess indigenous fruit tree use and poverty.

Scenario No.	Resource stock in t_0	IF use
1	Zero	Zero
2	Zero	42% of MFR
3	Zero	80% of MFR
4	As defined in the sample (compare with Table 17)	Zero
5	As defined in the sample (compare with Table 17)	42% of MFR

The model excludes dependency between the periods, e.g. inputs into agricultural and horticultural production from August to January as expressed by negative gross margins, which could be expected to result in higher gross margins during harvesting time from March through to June. However, neglect of these dependencies can be interpreted as the risk of crop failure, e.g. due to averse climatic conditions in the latter half of the cropping period. If a farmer plants her crops in the beginning of the wet season and uses rather high quantities of inputs, she still faces the risk of a short rainy season. If this happens, and rains fail to continue until February, the crop dries up and the inputs used are sunk. This means negative gross margins in period 1 may result in low gross margins in period 8.

6.3 Prevalence of income poverty

The poverty line based on Alwang et al. (2002) is at 4600 ZWD per adult equivalent and year[55]. The average household income is above the poverty line for the sample as well as the model household. 25% of the sample households were below the poverty line during the research period. In comparison, the national poverty headcount of Sala-i-Martin (2002) based on income data is at about 10% for 1998. The estimate of the

55 24000 ZWD per average household size of Takawira (Household Monitoring,).

poverty headcount based on consumption data by Alwang et al. (2002) is higher; it is at 48% for the rural areas and nationally at 35% for 1995 (ibid.). The sample households below the poverty threshold derived an average income of 2700 ZWD per adult equivalent. In comparison, Campbell et al. (2002) estimate that 71% of their households were below the "food poverty line" (28000 ZWD per household), which covers basic nutritional needs, and 90% were below the "consumption poverty line" (45000 ZWD per household)[56], the latter also covering some allowances for housing, clothing, education, health and transport. It is difficult to compare the poverty lines of Alwang et al. (2002) to Campbell et al. (2002) because the latter do not indicate the size of households in their sample.

The average annual household income based on the simulation is ZWD AEQ^{-1} 10690 (SD 8220) for the scenario that no surplus is available from the previous season and indigenous fruits substitute 42% of MFR. The average annual household income over the sample is ZWD AEQ^{-1} 8211 (SD 4868)[57]. Agricultural activities and livestock keeping are the major sources of income, followed by remittances and off-farm activities (Figure 12). Campbell et al. (2002) show for the south of Zimbabwe that wealthy households receive more remittances than poor households and also that the latter depend to a larger extent on woodland products. Wealth effects and indigenous fruit use are captured in the model only indirectly, namely by the resource stock the year of analysis starts with, the amount of remittances and other income received by the household, which all influence the extent of IF collection. Given the ongoing economic crisis with an annual GDP decline of between 1 and 8% from 1999 to 2002 (World Bank, 2003) and the high rate of unemployment, it can be expected that remittances have declined, and woodland products, including indigenous fruits, have become more vital as an income source. The difference between the sample and the model household regarding the share of indigenous fruit income accounts for increased IF consumption in times of need.

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56 In 1999 Zimbabwean dollars, Campbell et al. (2002). Both measures of poverty were defined specifically for their survey.

57 For this scenario, the annual household income corresponds to the total gross margin as defined in chapter 5, as no surplus from the previous year was available and loans were paid back at the end of the year.

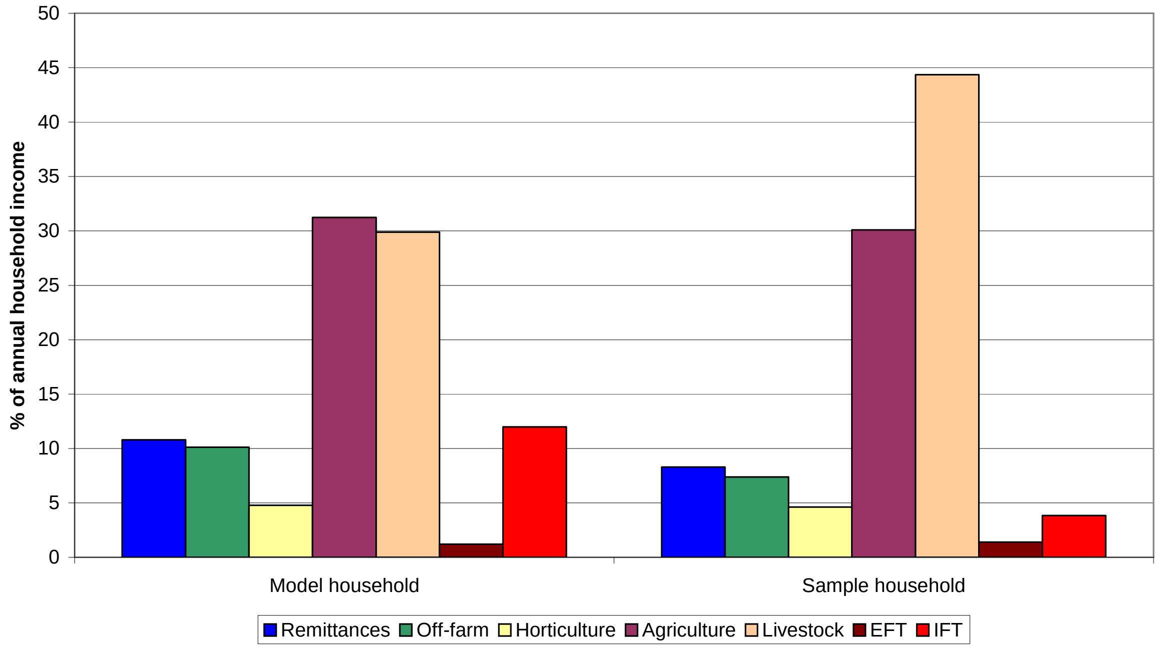

Figure 12. Annual household income by source.

Model: Scenario 2 (surplus = 0, IFT 42% of MFR), estimated over 25,000 iterations.
Sample: Takawira Resettlement Area, N = 20.
Source: Own calculation.

The contribution of each income source towards annual household income varies to different degrees (Table 20) and is higher for the model household. Agricultural and livestock activities show the highest variance.

Table 20. Variation in contribution of each income source towards annual household income.

	Standard deviation of each income source's contribution [%]						
	Remittances	Off-farm	Horticulture	Agriculture	Livestock	EFT	IFT
Model	0.34	0.37	0.40	4.21	2.13	0.15	0.86
Sample	0.11	0.13	0.10	0.27	0.38	0.02	0.07

Model: Scenario 2 (surplus = 0, IFT 42% of MFR), estimated over 25,000 iterations, @risk.
Sample: Takawira Resettlement Area, N = 20.
Source: Own calculation.

Poverty is a static concept, whereas vulnerability to poverty is a dynamic concept. It encompasses not only changes from year to year, but also seasonal fluctuations, as

Dercon & Krishnan (2000) show for Ethiopia. If seasonal changes are ignored, vulnerability is underestimated. In Zimbabwe, income flows are highly seasonal due to the differing climatic conditions over the year, which especially influence agricultural production as one of the major sources of subsistence income. Consequently, assessing the average annual income is not sufficient for analysis of vulnerability to poverty.

Figure 13 gives an overview of seasonal changes of income-generating activities for Takawira as discussed during the village meetings. These seasonal patterns are important in two ways. Labour requirements depend on seasonal fluctuations and income flows also follow seasonal patterns. Overall, during the wet season, agricultural activities are the major mode of employment, whereas off-farm activities are of more relevance during the dry winter months. Agricultural production commences in July with so-called winter ploughing of the fields. Agricultural production then pauses and continues in November with further field preparations and planting. Maize is weeded in December and finger millet and roundnuts in January. From March onwards, agricultural crops are harvested, starting with groundnuts, then maize and roundnuts. Finger millet is the last crop harvested. In August, maize is threshed. Horticultural crops are to some degree independent of rainfall and are cultivated during months of lower labour input into agricultural production. Whereas agricultural crops take some months between planting and harvesting, i.e. there is a gap between input and output flows, horticultural crops have a shorter cultivation cycle, so that input and output flows follow each other more closely. Horticultural crops provide income during months of low agricultural income. Livestock keeping does not have a seasonal labour peak. Depending on availability of forage, additional feed has to be provided in November just before the onset of the wet season, which would require additional labour. Medical treatments are usually carried out in March meaning that cash is required at this point in time. Indigenous fruits ripen during the period of low agricultural income and high cash requirements for agricultural inputs. Off-farm activities are usually pursued during the same months as horticultural activities, when agricultural production requires less labour input. Special household activities like thatching houses are performed during the agricultural slack period in the dry season. Social events concentrate around Christmas time.

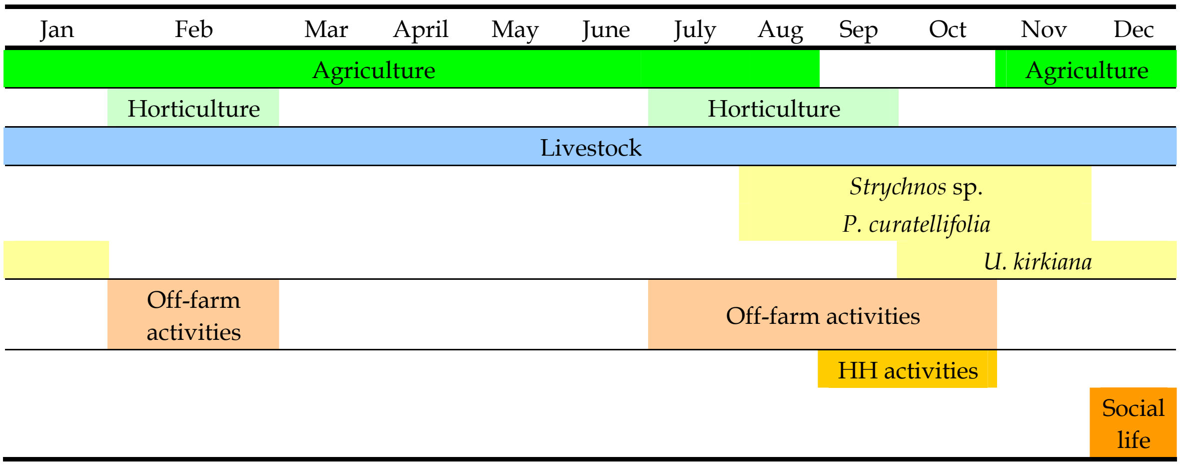

Figure 13. Seasonal calendar, Takawira.

Source: Village Meeting (own compilation).

This pattern is also reflected in the average income flows. Figure 14 shows the results of the simulated income flows over the year for the scenario with and without IFT use. The former additionally distinguishes between an IF contribution level of 42% versus 80% of MFR. It is also assessed how the situation changes if no surplus is carried over from the previous year.

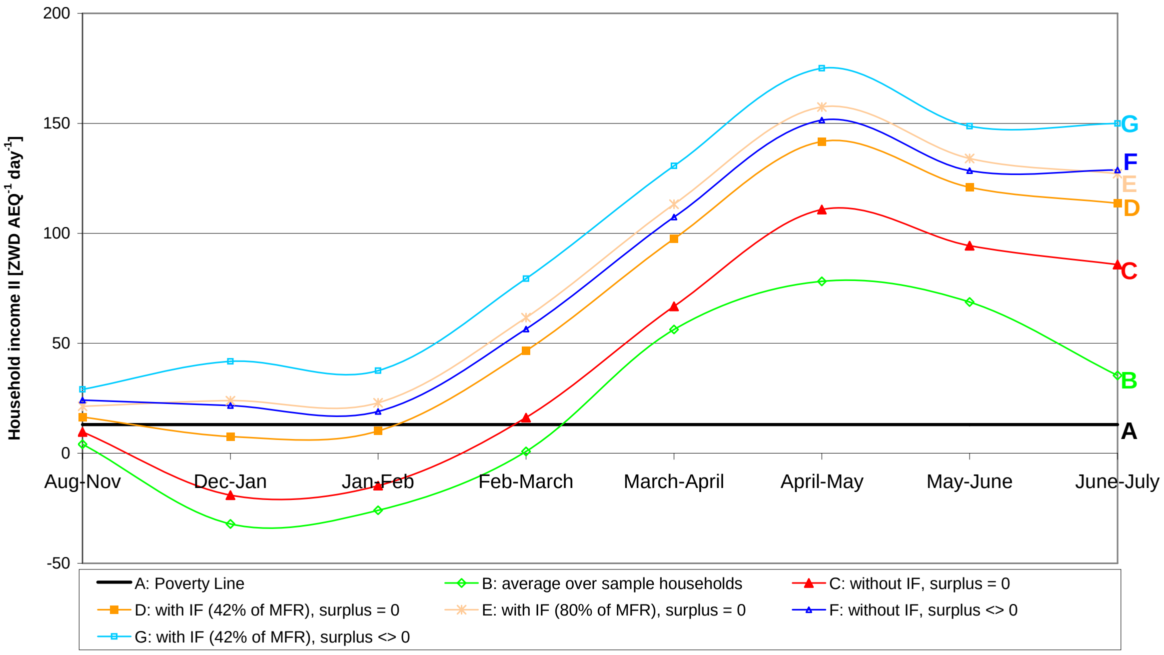

Figure 14. Average daily income flows throughout the year, Takawira.

Source: Own simulation based on Household monitoring, Takawira.

When a surplus from the previous period is carried over, the household remains above the poverty line, even if no indigenous fruit tree products are available. If the surplus from the previous period is zero, the situation changes. Then the level of income depends on the level of IFT availability. The household not only falls below the poverty line when no surplus has been carried over and no indigenous fruits are available, but actually displays a negative income during the period from November to February[58]. This is due to the fact that, during the period from November to January, gross margins of agricultural production are mostly negative due to the expenses incurred for seeds and fertilisers. The income-smoothing mechanisms, i.e. the taking out of informal loans and the use of savings, are not sufficient to bridge the gap. The question is how the household copes with this. For one, the household may be able to access additional (informal) loans exceeding the amount derived from the household monitoring. Second, if the credit limit were fixed, one would expect the household to reduce input into agricultural production, which is not included as a coping strategy in the model. However, reduced agricultural production also implies reduced household income during the latter periods of the cropping season, i.e. March to June. Such a strategy could imply a shift from stochastic to persistent poverty.

If indigenous fruits are available and replace up to 42% of the MFR, the household generates a positive income, but still remains below the poverty line from the beginning of December until February. This means that expenses incurred for production are covered since the model is based on gross margins, but MFR and other household cash expenditure are not. If the household can replace up to 80% of MFR by enhanced indigenous fruit use, it remains above the poverty line. This means MFR and production costs are covered.

Overall, indigenous fruit income accrues at a time at which income is rather low. Furthermore, indigenous fruits provide food and nutrition at a time when the labour input to agricultural production is very high and thus energy requirements are also high.

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58 Overlapping seasons in the graph mean that the period was monitored from the middle of one month to the middle of the next month.

As shown in Table 18 and also by the results of Cavendish (2000), the three indigenous fruit tree species are part of a natural resource basket rural households use. Thus, survival also depends on the availability of other environmental foods like wild animals and indigenous vegetables, which were excluded from this survey. Finally, Figure 14 shows that the household on average generates a surplus that can be transferred to the next year, contributes to savings or is available for realising investments.

For better comparison, Figure 14 also shows the average daily income of the households of Takawira. Their average household income is below the results from the simulation model. Thus, the model may overestimate monthly average income flows[59].

The critical period refers to the period when availability of food and income resources are at their lowest. It depends on the maize harvest from the previous agricultural production season and thus on how much grain households are able to store for the next harvest. With a rather low maize harvest, the critical period starts in August and continues through to December – February, depending on the resource base of rural households. Households that have agricultural fields with access to the ground water table -- and therefore better access to water for the plants -- can plant maize early and harvest the first green maize in December. Normally, harvest of green maize crops starts in January and the ripe crop is harvested in April. The data collection rounds one and two and to some degree also round three fall within the critical period. For the critical period (here: monitoring round one and two), i.e. August to January, agricultural income is negative. During this period, households that have zero surpluses from the previous period and substitute 42% of MFR by using indigenous fruits generate an average income of 2316 ZWD per AEQ (SD 2012). The average over the sample is lower; it is 947 ZWD per AEQ (SD 1901).

[59] This is due to the choice of the density distributions for each income source. Among the specified density distributions are some that are limited at the left side but not at the right side, e.g. the exponential and log-logistic distribution, which bias the results towards the upper end of income.

During this period, households rely on livestock keeping, indigenous fruits, off-farm and household activities as well as remittances (Figure 15). Livestock income in the beginning of the cropping season is derived mostly from draught power and manure inputs to agricultural production. Thus, it only indirectly contributes towards food security. Indigenous fruit income is of special importance for households that do not have other income sources sufficiently large to cover expenses for agricultural production. As for the annual household income, agricultural and livestock income show the highest variance, as indicated by the standard deviation shown by the error bars.

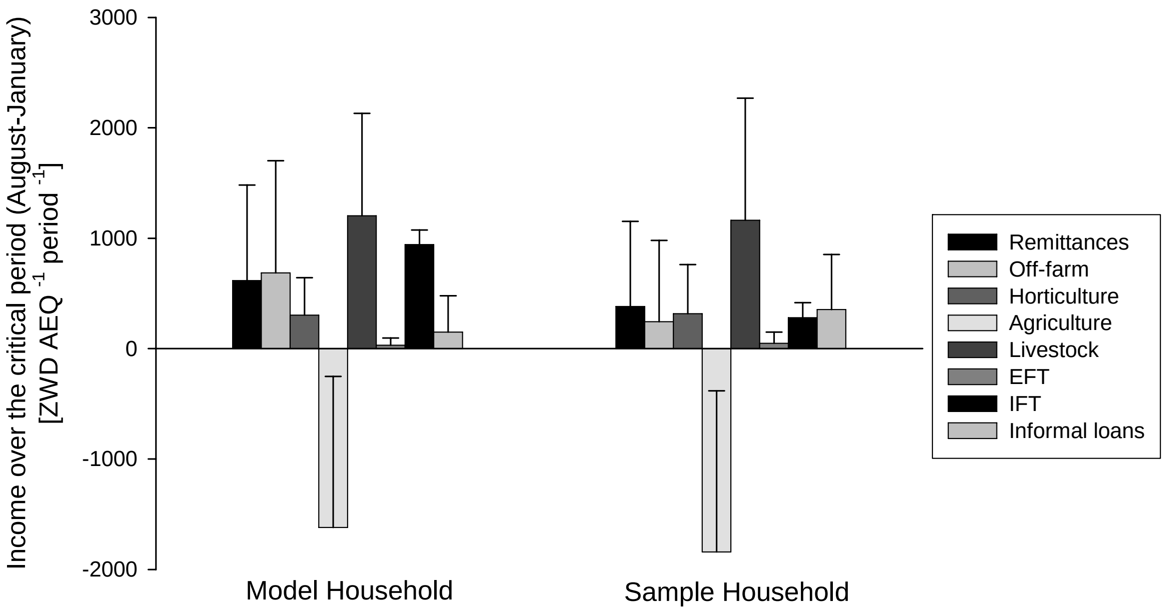

Figure 15. Household income by source from August to January.

Model: Scenario 2 (surplus = 0, IFT 42% of MFR), estimated over 25,000 iterations.
Sample: Takawira Resettlement Area, N = 20.
Source: Own calculation.

Since the household income in one season is derived from various sources, the sensitivity of the household income towards each of its components is assessed for the second half of the critical period, i.e. December to January. This period's household income depends on income from each of the activities in periods 1 and 2, on the availability of loans and on household expenditure including consumption at the level of minimum food requirements and further expenditure such as school fees.

The sensitivity analysis is carried out in order to determine the relationship between the household income and its sources for scenarios 2, 3 and 5, i.e. the scenarios with indigenous fruit tree use. For this purpose, simulation data are further analysed by linear regression. The functional form underlying the regression is given by equation 20 (p. 89)[60]. The sensitivity analysis uses the standardised beta coefficients as an indicator of the household income's sensitivity to changes in income generated from each of the sources. It aims to establish the relative strength of each of the income sources affecting the household income during the critical period[61].

The taking out of a loan in the first half of the critical period depends on the surplus available in the beginning of this period (t_0), income, i.e. gross margins, from all activities, household consumption and expenditure of this period. Taking out an informal loan in the second half of the critical period depends on the same factors and additionally on income and household expenditure of this period. Indigenous fruit income of the first half of the critical period depends on the surplus at the beginning of the critical period, household consumption plus expenditure and cash required for production activities. IFT income of the second half of the critical period depends on the same factors and, additionally, income, expenditure and cash requirements of the second half of the critical period.

Household income of the latter half of the critical period is regressed on each income component and household expenditure including MFR consumption of both sub-periods of the critical period. The problem of multicollinearity is ignored; it is assumed that the linear combination caused by the income smoothing mechanism of enhancing IFT collection if income falls below certain levels prevails[62]. If the income-

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60 As expected, the three regression models result in a R-square of 1. The two income-smoothing conditions built into the model cause multicollinearity in the simulated data set.

61 The critical period refers to the period from the middle of August until the beginning/middle of January that was covered by two monitoring rounds. The first half of the critical period refers to the first monitoring round that covered all activities from the middle of August to the end of November (= period 1), while the second half of the critical period refers to the period covering the beginning of December to the beginning/middle of January (= period 2).

62 Kennedy (2003, p. 210) justifies the inaction with respect to multicollinearity if it is expected to prevail.

smoothing mechanism followed a different pattern, the simulation model and the regression would have to be adapted accordingly. Figure 16 shows the standardised beta coefficients for sources of household income in the period December to January for each of the three scenarios.

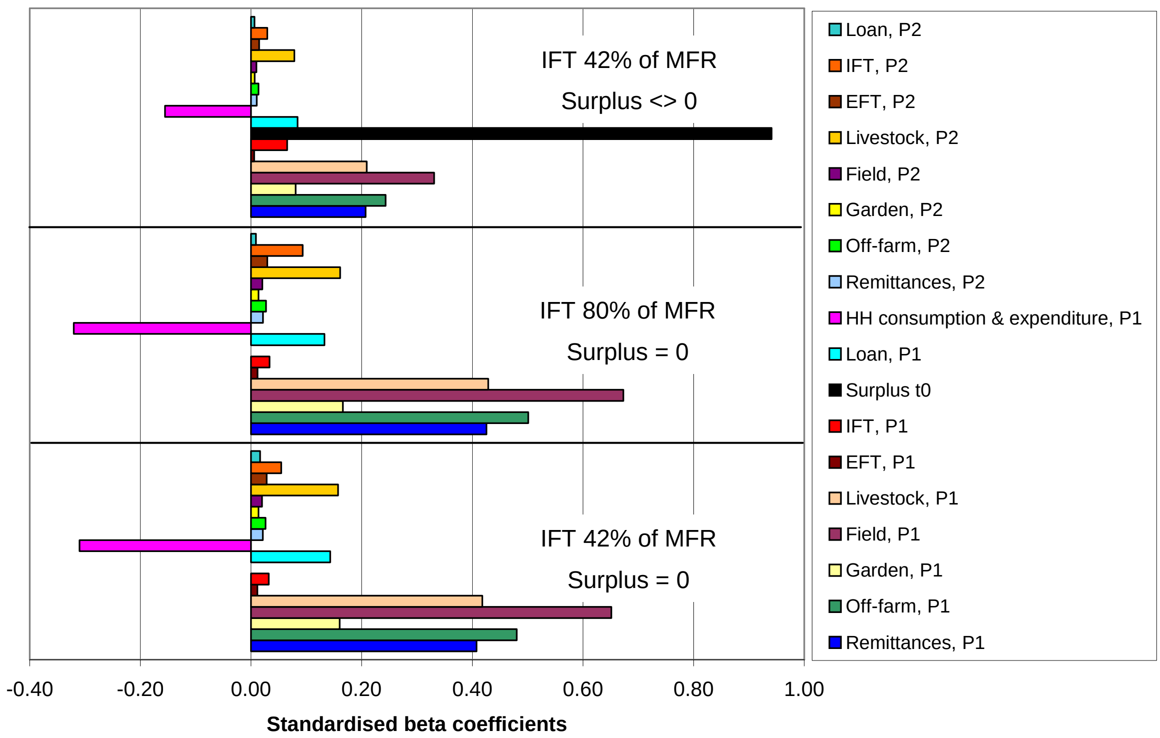

Figure 16. Sensitivity of household income to changes in each income component during the second half of the critical period (December – January).

Note: The columns follow the same sequence as the labelling in the legend, easiest to read from the bottom up.

Source: Own simulation based on Household monitoring, Takawira.

Over all of the three scenarios, changes in income from the first period's activities have a higher influence on income in the second half of the critical period than income of the second half of the critical period itself. Livestock and indigenous fruit income of the second half of the critical period exert the greatest influence in this period. Changes in the surplus carried over from the previous year have the highest effect on household income in December, followed by income from agricultural activities in the first half of the critical period, due to high costs of production inputs bought in this period. High inputs in agricultural production, e.g. for fertilisers, place the household in a better position to have a successful cropping season. As expected, the income from indigenous fruit trees of period 2 has the highest influence if the fruits replace 80% of MFR, followed by the case in which they replace 42% of MFR, when no surplus has been carried over.

With respect to indigenous fruit income from period 1, the sequence of the scenarios regarding the size of the standardised beta coefficients changes. The influence of IF income on the household income is highest for the case where surplus is carried over. This is due to the fact that for some cases a negative surplus, e.g. non-repaid loan, is carried over, which has to be paid back during the first period, August to November. Income from livestock keeping also highly affects changes in income. Two other sources of income, namely receipt of remittances and off-farm income, also show large influence on household income.

6.4 Vulnerability to poverty

However, even if average income flows remain above the poverty line, in some instances the household still falls below the poverty line. Consequently, the criterion of average (expected) income is not sufficient to assess the vulnerability to poverty. Figure 17 illustrates the variability of the household income per adult equivalent during the second half of the critical period. It shows that the probability of falling below the poverty line is highest if no surplus from the given previous year was available in t_0 and no indigenous fruits can be used for income smoothing.

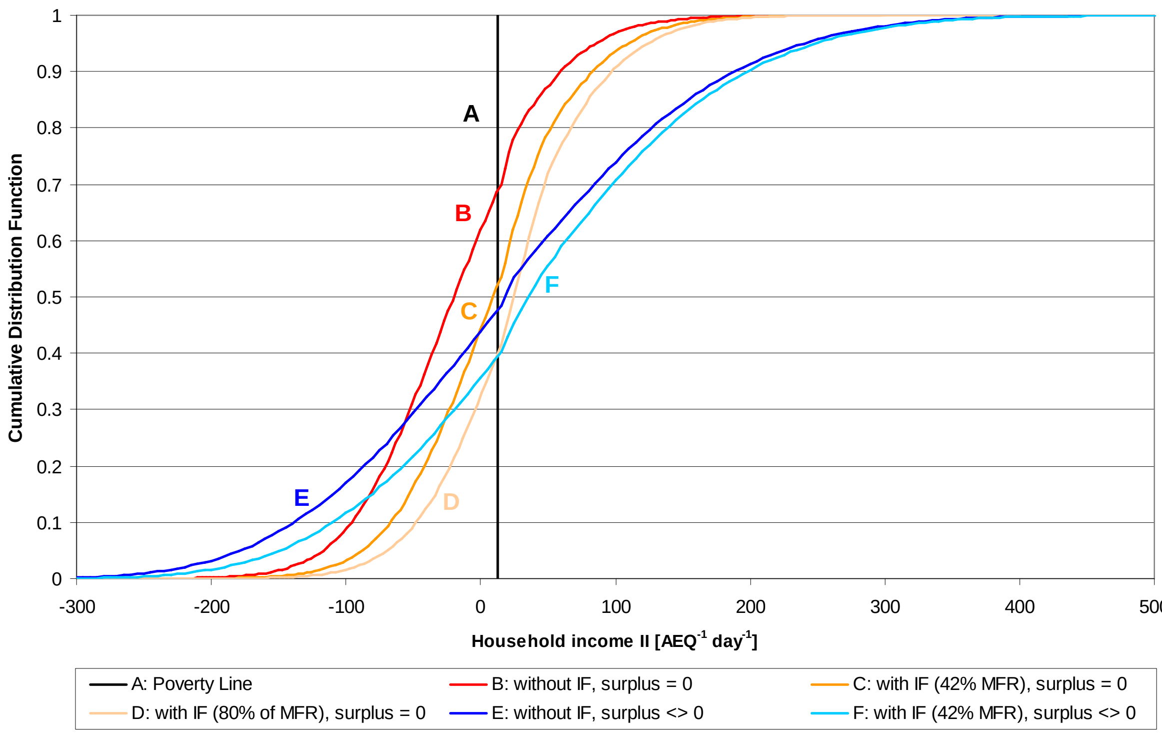

Figure 17. Cumulative distribution function of the household income for different scenarios during the second half of the critical period, December – January.

Source: Own simulation based on Household monitoring, Takawira.

The impact of IFT, i.e. comparing scenario 1 (curve B) with scenario 2 (curve C) and scenario 4 (curve E) with scenario 5 (curve F) with respect to the probability to fall below the poverty line, is considerable. Availability of IF reduces the probability of falling below the poverty line by about 10-20%. However, overall vulnerability remains high during the critical period.

Vulnerability to income poverty varies over the course of the year (Figure 18). It is highest during the period from August to January, when agricultural production requires the most inputs and does not yet provide sufficient income. During this period IF are available and thus reduce the probability of falling below the poverty line. The higher the share of IF towards MFR, the lower the vulnerability to income poverty is. Again, one has to bear in mind that other natural resources not included also contribute towards reducing vulnerability to income poverty.

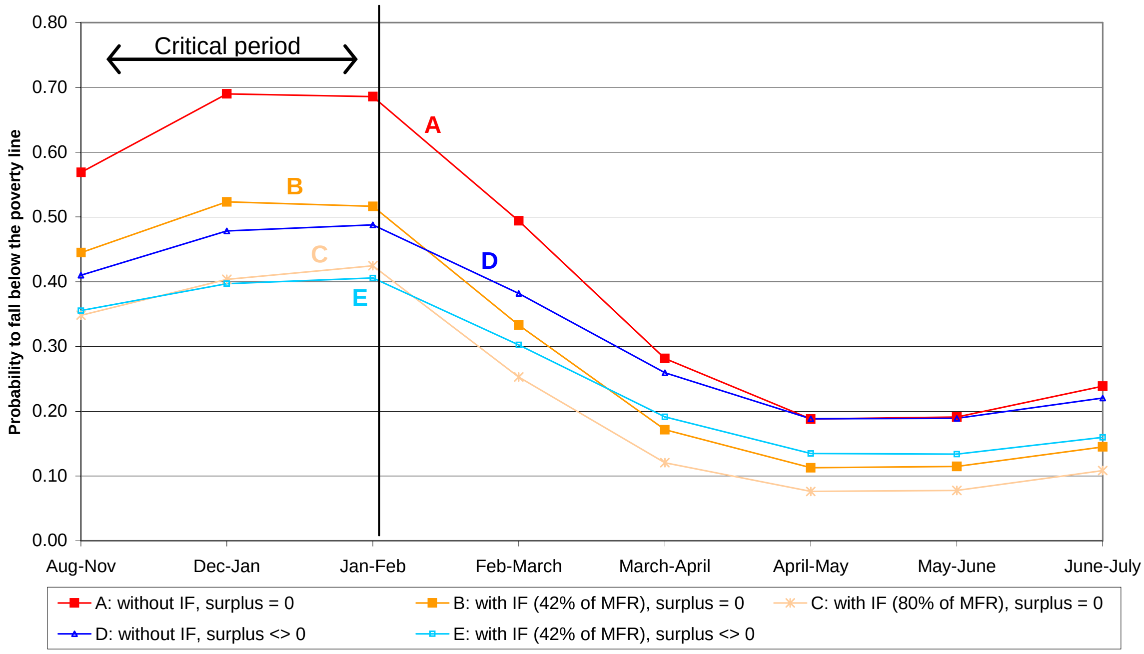

Figure 18. Probability of falling below the poverty line throughout the year.

Source: Own simulation results.

The availability of indigenous fruits lowers vulnerability by 5.4% to 8.2% if surplus from the previous year is available (curve D and E). If the surplus in t_0 is zero, the relative importance of IF increases. It lessens vulnerability by 7.5% to 17.0% if IF replace 42% of MFR (curve A and B), and by 11.2% to 28.6% if IF replace 80% of MFR (curve A and C).

Overall, the vulnerability to poverty as defined in equation 20 (p. 88) over the whole year is very high. The likelihood that a household will fall below the poverty line at least during one period of the year is between almost 90% and over 90% depending on the scenario (Table 21).

Table 21. Vulnerability to income poverty within one year.

Scenario	Share of MFR substituted by IF	Probability of experiencing at least one period of poverty within one year [%]
	Surplus = 0	
1	without IF	99.24
2	with IF 42% of MFR	95.25
3	with IF 80% of MFR	88.84
	Surplus <> 0	
4	without IF	96.30
5	with IF 42% of MFR	91.79

Source: Own simulation.

6.5 Summary

Poverty is prevalent in Takawira; 25% of the sample households were below the poverty line during the research period and derived an average income of 2700 ZWD per AEQ. The proportion of poor households is between the estimates of the national poverty headcount that are provided by other surveys. Based on deflated gross margin and household expenditure data, household income is simulated over the course of the year. Five different scenarios depending on availability of an income surplus from the previous cropping season and indigenous fruits are assessed.

With respect to the scenario in which no surplus is available from the previous season and indigenous fruits replace 42% of minimum food requirements, the average annual household income is ZWD AEQ^{-1} 10690 (SD 8220), with agricultural activities and livestock keeping the major sources of income. Cropping and income-generating activities follow seasonal fluctuations and therefore the household income also fluctuates in the course of the year. It is lowest between August and January and reaches a peak in April/May. The higher the resource stock that was carried over to the new cropping season, the higher the household income. Additionally, the greater indigenous fruit availability and therefore the amount of minimum food requirements that can be substituted by indigenous fruits the higher the household income is. Sensitivity analysis of the household income during the second half of the critical period, i.e. December to January, shows that the availability of a surplus has the highest influence on the household income, followed by agriculture, off-farm, livestock and remittances. If a surplus is available, then indigenous fruit income from the first half of the critical period is of higher influence than indigenous fruit income from the latter half of the critical period. If no surplus is available, indigenous fruit income from the second half becomes more important. This is due to the fact that sometimes a negative surplus, e.g. an informal loan that has to be repaid, was carried over and indigenous fruits contribute to filling this gap. Although indigenous fruits contribute to the household income, other sources of income show higher influence on the household income. The highest influence stems from production of agricultural crops, which contribute a major share towards rural incomes.

The analysis further shows that vulnerability to poverty is also subject to seasonal fluctuations in Takawira. Vulnerability is highest between August and January. It depends on the surplus that was carried over from the previous year and also on the degree to which indigenous fruits are available for income smoothing. Indigenous fruit income reduces the probability of falling below the poverty line during the critical period by nearly 10-30% depending on the availability of the fruits.

Indigenous fruit income is relatively more important for households that have less income from other sources during the critical period of the years. This means that households with little income via remittances or from off-farm activities or horticultural activities from August to January are more dependent on indigenous fruits than other households. Also, indigenous fruits are available for household consumption at a time when the energy requirements of farm households are high due to labour input to agricultural production.

7 Investment in planting of domesticated indigenous fruit trees

This chapter analyses the investment decision from an ex ante perspective of the farm household. First, management and production parameters that determine costs and benefits of planting are analysed. Then, the risk-adjusted rate of return is derived, and finally, the values of the options to plant IFT are assessed and specifically the value of immediate investment versus the value of waiting to invest is analysed. The decision to plant depends on the degree of improvement via the domestication programme and also on the costs of collecting the fruits from the Communal Areas. The influence of variations in these two factors on the decision to plant is investigated in the latter part of this chapter. Because only fruits of the most popular species, *U. kirkiana,* are frequently traded in the market, but not fruits of the other two target species, investment analysis was carried out for this species only[63].

7.1 Management and production parameters

The investment analysis is based on data collected during the household monitoring visits, which allowed collection of detailed income, expenditure and labour data. These households have between zero and 154 *U. kirkiana* trees of varying age and size with an average of 24 trees. These trees are naturally grown trees that have been preserved in farmers' fields.

Costs of seedling production

It is assumed that farmers buy seedlings. The price is based on average production costs that include labour valued at the local wage rate and material inputs, i.e. tubes. Labour requirements for seedling production are available from the ICRAF Research Station in Makoka, Malawi (Maghembe, 1999) (Table 22). The germination rate for *U.*

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[63] Parts of this chapter were presented at the 14th Annual Meeting of the European Association of Environmental and Resource Economists, Budapest June 25th – 28th, 2004.

kirkiana seeds is at 80% (Chidumayo 1997), which has been accounted for in calculating the costs per seedling.

Table 22 Costs of *Uapaca kirkiana* seedling production.

Type of input	Costs[1)] [ZWD seedling^{-1}]
Seedlings	
Labour	
Collecting fruits[2)]	0.03
Extracting seeds	0.12
Treatment of seeds	0.12
Soil collection & transport	0.13
Filling tubes & seeding[3)]	0.36
Transport	0.04
Watering	8.01
Weeding	0.22
Other labour (e.g. standing pots upright, etc.)	1.90
Material Inputs	
Fruit	0.00
Soil	0.00
Water	0.00
Tubes	0.25
Non-grafted seedling costs	**11.17**
Costs per orchard of 35 seedlings [ZWD orchard^{-1}]	**391.0**
Grafting	
Labour	
Collection of scion material	8.29
Grafting	1.81
Costs of grafting per seedling	**10.10**
Costs per orchard of 7 trees	**70.7**
Seedling plus grafting costs per orchard [ZWD orchard^{-1}]	**461.7**
Seedling plus grafting costs per tree survived[4)]	**92.3**

1) These figures take the germination rate of 80% into account.

2) 3 seeds per fruit

3) Space requirements 1 m^2 100tubes^{-1}

4) Orchard of five trees.

Source: Labour requirements according to (Maghembe, 1999) and own information, valued at the average wage rate of Murehwa, derived from the socio-economic survey.

In order to establish an orchard of five non-domesticated *U. kirkiana* trees, a farmer has to plant 24 seedlings due to poor survival rates of about 20% during the first year after planting (Chidumayo, 1997). For the establishment of an orchard of equal size of domesticated trees, 35 trees have to be planted, because grafting success is at 70% for a skilled grafter (Mhango et al., 2002). Grafting is assumed to take place in situ. It is assumed that once trees have survived the first year and grafting, mortality drops down to 0%. Costs of planting the seedlings and labour for protecting them by a fence are also considered to be included in initial investment cost. These two factors sum up to ZWD 710 for the orchard of initially 35 seedlings out of which only five survive.

Fruit tree management

Farmers perform few management tasks on naturally grown indigenous fruit trees. The trees are pruned at the end of the dry season to allow better access to agricultural crops cultivated underneath. Dead or damaged branches are cut for firewood. The area around the trees is weeded when weeding the field, which is generally done twice during the rainy season. Since most trees grow near or in agricultural fields, they benefit from manure and fertiliser application to the crops, which is carried out once at the beginning of the wet season. Only two of the 19 farmers had applied manure purposely to *U. kirkiana* trees. All farmers report that trees in their fields bear more fruits over a longer period than trees from the commons, which they attribute to the application of manure.

However, exotic fruit trees, like avocado and mango, are managed more intensively. This includes watering, weeding, fertilising, pruning, and mulching. The trees are generally protected from livestock damage by a fence that has to be repaired regularly. Also, dead or damaged branches are regularly removed, and micro-catchments[64] are built and maintained around the trees.

Data on orchards of planted indigenous fruit trees are not available. It is assumed that an orchard as specified above requires management similar to that of exotic fruit trees. Table 23 presents the management of exotic fruit trees as conducted by households of Murehwa and Takawira. For example, watering ensures survival and growth, especially for younger seedlings. Weeding and fertilising improve the nutritional condition of the tree, whereas pruning promotes growth and eases harvesting. Mulching maintains moisture around the tree. Fencing is necessary to protect seedlings from livestock damage when they are small. Pesticide spraying, however, is

[64] Micro-catchments are small trenches that preserve moisture and water around the tree.

not necessary as indigenous fruit trees are locally adapted and less susceptible to pests and diseases.

Table 23. Labour inputs for management of exotic fruit trees in Murehwa and Takawira and specification for IFT orchards.

Exotic fruit tree orchards				Specification for IFT orchards
Task	Labour[1)] [hour tree^{-1}]	Frequency[2)] [# year^{-1}]	Season[3)]	
Watering	0.8	1-18	DS	trees < 4 years: once a week, DS trees > 4 years once per year
Weeding	0.6	2	WS	as exotic fruit trees
Fertilising	0.6	1	before WS	as exotic fruit trees
Pruning	0.7	1	DS	as exotic fruit trees
Cut dead & damaged branches	0.4	52	DS	included in miscellaneous
Mulching	0.4	1	DS	as exotic fruit trees
Building of fences	1.1	1	DS	once after planting
Maintenance of fences				included in miscellaneous
Micro-catchments	0.4	1	WS	as exotic fruit trees

1) Mean over all households; both locations.
2) Mode over all households; both locations.
3) DS: dry season, WS: wet season.
Source: Household monitoring.

The last column of Table 23 describes the management measures for planted indigenous fruit trees as assumed in the investment analysis. Most of the management tasks are carried out during the dry season; weeding takes place during the wet season and dead branches are removed throughout the year. Fruits ripen during the wet season. It is assumed that an orchard of indigenous fruit trees is planted closer to the homestead. Harvesting labour estimates are based on data for harvesting time of indigenous fruits from trees that farmers preserved in their fields and around the homestead.

The age-yield function

Yield is variable among years and individual trees; farmers thus estimated minimum, maximum and modal yields of trees in their own fields. The yield first increases and then starts to decline after 35 to 45 years of production (Mwamba, 2000). From farmers' yield estimates and expert information, age-yield functions for the minimum, the maximum and the modal yield were approximated using the Hoerl function (Haworth & Vincent, 1977):

$$u = \upsilon g^{\zeta} e^{\kappa g} . \tag{21}$$

Yield, u, solely depends on age, g (here: productive period); the coefficients υ, ζ, κ are estimated via linear regression after transforming equation (21) into $\ln u = \ln \upsilon + \zeta \ln g + \kappa g$. Usually, an age-yield function is established, but due to the limited recall abilities of the farmers and the fact that they tend to notice the time when a tree starts bearing fruits rather than the time it germinates, data on the tree's productive period are found to be more reliable than information on the age of the tree. Thus, the age-yield function in this study refers instead to the production period yield function.

Functions are based on inventories of 38 naturally grown *Uapaca kirkiana* trees that farmers preserved in their fields and owners' information on the observed minimum, modal and maximum yield levels. For some trees, farmers were not able to estimate all yield levels, e.g. for young trees few observations on the maximum possible yield for a tree of this age were available. Three additional points were used to adjust the functions to shift downwards from a productive age of about 15 years onwards, since yields eventually decline with age (Mwamba 2000). The oldest tree for which farmer estimates were available had been producing fruits for about 30 years.

The age-yield functions thus derived are used for the investment analysis. The origin of the function is the age at which maturity sets in, i.e. the year of the first fruit production. At this point, non-improved trees are between 11 and 16 years old (farmer estimates, household monitoring). Yield functions for minimum, modal and maximum yield are given in Table 24.

Table 24. Regression results of the parameters of the age-yield function.

Yield	Parameter[1)]			Criteria of estimator[2)]	
	$ln\ \upsilon$	ζ	κ		
Maximum	2.9640***	1.1270***	-0.0861***	R^2=0.751	F=48***
SE	(0.311)	(0.177)	(0.009)	SE=0.73	Df=29
Mode	2.2390***	1.1550***	-0.0806***	R^2=684	F=42***
SE	(0.231)	(0.150)	(0.009)	SE=0.74	Df=36
Minimum	1.4840***	1.1720***	-0.0735***	R^2=0.661	F=31***
SE	(0.320)	(0.009)	(0.182)	SE=0.75	Df=29

1) First row: parameter values *: significance level p≤0.1, **: p≤0.05, ***: p≤0.01; second row: standard error.

2) R^2 = adjusted R^2, SE = standard error, F = F-value, Df = degrees of freedom.

Source: Own calculation (tree inventories & farmer estimates, household monitoring, expert interviews).

Fruit yield for each age is defined as a triangular distribution, with the minimum and maximum as lower and upper boundary, from which data are drawn stochastically because yield is variable between years and individual trees (Chidumayo, 1997). Fruit yield in a given year is assumed to be independent of the yield of previous years. One draw in the simulation for the realisation of the yield serves as yield estimate for all trees within the orchard. Fruit prices are considered to follow a uniform distribution between ZWD kg^{-1} 0.4 and ZWD kg^{-1} 18, which are the minimum and maximum farm gate price households received in 1999/2000.

The optimal life span of the orchard, *T*, taking into account the multiple products the trees provide, is where returns to labour are maximised. Factors determining *T* are the fruit-, leaf- and wood-production functions of the trees as well as the prices for these products. Leaf and wood production functions are found in Chidumayo (1997), fruit production (as described before) as well as price estimates for the various products are based on own surveys (Table 25). Prices of the various products are either market prices of the products or market prices of substitutes.

Table 25. Factors determining the net present value of investment in indigenous fruit trees.

Factor	Description	Source
	Vector of benefits of planting, b_t	
leaves, quantity	growth function	Chidumayo, 1997
leaves, price	constant	Survey 99/00
wood, quantity	growth function	Chidumayo, 1997
wood, price	constant	Survey 99/00
fruit, quantity	triangular distribution based on Hoerl function	HH monitoring, Expert
fruit, price	uniform distribution	interviews 99/00
maturity	non-domesticated: discrete uniform 11≤m≤16	Experts
	Vector of costs of planting, c_t	
labour, quantity	management: acc. to management of EFT harvest: depending on yield	Household monitoring
wage rate	constant	Socio-economic survey

7.2 The risk-adjusted rate of return

The risk-adjusted interest rate is determined via returns on the small-scale farm household's market portfolio using the Capital Asset Pricing Model. The risk-free interest rate is specified through the interest rate on membership in a savings club, which is zero[65]. The market portfolio is defined as the portfolio of all agricultural, horticultural, livestock-keeping and off-farm activities small-scale farmers pursue (see chapter 5). Each of the enterprises is considered to be one title within the market portfolio. Variability in the rates of return on the portfolio enterprises over the cross section is assumed to project variability of the market portfolio. The expected rate of return on the market portfolio, $E[r_m]$, is the sum over the weighted expected rates of return on each enterprise in the portfolio (equation 22):

$$E[r_m] = \sum_{a=1}^{A} \omega_a E[r_a]. \qquad (22)$$

65 In the literature, government bonds are often used as an example of riskless assets. However, Zimbabwean small-scale farmers do not have access to government bonds, while most are members of savings clubs.

The rate of return of activity *a*, $r_a = \frac{O_a}{C_a + LC_a + D_a} - 1$, depends on its gross income, *O*, variable cost, *C*, opportunity cost of land, *D*, and labour cost, *LC*. Contrary to gross margin calculations, here labour costs additionally include family labour, which is valued at the average wage rate.

$E[r_a]$ is the expected rate of return on activity *a* (1 = off-farm activities, 2 = horticultural activities, 3 = agricultural activities and 4 = livestock keeping), which is the average over the sample of households. The weight of activity *a* in the portfolio, ω_a, is defined as the average weight of the activity in each farmer's portfolio, $\frac{1}{N}\sum_{n=1}^{N}\frac{C_{an} + LC_{an} + D_{an}}{\sum_{a=1}^{A} C_{an} + LC_{an} + D_{an}}$. *N* is the number of farmers in the sample.

Identical to the gross margins, inputs and outputs of the portfolio are valued at the average price over the period August 1999 – August 2000. Due to the high rate of inflation, rates of return for farm activities are adjusted by using 50% of the GDP deflator (59.9%) provided by the World Bank (2003)[66]. As for the gross margin calculations, the costs of capital input are valued at the risk-free interest rate and the opportunity costs of land are assumed to be zero.

The variance of the market portfolio can be described through a linear combination of the variances and covariances of the rates of return of its titles r_a and r_k (equation (23)) (Kruschwitz, 1999), and transforms into equation (23') for the four titles under consideration.

$$Var[r_m] = \sum_{a=1}^{A}\sum_{k=1}^{A}\omega_a\omega_k Cov[r_a, r_k], \qquad (23)$$

66 The GDP deflator, divided by 2, was used to adjust for the use of average prices over the year in valuing inputs and outputs.

$$Var[r_m] = \omega_1^{\,2} Var[r_1] + 2\omega_1\omega_2 Cov[r_1, r_2] + 2\omega_1\omega_3 Cov[r_1, r_3] + 2\omega_1\omega_4 Cov[r_1, r_4]$$
$$+ \omega_2^{\,2} Var[r_2] + 2\omega_2\omega_3 Cov[r_2, r_3] + 2\omega_2\omega_4 Cov[r_2, r_4]$$
$$+ \omega_3^{\,2} Var[r_3] + 2\omega_3\omega_4 Cov[r_3, r_4] + \omega_4^{\,2} Var[r_4]. \qquad (23')$$

The covariance between the market rate of return and the rate of return of planting domesticated trees is estimated via the covariance between the rates of return of the tree use enterprise, r_{trees}, i.e. collection of indigenous fruits and production of exotic fruits, and the rates of return on the market portfolio, r_m. r_{trees} is computed analogously to the rate of return on the other titles of the portfolio (equation 22).

Comparison between the rates of return on titles in the market portfolio (Table 26) and rates of return on tree enterprises (Table 28) shows that the latter yield relatively high rates of return, as can be expected from figures on labour productivity.

Table 26. Rates of return on the enterprises of the market portfolio for households of Murehwa [% * 100].

HH No.	Off-farm	Horticulture	Agriculture	Livestock	Market portfolio, r_m
1	-0.20	-0.09	0.52	0.11	0.21
2	0.01	2.14	1.57	0.82	1.23
3	2.14	0.95	-0.32	-0.27	0.05
4	0.49	0.82	-0.67	0.31	0.08
5	0.40	-0.87	0.44	0.20	-0.03
6	0.63	-0.10	1.04	-0.19	0.62
7	-0.13	-0.77	1.15	-0.38	-0.01
8	0.19	-1.00	-0.18	-0.15	-0.11
9	0.82	-0.44	0.59	0.15	0.17
10	-0.04	1.56	1.96	0.02	0.64
11	1.33	-0.18	-0.40	0.07	0.17
12	-0.28	1.53	-0.18	-0.12	0.10
13	1.74	-0.48	-0.62	-0.31	0.15
14	-0.23	1.06	0.40	-0.41	-0.11
15	-0.33	-0.08	0.38	-0.33	-0.15
16	-0.45	-0.80	-0.51	-0.14	-0.52
17	-0.22	-0.18	-0.77	-1.00	-0.46
18	0.24	-0.24	-0.01	0.68	0.23
19	-0.85	-0.60	-0.56	-0.11	-0.32

Source: Own calculation (Household monitoring).

The expected rate of return on the market portfolio for Murehwa is 10.24%. The variance of the market portfolio is relatively low. The details of the variance-covariance matrix of the four titles of the market portfolio are shown in Table 27. The titles are neither perfectly positively nor negatively correlated with each other. Results show that horticultural and off-farm activities do not move together, whereas horticulture and agriculture show a slightly inverse relationship. All other covariances among the titles of the market portfolio are slightly positive. Agricultural and livestock enterprises have on average the highest weight in the portfolio. The resulting market price of risk is about 0.6125 when using the risk-free rate of return of 0%.

Table 27. Variance-covariance matrix of the market portfolio, Murehwa.

	Titles of the market portfolio, Murehwa				
	Off-farm	Horticulture	Agriculture	Livestock	Weights, ω
Off-farm	0.60	-	-	-	0.16
Horticulture	0.00	0.87	-	-	0.16
Agriculture	-0.11	0.26	0.63	-	0.29
Livestock	0.02	0.10	0.10	0.16	0.38
$Var[r_m]$					0.1671

Source: Own calculation (Household monitoring).

Table 28 shows the rates of return on tree enterprises. The rates vary strongly between households. A rate of return of -100% indicates that these households have exotic fruit trees that are very young and thus require some management, but do not produce much output. On the other hand, a very high rate of return for EFT reflects a household that owns mature orchards that are at high production levels and require few (management) inputs.

Table 28. Rates of return on tree enterprises for households of Murehwa [% * 100].

HH	EFT	*P. curatellifolia* & *Strychnos* sp.	*U. kirkiana*	All trees, r_V
1	5.47	5.89	1.69	4.66
2	2.53	8.13	1.65	2.21
3	8.43	16.96	0.14	4.89
4	0.72	1.81	3.30	0.85
5	0.88	0.19	0.97	0.85
6	-1.00	3.38	0.35	-0.04
7	-1.00	11.66	1.18	0.13
8	7.77	-0.35	0.52	4.77
9	4.77	9.81	0.29	2.61
10	8.75	18.78	13.60	11.11
11	1.08	2.80	2.62	1.64
12	0.59	15.15	0.82	0.71
13	0.04	0.63	0.12	0.21
14	6.18	11.92	1.22	5.40
15	3.85	2.37	2.56	3.34
16	-0.55	2.35	2.29	-0.03
17	1.83	1.52	1.25	1.66
18	2.75	-0.06	-0.84	0.94
19	-0.84	2.26	2.84	0.61

EFT = exotic fruit trees

Source: Own calculation (Household monitoring).

The risk-adjusted rate of return is at 15.64% for a risk-free rate of return of 0% (Table 29). The systematic risk of the tree enterprises can be expressed by the so-called beta factor, $\frac{Cov[r_m r_V]}{Var[r_m]}$, which is 1.53. The market portfolio has a beta factor of one. Thus, in comparison, the tree enterprises amplify the overall movements of the market portfolio. A title with a beta factor below one moves in the same direction, but not as far as the market portfolio (Brealey & Myers, 2000). The risk-adjusted rate of return is higher than the rate of return of the market portfolio, which shows a positive risk premium for using trees due to the characteristics of the factors that determine the beta factor of the tree enterprises.

Table 29. Risk-free interest rate, market price of risk and risk-adjusted rate of return, Murehwa.

Risk-free interest rate r	Market price of risk λ	Risk-adjusted rate of return μ
0.00%	0.6125	15.64%
3.00%	0.4330	14.06%
5.00%	0.3133	13.00%

Source: Own calculation (Household monitoring).

When the risk-free rate of return increases, the market risk premium, $E[r_m]-r$, decreases and consequently the market price of risk also decreases. In the present case, this results in an overall decrease of the risk-adjusted rate of return given the covariance of returns on trees and returns on the market portfolio (0.2554). IFT planting can be interpreted as income diversification and thus as risk-management strategy. However, the positive correlation between the tree enterprise and the portfolio shows that both move parallel, so that in this case diversification does not contribute greatly to risk reduction.

7.3 Collection of indigenous fruits and investment in planting of non-domesticated IFT

Revenue from collecting indigenous fruits tree products from naturally grown trees in the Communal Areas net of collection cost can be interpreted as an annuity. It ranges from ZWD 262 – ZWD 6528, with a mean of ZWD 1285 (household monitoring). If the annuity of collection is simulated based on stochastic prices following a uniform distribution with the minimum and maximum farm gate price as lower and upper bound, respectively, it is, on average, equal to ZWD 3187. The annuity of planting non-domesticated fruit trees, which mature between 11 and 16 years of age (farmer estimates; own survey)[67], is, on average, ZWD -158. Table 30 compares the returns to labour from planting wild fruit trees to the returns from the collecting their products from the Communal Areas.

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[67] Mwamba (1996) reports results from *U. kirkiana* trials according to which the trees bear fruits after eight years.

Table 30. Returns to labour from collecting indigenous fruits from naturally grown trees in the Communal Areas in comparison to returns to labour from planting non-domesticated IFT.

Access to fruits via …	Farm gate price of fruits	Returns to labour [ZWD day^{-1}]
Collecting IFT products from Communal Areas[1)]	Household monitoring	222 (228)
Collecting IFT products from Communal Areas	Uniform (0.4;18) [2)]	506 (255)
Planting non-domesticated IFT[3)]	Uniform (0.4;18) [2)]	52 (34)

1) Data over 19 households from Murehwa (household monitoring). Figures give the average over all households. Figures in parentheses give the standard deviation.

2) Distribution, defined by the minimum and maximum farm gate price of the household monitoring.

3) IFT mature between 11-16 years: For an orchard of five trees. Figures give present value of planting non-domesticated trees, $V_{nonDT\infty}$ that is determined analogously to $V_{DT\infty}$.

As returns to labour from planting non-domesticated species are below the average wage rate and the annuity is thus negative, the value of the option to plant non-domesticated IFT equals zero. Therefore, the question emerges of how much collection costs have to rise or, alternatively, how much trees need to be improved so that planting of trees is economically attractive.

Estimation of decision criteria

The costs and benefits of IFT products from planted trees are difficult to compare with the collection of IFT products from the Communal Areas. To facilitate comparison, V is established on the basis of returns to labour (see equation (24)). The first term refers to the value per labour-day, L_{DT}, of domesticated trees, V_{DT}, and the second term to the value per labour-day of collecting fruits, L_C, from the wild, V_C. LC_{DT} and LC_C give labour cost for planting improved trees and collection from the wild, respectively.

$$V = \frac{\left[\dfrac{(NPV_{DT} + \int_{t=0}^{T}(LC_{DT,t})e^{-\mu t}dt + I)}{\int_{t=0}^{T}(L_{DT,t})e^{-\mu t}dt}\right] - \left[\dfrac{NPV_C + \int_{t=0}^{T}(LC_{C,t})e^{-\mu t}dt}{\int_{t=0}^{T}(L_{C,t})e^{-\mu t}dt}\right]}{1 - e^{-\mu T}}. \qquad (24)$$

Improvement of the domesticated trees can occur with respect to selection (breeding) of superior species, e.g. taste and fruit size can be improved, and through establishing appropriate vegetative propagation methods. The latter is a pre-requisite for shortening the period to maturity, which for the unimproved species with a period of 11 to 16 years is rather long.

For the calculation of V and V^*, information about the net present value of planting IFT is required, as are the drift and variance rates, α and σ, of the geometric Brownian motion. The drift and variance rates are estimated using a Monte Carlo simulation model in the @risk and Excel environment (Palisade, 2000). Similar to Winter-Nelson & Amegbeto (1998) and Purvis et al. (1995), V is not constant, but rather, follows a geometric Brownian motion. The discrete change of V between V_{DT} and V_C can be defined as the difference of the natural logarithms between V_{DT} and V_C[68]. Through simulation, values for V_{DT} and V_C are generated and the difference between V_{DT} and V_C is calculated by $\Delta(\ln V_j) = \ln(V_{DT}) - \ln(V_C)$. The subscript j denotes the sample size over which the difference is calculated, which is done over 50,000 iterations. The growth rate, α, of dV is the arithmetic mean over all $\Delta(\ln V_j)$ and the variance rate, σ, is the standard deviation over all $\Delta(\ln V_j)$. V is modelled as mean over $V = (NPV_{DT\infty} + I) - (NPV_{C\infty})$.

Investment scenarios

The expected economic gain from planting domesticated indigenous fruit trees depends on the level of tree improvements and the relative level of opportunity costs, i.e. the collection of fruits from the Communal Areas. The initial investment analysis is based on the risk-free rate of return of 0%. Additionally, the effect of an increasing risk-free rate of return on the investment decision is assessed. Overall, the following scenarios are assessed, Table 31:

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68 If V follows the geometric Brownian motion, then the change in $\ln V$ between t and t+1 is normally distributed. Thus, the expected value of V_{t+1} is $E(V_{t+1}) = V_t e^{\alpha(t+1)}$ (Hull, 2003), from which equation $\Delta(\ln V_j) = \ln(V_{DT}) - \ln(V_C)$ can be derived (t+1 refers to domesticated trees, DT, and t refers to collection of the fruits, C).

Table 31. Scenarios assessed in the investment analysis.

Scenario	Maturity	Yield level	Fruit quality	Collection costs	Risk-free rate of return
1	↓	–	–	↑	0%
2	↓	↑	–	–	0%
3	2 years	–	↑	↑	0%
4	2 years	↑	↑	–	0%
5	2 years	–	–	↑	↑
6	2 years	↑	–	–	↑

1) ↓ = decrease, ↑ = increase, – = no change in comparison to the household monitoring.

A shift in maturity is modelled by shifting the first fruit yield to a younger age. Yield improvements are modelled by moving the level of the modal yield upwards compared to the yield level of non-domesticated trees. A higher fruit quality of domesticated fruits is reflected by a higher fruit price that exceeds the price of non-domesticated fruits randomly by one to three times. Finally, the increase in collection costs is modelled as an increase in the number of labour days needed to collect the same amount of indigenous fruits from the Communal Areas in comparison to the household monitoring.

7.4 Domestication, fruit collection costs and investment in IFT planting

The values of the option to invest were assessed at the optimal life span of the orchard *T*, at which returns to labour are maximised. Results show that the optimal rotation period does not change for changing yield levels. It is, however, influenced by the age at which maturity sets in, the risk-free rate of return and the fruit price (Table 32).

Table 32. Optimal rotation period for non-domesticated and domesticated IFT [years].

	Fruit price	Uniform (0.4;18)			Uniform (0.4;18) * Uniform (1;3)
	Risk-free rate of return	*r* = 0%	*r* = 3%	*r* = 5%	*r* = 0%
Maturity [years]	2	48	47	46	47
	4	56	-	-	-
	6	62	-	-	-
	8	70	-	-	-
	10	76	-	-	-
	11-16[1)]	84			

-: Not assessed.

1) non-domesticated IFT.

Source: Own calculation.

Simulation results show that a shift in maturity to two years from currently 11-16 years of age is not sufficient to trigger investment.

Additionally, the costs of collecting fruits from the Communal Areas have to rise, while the yield function remains the same as for non-domesticated IFT (scenario 1) (Table 33 and Table 34). Alternatively, the yield function must shift upwards at the current level of collection costs (scenario 2) (Table 35 and Table 36).

Table 33. Growth rate, variance and hurdle rate of the option to invest for scenario 1 and maturity at two years.

	Collection costs [times the current level]							
Parameter	Current	2.0	2.5	2.7	2.8	2.9	3.0	3.1
Growth rate	-0.946	-0.253	-0.029	0.047	0.084	0.120	0.154	0.186
Variance	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Hurdle rate	1.01	1.03	1.06	1.11	1.16	1.31	5.27	∞

Source: Own calculation.

As the growth rate approaches the risk-adjusted discount rate, the hurdle rate increases. In this case, the convenience yield, i.e. the opportunity cost of waiting to invest, grows smaller and waiting turns out to be of higher value (see also Dixit & Pindyck, 1994). Both the trigger value and the present value of investment increase when collection costs rise (Table 34). The present value also grows because the incremental benefit from planting grows when the alternative becomes more costly.

Table 34. Trigger and present values of the option to invest for scenario 1 and maturity at two years [ZWD day^{-1}].

	Collection costs [times the current level]							
Decision criteria	Current	2.0	2.5	2.7	2.8	2.9	3.0	3.1
Trigger value	23.1	23.5	24.3	25.3	26.5	30.0	120.8	∞
Present value	-299.2	-46.0	4.8	19.9	**26.6**	**33.0**	38.6	43.9

Source: Own calculation.

Figures in Table 34 show that investment in planting improved indigenous fruit trees according to the conventional NPV approach requires the present value of investment to exceed initial investment cost, i.e. ZWD 23 per labour day. This would be the case for an increase in collection cost of 2.7 to 2.8 times the current level. The decision to invest according to the real option criterion, i.e. present value exceeds trigger value, shows that immediate adoption commences when collection costs increase by 2.8 to 2.9 times.

Figure 19 shows the value of immediate investment and the value of waiting to invest for a 2.9-fold versus a 3-fold increase in collection costs. For a collection cost increase to three times the current level, waiting becomes the profit-maximising strategy. In this area, the growth rate of the present value of investment comes closer to the risk-adjusted rate of return. Thus the value of waiting shifts upwards. Once the growth rate exceeds the risk-adjusted discount rate, farmers wait to invest indefinitely. The trigger value grows relatively faster than the present value if collection costs increase from 2.9 to 3 times the current level. (levels of collection costs are denoted by the indices in Figure 19).

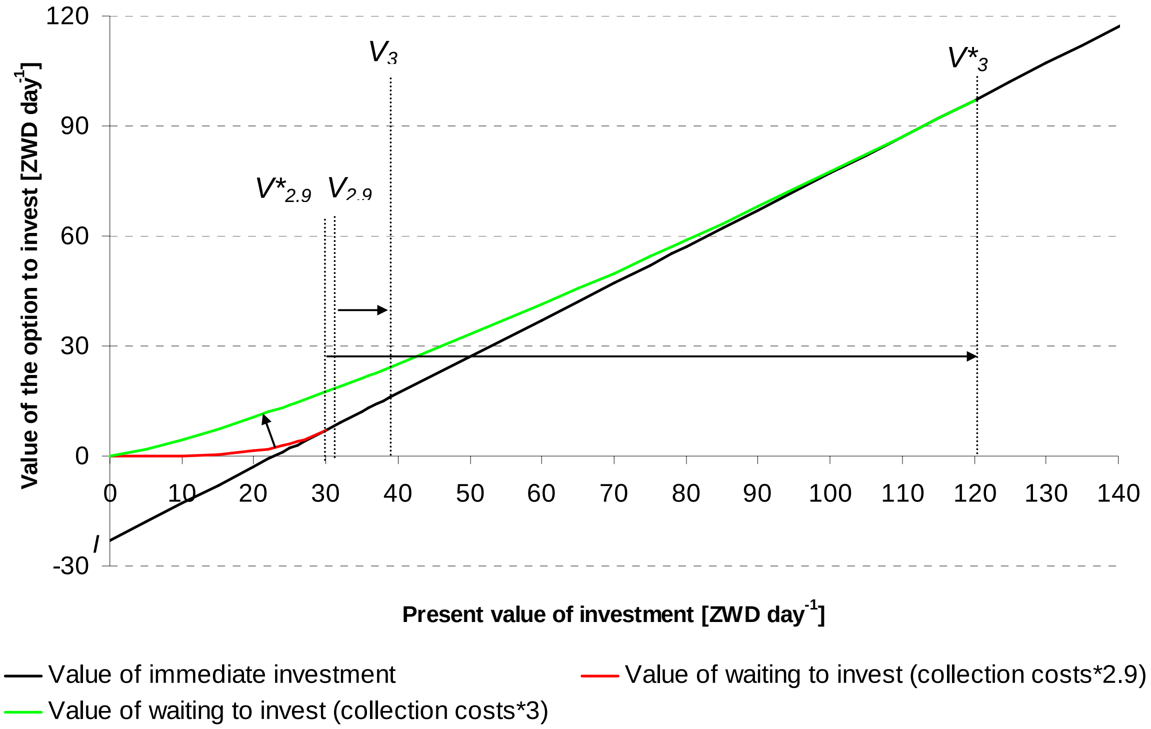

Figure 19. Value of immediate investment and waiting for scenario 1 and maturity at two years.

The indices of the present and trigger values refer to the increase of collection cost.
Source: Own calculation.

Scenario 2 shows the yield increase in addition to a shift in maturity to two years of age (Table 35 and Table 36). For this scenario, the modal yield was shifted. Minimum and maximum yield were also shifted, but the difference between the latter two levels and the modal yield level was kept constant, resulting in a constant variance. If the range between minimum and maximum yield increased, the variance would also increase and thus so would the hurdle rate. Such an increased variance would lead to a higher value of the option to invest, since possible future benefits increase but the possible loss remains the same (McDonald & Siegel, 1986).

The hurdle rate grows with increasing improvements of the domesticated trees (Table 35).

Table 35. Growth rate, variance and hurdle rate of the option to invest for scenario 2 and maturity at two years.

	Yield increase [times the non-domesticated level]				
Parameter	8 times	9 times	10 times	12 times	16 times
Growth rate	-0.032	-0.007	0.015	0.050	0.092
Variance	0.016	0.017	0.016	0.016	0.016
Hurdle rate	1.04	1.05	1.06	1.07	1.12

Source: Own calculation.

With increasing yield level, labour input into harvesting of the fruits also increases, so that initial investment cost per labour day decreases (Table 36). This effect exceeds the effect of the increasing hurdle rate and results in a declining trigger value. As the present value of investment increases, investment is triggered at a ninefold yield increase. At this level of improvement, the present value exceeds the trigger value.

Table 36. Initial investment costs, trigger and present values for scenario 2 and maturity at two years [ZWD day^{-1}].

	Yield increase [times the non-domesticated level]				
Decision criteria	8 times	9 times	10 times	12 times	16 times
Initial investment costs	8.3	7.6	7.1	6.2	5.1
Trigger value	8.6	8.0	7.5	6.7	5.7
Present value	6.6	**20.0**	**31.2**	**49.9**	**74.2**

Source: Own calculation.

Implications of a ninefold yield increase for the shape of the age-yield function are shown in Figure 20. Such an increase implies that instead of producing between 35 and 113 kg of fruits per tree (modal yield 64 kg per tree) at the level of maximum production, improved trees bear between 547 and 624 kg per tree (modal yield 576 kg per tree). Of course, with respect to the implications of these results, it has to be discussed amongst breeders whether this is a feasible improvement for physiological reasons, e.g. is the tree structure strong enough to bear the additional load?

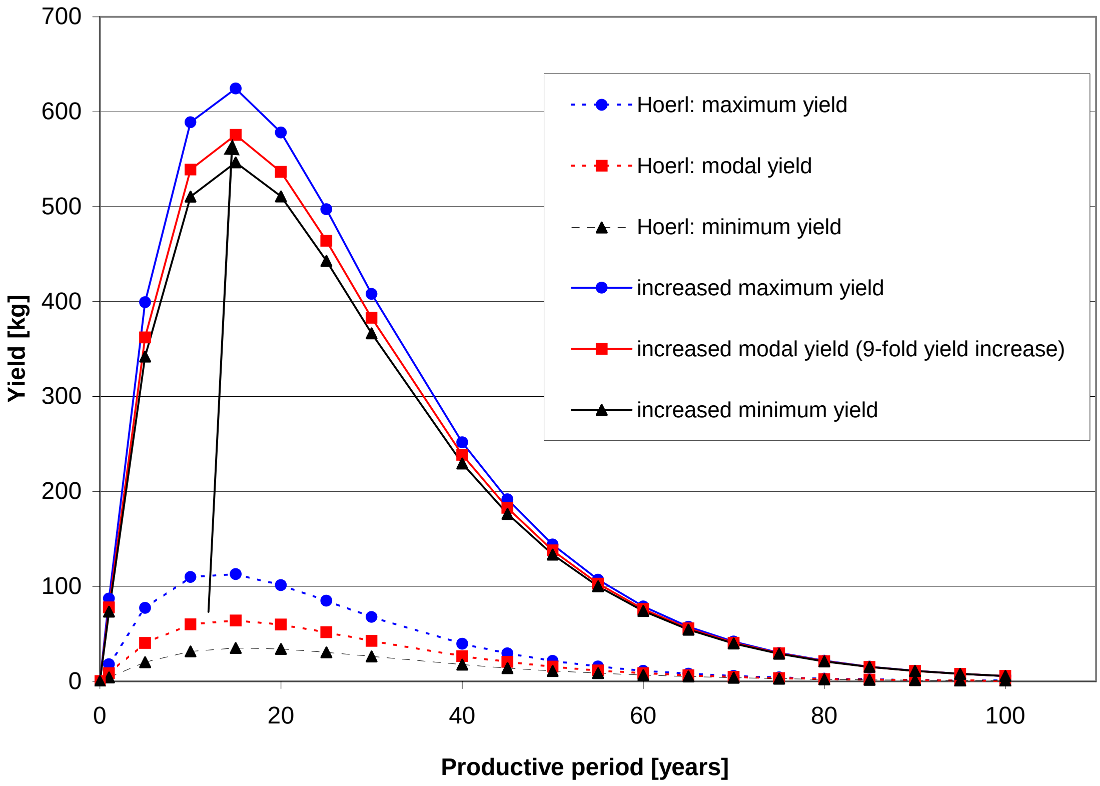

Figure 20. Age-yield function of non-domesticated and domesticated *U. kirkiana* trees with increased level of fruit production.

Source: Tree inventories and farmer estimates, household monitoring, expert interviews.

Since from the state of biological research at the time of this study it is not clear whether a shift in maturity to an age of two years is technically feasible, the effects of older age at maturity combined with yield increases or rising collection costs on the trigger and present values are evaluated.

Table 37 shows the changes necessary to immediately initiate investment for those maturity ages. For example, inducing maturity at an age of four years requires, in addition, a yield increase of greater than 10, but lower than 40 times the non-domesticated level. From then on, waiting to invest commences. Thus, the older the age at maturity, the more yields needs to rise in order to initiate adoption of the new technology.

Table 37. Immediate investment in planting domesticated IFT for Scenario 1 and 2[1)].

Scenario		Maturity [years]				
		2	4	6	8	10
1	Collection costs increases [times the current level]	2.7-3.0	-	-	-	-
2	Yield increase [times the non-domesticated level]	9-30	10-40	12-56	16-80	24-104

1) Lower bound: immediate investment; upper bound: waiting to invest.

Source: Own calculation.

Increased collection costs and older age at maturity of improved IFT result in non-adoption of IFT planting. In this case the trigger value rises relatively stronger than the present value of investment (Figure 21).

Figure 21 illustrates the effect of older age at maturity and higher collection costs on the present and trigger values. Results show that the gap between the trigger value and the present value grows larger the older the trees are at maturity. This means that without increasing the level of yield in addition to inducing precocity, the minimum improvement to initiate investment is at maturity of two years. Rising costs of IF collection from the Communal Areas will not change this result. This means that in areas with lower IFT abundance, this is the minimum level of improvement necessary to trigger investment, *ceteris paribus*.

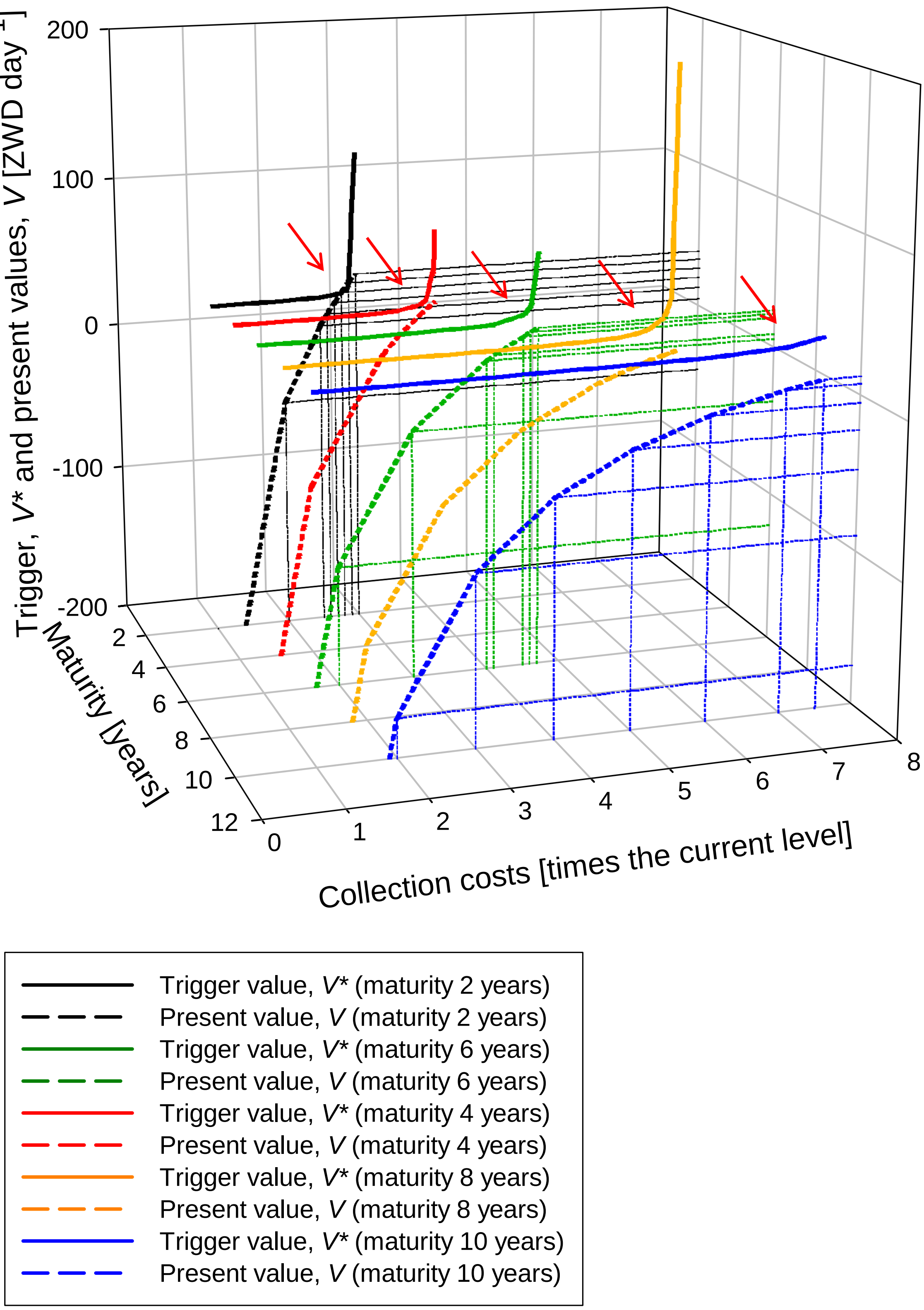

Figure 21. Trigger and present values for Scenario 1.

The arrows in the figure point to the gaps between the trigger and present value curves.
Source: Own calculation.

Improvements of fruit quality

Fruit quality could be improved for better taste and larger size by selection of appropriate genotypes from the Miombo woodlands and further breeding efforts. Trees with the desired properties could thus be multiplied by vegetative propagation techniques. It is assumed that such an improvement would result in stochastically one to three times higher fruit prices. This is addressed in scenario 3 and 4 in combination with increased collection costs and increased yield, respectively. The assumption that fruits of higher quality fetch higher fruit prices can be justified based on the results of Ramadhani (2002), which show that consumers have a high willingness to pay for indigenous fruits. Her study shows that 25% of consumers would buy even non-improved *U. kirikiana* fruits at double the market price. Her results further show that consumers prefer larger fruits. The one- to threefold price increase associated with improved fruit quality serves as an example of the influence of price on the decision to invest. Further market studies need to establish in more detail the willingness to pay for certain types of fruit quality increases.

Results for this scenario show that investment takes place at lower increases of collection costs (scenario 3). Adoption would commence for collection costs increases by 1.3 to less than 2 times the current level (Table 38). Also, immediate investment turns uneconomical at lower levels of collection costs as compared to the previous scenarios and waiting to invest commences.

Table 38. Trigger and present values of the option to invest for scenario 3 [ZWD day^{-1}].

	Collection costs [times the current level]				
Decision criteria	Current level	1.1	1.3	1.5	2
Trigger value	26.0	26.9	30.6	51.2	∞
Present value	-86.8	-40.4	**31.0**	**83.2**	166.9

Source: Own calculation.

Similar effects can be observed when simulating the effect of an improvement of the fruit quality in combination with yield increases (scenario 4). As expected, much lower levels of a yield increase are required to initiate immediate investment as compared to the case without fruit quality improvements (Table 39). Results for this scenario also show that the variance underlying the stochastic process the present value is assumed to follow increases. This leads to a growing hurdle rate and trigger value as well as to a higher value of waiting to invest. This is consistent with the findings of McDonald & Siegel (1986, p. 714), who demonstrate that "an increase in variance increases the spread of possible future values for *V/I*, and hence the maximum possible gain, while leaving unchanged the maximum possible loss". Winter-Nelson & Amegbeto (1998) also show that an increased variance of returns on investment in soil conservation on Kenya leads to an enhanced value of waiting. Overall, investment still commences at a lower level of yield increases as the present value of investment rises relatively stronger than the trigger value when fruit quality is improved.

Table 39. Initial investment costs, trigger and present values for scenario 4 [ZWD day^{-1}].

	Yield increase [times the non-domesticated level]			
	Current level	1.5 times	2 times	6 times
Initial investment costs	22.5	19.7	17.6	9.5
Trigger value	26.0	26.1	37.1	∞
Present value	-86.9	**27.9**	**119.0**	453.1

Source: Own calculation.

Further implications of increased fruit prices exist. One might expect the risk-adjusted discount rate to adjust due to the influence of the fruit price on the covariance between the market portfolio and the tree enterprises, $\mathrm{Cov}(r_m,r_V)$. Since the rate of return on the tree enterprises is the weighted average return on both exotic and indigenous fruit trees, one can still claim that spanning holds due to the domesticated, in this case exotic, fruit trees in the replicating portfolio.

Influence of the risk-free rate of return

The influence of the risk-free rate of return on the investment decision has two effects. First, an increasing risk-free rate of return results in a decreasing risk-adjusted rate of return. Second, the latter influences the optimal rotation period. Overall, the higher the risk-free interest rate, the lower the trigger value and the higher the present value. At first glance, this is surprising, since the hurdle rate grows with increasing *r*.

However, this result can be explained by the decline in the optimal rotation period that also reduces labour input and thus initial investment costs.

With respect to IFT that mature at 2 years of age and for which yield remains at the non-domesticated level (scenario 5), even rising collection costs will not trigger investment. This is due to the trigger value that increases relatively faster than the present value of investment (Table 40).

Table 40. Trigger and present values of the option to invest for scenario 5 [ZWD day^{-1}].

		Relative increase of collection costs [times the current level]				
	Decision criteria	Current level	2.0	2.6	2.7	2.8
r = 3%	Hurdle rate	1.01	1.04	1.23	1.71	∞
	Trigger value	20.8	21.3	25.3	35.3	∞
	Present value	-288.3	-33.7	25.0	32.5	39.2
r = 5%	Hurdle rate	1.01	1.05	2.55	∞	∞
	Trigger value	19.4	20.1	48.9	∞	∞
	Present value	-279.2	-25.9	32.8	40.2	46.7

Source: Own calculation.

At a higher risk-adjusted rate of return yield has to increase more than six times the current level for trees that start producing fruits at two years to initiate immediate investment (Scenario 6; Table 41; Figure 22).

Table 41. Initial investment costs, trigger and present values for scenario 6 [ZWD day^{-1}].

		Yield increase [times the non-domesticated level]						
	Decision criteria	Current level	6	8	12	16	20	24
r = 3%	Hurdle rate	1.01	1.04	1.06	1.15	1.47	3.37	∞
	Initial investment costs	20.6	8.8	7.2	5.4	4.4	3.7	3.3
	Trigger value	20.8	9.1	7.7	6.2	6.4	12.5	∞
	Present value[3)]	-288.3	-18.5	**16.6**	**57.4**	**81.1**	**95.6**	105.8
r = 5%	Hurdle rate	1.01	1.05	1.10	1.36	2.93	∞	∞
	Initial investment costs	19.2	8.0	6.5	4.9	4.0	3.4	3.0
	Trigger value	19.4	8.4	7.2	6.7	11.8	∞	∞
	Present value[3)]	-279.2	-11.7	**22.7**	**62.1**	**84.1**	99.2	108.7

Source: Own calculation.

In conclusion, at higher risk-adjusted discount rates, lower yield improvements trigger investment, although the influence of an increased risk-free rate of return is rather small (Figure 22). The necessary level of yield increase is still between six- and eightfold.

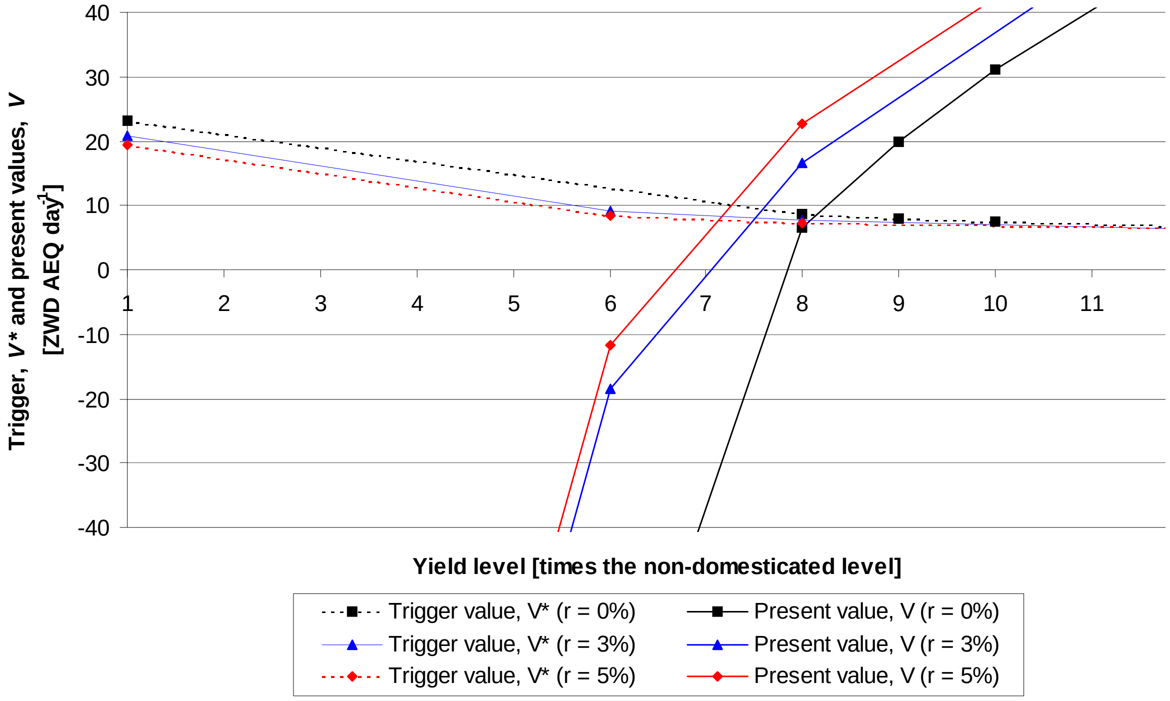

Figure 22. Trigger and present values of scenario 6.

Source: Own calculation.

7.6 Summary

This chapter describes the factors that determine costs, e.g. labour inputs, and benefits of planting domesticated indigenous fruit trees. Furthermore, it assesses the risk-adjusted rate of return of planting domesticated IFT and the influence of the risk-free rate of return on the risk-adjusted rate of return and on investment. It further analyses the impact of tree improvements and of rising costs of collecting the fruits from naturally grown trees in the Communal Areas on the value of waiting to invest versus the value of immediate investment in planting of domesticated IFT.

Results presented here indicate that under current conditions, IFT planting in Zimbabwe is not economically attractive. IFT cultivation contributes to diversification of income. However, the rates of return on tree enterprises and the household portfolio are positively correlated, so that diversification does not contribute much towards risk-management. Planting trees would only be economically attractive if IF supply from the Communal Areas was dramatically reduced or if trees were much improved.

With current performance levels of IFT, indigenous fruit collection from naturally grown trees in the Communal Areas and trees preserved in farmers' field yields considerably higher returns to labour than planting non-domesticated trees. Consequently, indigenous fruit trees require significant improvements in order to induce investment. Such improvements would have to induce maturity earlier and enhance yields. Alternatively, increasing costs of collection of IF from the Communal Areas in combination with lower levels of tree improvements induce investment, *ceteris paribus*. If fruit quality is improved via the domestication programme so that domesticated fruits fetch up to three times as much as non-domesticated ones, then lower levels of yield or collection costs increase trigger investment.

The results presented here have implications for assessing the prospects of the domestication programme of indigenous fruit trees of Southern Africa. Based on the results, inducing precocity seems to be a pre-condition for making the investment economically attractive, while the effect of increased fruit quality seems to be relatively stronger than the effect of enhancing the yield. With respect to the increased fruit quality, further research is needed to assess the potential willingness of consumers to pay for enhanced fruit quality. With respect to the other tree improvements, further research is needed to analyse the feasibility of such improvements.

8 Conclusions and recommendations

This research is part of the 'Domestication of Indigenous Fruit Trees Programme' of the World Agroforestry Centre (ICRAF, formerly International Centre for Research in Agroforestry). Its objective is to assess the economics of indigenous fruit collection and planting of indigenous fruit trees of the Miombo Zone. The study complements research of Ramadhani (2002), who assessed marketing aspects of indigenous fruits in Zimbabwe.

This study explores three research questions: (1) What is the status quo of indigenous fruit use and sale of rural households in Zimbabwe? (2) What is the contribution of indigenous fruit trees to reducing poverty and the vulnerability of the rural poor to poverty and food insecurity? and (3) Which factors determine the decision to invest in indigenous fruit tree planting from farmers' perspective?

8.1 Status quo of indigenous fruit use

Currently, farmers mostly collect IFT products from the commons. Collection and home consumption of indigenous fruits is popular among all rural people at the two research sites. Children are the main consumers of indigenous fruits. The present study confirms the results of Nyoka and Rukuni (2000) showing that differences in consumption patterns exist among the fruit species under consideration. Rural households generally consume fruits of *U. kirkiana* as a snack and rarely as a main meal. However, in years of maize shortage, people switch to consuming fruits of *P. curatellifolia* as a main meal. Ramadhani (2002) reported that indigenous fruits are popular for consumption and, despite poor marketing infrastructure leading to low quality and irregular supply of the fruits, are widely traded throughout Zimbabwe. Cash income from fruits accrues at a critical period of the year. This is especially important for households with less income from remittances.

Collection of indigenous fruits and other indigenous fruit tree products like leaves for fertiliser accounts for about 6.6% and 3.4%, respectively, of the total gross margin, i.e. the sum of gross margins over all enterprises, of rural households of the two study sites, Murehwa and Takawira. The gross margin of *U. kirkiana* use was ZWD 1910 and

531 in Murehwa and Takawira, respectively. The value for Murehwa is within the range of income reported for an indigenous fruit species in Cameroon (Ayuk et al. 1999). At the exchange rate of December 1999, *U. kirkiana* generates an income per household of about USD 50 in Murehwa and USD 14 in Takawira. These values are lower than the USD 78 reported by Shackleton et al. (2002). However, Shackleton et al. (2002) included a higher variety of wild fruits in their analysis.

Valued at the prevailing wage rate in percent of the market value of IFT products used, time spent on indigenous fruit collection is lower than that applied by Campbell et al. (1997). Labour productivity of collecting IFT products from the Communal Areas and farmers' fields is higher than the wage rate for casual labour and nearly all other enterprises such as home industry activities like arts and crafts production, brick moulding, broom making and beer brewing, horticulture, agriculture and livestock. This means that collection of indigenous fruit tree products competes well with other income-generating activities. However, the advantage of collection of indigenous fruit tree products depends on the relative success of the other income-generating activities in the farmers' portfolio, which vary across the region and also over time.

Sale of indigenous fruits is a seasonal activity and depends on the cash requirements at hand (Campbell et al., 2002). The finding that households with less access to cash via remittances are significantly more often involved in sale than other households also highlights this fact. However, collection of IF represents a highly seasonal activity, so farmers are unlikely to rely exclusively on IF collection.

8.2 Indigenous fruits, poverty and vulnerability

The contribution that collection of indigenous fruits from the commons can make towards poverty reduction, food security and reduction of vulnerability is assessed using a stochastic simulation model. The model allows the assessment of monthly income flows and of the vulnerability of income to falls below the threshold level of income necessary to cover daily minimum food requirements.

Income and expenditure distributions are fitted on data from the household survey of Takawira. Seasonal aspects in income generation are important since households face risks within a given year of periodically falling below the poverty line, even if there are no major external shocks. This is reflected in the results, which show vulnerability changes throughout the year. These are highest in the beginning of the cropping season, when inputs to agricultural production are purchased. Indigenous fruit tree products contribute significantly to household income, which is the total gross margin plus informal loans and the surplus from the previous period. The more indigenous fruits contribute towards minimum food requirements, the less vulnerable households are. Agricultural and livestock income contribute the highest shares to annual income. Livestock keeping, indigenous fruits, off-farm and household activities as well as remittances are the most important sources of income during the critical period. Variance in income from remittances, agriculture and off-farm activities results in relatively larger changes in the household income than variance in income from other sources.

Although results show that indigenous fruit trees contribute to reducing vulnerability to poverty and other studies also show that poor households rely on income from woodland products, woodland products do not necessarily contribute to lifting people out of poverty in the long run (Campbell et al. 2002)[69]. Results support the conclusion of Campbell et al. (2002) that woodlands instead constitute a source of cash income when other cash sources are low and serve as safety net in times of drought.

Overall, it is concluded that indigenous fruit trees make poor rural households less vulnerable to poverty and food insecurity, especially during the critical period of the year. During this period, IF, depending on their availability and the resource stock of the rural household, reduce by about 10% to 30% the probability of falling below the poverty threshold, which is set at the income level that covers minimum food requirements. Thus, IFT contribute to poor rural households' safety net. This is especially so for households with fewer alternative income sources or a relatively smaller income during the critical period. Another important fact is that households do not incur up-front costs when collecting IF from the Communal and other areas.

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[69] Their study further shows that market factors influence vulnerability to a greater extent than rainfall, community institutions, soil quality and other factors.

Thus, the entry barrier to IFT use is very low, especially for households close to the resource.

8.3 Farmer-led investment in on-farm IFT planting

The 'Domestication of Indigenous Fruit Trees Programme' of the World Agroforestry Centre aims to provide farmers with improved IFT in order to promote on-farm planting. Thus, the programme aims at enhancing rural incomes and at the same time preserving biodiversity as the IFT are also threatened by the continuing deforestation in the Southern African region. Making improved IFT planting material available adds another possibility to the farmers' portfolio of income-generating enterprises. Adoption of indigenous fruit tree planting depends not only on the net present value but also on the option value of planting. Both aspects depend on the costs and benefits and the implicit risk. The latter is not the overall variability, but rather the non-diversifiable risk, captured by the covariance of the new activity and the existing household portfolio. The covariance determines the discount rate used for evaluation of the option to invest in planting indigenous fruit trees. This covariance is estimated by using so-called spanning assets for constructing the replicating portfolio, which carry the same risk characteristics as the new asset in question. In this study the replicating portfolio consists of indigenous and exotic fruit tree enterprises.

Six scenarios for investment analysis are considered depending on the improvement of domesticated IFT with respect to age at maturity, yield level and fruit quality, costs of collecting IF from the Communal and other areas and the level of the risk-adjusted discount rate. Inducing precocity, i.e. advancing first fruit production to an earlier age, could be achieved through invention of an appropriate vegetative propagation technology, whereas improvements in fruit quality and yield increases would result from a combination of selecting superior genotypes and appropriate vegetative propagation technology. Increased collection costs for tree products from the Communal Areas address the situation in areas where the fruit trees are less abundant than in the research area. This would also apply to a situation where deforestation increases and indigenous fruit trees are also being cut.

Under current conditions, collecting fruits from the Communal Areas maximises household utility. That means that under present conditions, farmers cannot be expected to plant unimproved indigenous fruit trees for reasons of income generation, since collection of the IFT products from forests and the common lands yields comparatively higher returns to labour than from planting the trees.

Even if fruit productivity traits can be improved, e.g. by advancing maturity to two years through breeding, this is not sufficient to render immediate investment economically attractive. Other factors such as collection costs for IFT products from the forests and the common lands and/or fruit yield must also increase substantially to trigger tree planting. An increase of collection costs would correspond to a scenario where deforestation has advanced, so that planting IFT could be an alternative for areas with a lower abundance of the IFT, *c.p*. The switch to on-farm planting would also take place if breeding efforts on IFT increased the yield level. The older the domesticated trees are at first fruit production, the higher the yield increase has to be in order to induce immediate investment.

The most promising breeding effort seems to be improvements that cause precocity in combination with improvements of fruit quality that lead to higher prices for domesticated fruits. Here, relatively smaller additional improvements in terms of precocity and yield increase are necessary to initiate investment.

The analysis further shows that the effects of tree improvements and/or increases of collection costs on the decision to invest move in very narrow boundaries. Both scenarios result in higher present values of investment, but also in higher trigger values. The present value of investment exceeds the trigger value, which results in immediate investment for a narrow range of assumption changes only. Thus, in order to induce immediate investment, the domestication programme would have to achieve high levels of improvements within those boundaries so that the present value exceeds the trigger value.

8.4 Recommendations for policies and further research

Biological researchers working on the domestication program should **assess the feasibility of achieving the level of technical changes** that would be required to render the technology sufficiently attractive for farmers to invest. This means that it needs to be assessed at which age domesticated IFT bear the first fruits. Additionally, researchers need to evaluate whether the yield increases are physically feasible, i.e. can domesticated trees bear the additional fruit load? With respect to enhanced fruit quality, studies could follow up on the study of Ramadhani (2002) and further **analyse willingness to pay for different fruit characteristics, e.g. colour, size and taste**. Selection could then target the fruit characteristic for quality improvement that yields the highest willingness to pay. If commercialisation enhanced and the level of tree improvement did not lead to on-farm cultivation, but rather concentrated only on wild resources, non-sustainable harvesting techniques could result in destruction of the resource base (see also the findings of Abebaw & Virchow, 2003).

Concerning the extent to which trees have to be improved, this study's simulations provide ex ante impact assessment for ongoing research programs. Such information can guide researchers and research managers in deciding on future research priorities. If improvement levels are not feasible (or only at high costs/under constraints) an alternative strategy for conservation of biodiversity could be **promotion of indigenous fruit tree conservation in their natural habitat**. The efforts towards conservation of this natural resource can further be justified by the role they play in providing risk-coping means in times of need during the year and their contribution to reduction of vulnerability.

However, conservation is a complex issue that is influenced by institutional arrangements and the level of enforceability of rules regulating IFT use. Sustainability of such protected conservation areas depends on pressure from external factors and competing interests among forest users, i.e. communities adjacent to the conservation areas, which rely on collection of these resources and the state (Abebaw & Virchow, 2003). Alternative income-generating activities may reduce pressure on the natural resource (Abebaw & Virchow, 2003). For example, in Sri Lanka growth of agricultural profitability has been proven to result in higher natural resource use stocks (Gunatileke & Chakravorty, 2003). Thus, conservation measures need to be accompanied by agricultural development; otherwise, local communities adjacent to the resource may bear a disproportionate share of the costs, although biodiversity protection provides a global public good (Gunatileke & Chakravorty, 2003).

Conservation in farmers' fields may provide a solution to some extent. However, if farmers maintain agro-biodiversity in their own fields, they will maintain it up to the level at which private marginal benefits equal private marginal cost of conservation. This equilibrium is influenced by external variables, i.e. price changes affecting costs and benefits. In situ conservation of economically less important crops can be very costly since opportunity costs to farmers are rather high (Wale & Virchow, 2003). The question then is the external benefit derived from resource conservation and appropriate subsidy schemes that compensate farmers for the conservation costs they bear. Designing contracts may be one strategy to induce farmers to conserve in situ biodiversity (Wale et al., 2003).

To further validate the findings of the investment analysis, more investigations should be carried out in other **target areas where the abundance of IFT is lower**. Hence, data need to be collected from other Southern African countries that have shown higher deforestation rates than Zimbabwe in the past. Results from such studies would provide a clearer picture of the adoption potential of improved IFT throughout the region.

Returns to labour may vary in other regions of Zimbabwe with higher or lower costs of collection for IFT products, e.g. in areas with lower abundance of trees. Overall, the rate of deforestation is estimated at 1.5% annually from 1990 to 2000 in Zimbabwe (FAO, 2001). However, evidence on the effects of deforestation on indigenous fruit trees is contradictory (see chapter 2.2.3). Therefore, further research on the **effects of deforestation on each indigenous fruit tree by species** is recommended, especially since use and extent of use differ among species. If deforestation also affects the three indigenous fruit trees under consideration, it will increase collection costs and labour productivity will thus diminish, which will affect all households.

With respect to the study of Rukuni et al. (1998) and the findings of Leakey et al. (2004), it seems worthwhile to assess indigenous fruit trees and deforestation from another angle: Is tree-cutting part of a domestication process, i.e. selective? Even if growing population pressure or institutional failure seem to be driving factors of deforestation, in the presence of selective tree cutting one could argue that only those trees that generate lower marginal benefits than costs (in terms of obstructing field work) will be cut. The question is whether the number of remaining trees is sufficiently large to maintain biodiversity. If not, one has to analyse incentives that could alter farmers' decisions.

If planting of domesticated trees commences, then the interaction between availability of improved cultivars and on-farm management of the remaining natural resource base needs to be assessed (Leakey & Tomich, 1999). Also, **market reaction to increased supply of indigenous fruits** needs to be analysed, i.e. would the market clear under those conditions?

Intra-household resources distribution and gender aspects determine whether enhanced income via farmer-led planting enhances overall household well-being. Currently, mainly women are involved in sale of the fruits; however, if returns to labour rise, men might take over this activity as has happened previously (Neumann & Hirsch, 2000).

From a methodological point of view, the **age-yield function could be reassessed** based on a larger sample or under trial conditions in order to clarify contradictory production levels found in this study and the figures provided by Mwamba (1996).

The model household of the poverty assessment can employ coping (income-smoothing) mechanisms by taking out informal loans, using savings up to the level identified in the household survey and enhancing indigenous fruit use. The model could be extended to incorporate further **consumption-smoothing mechanisms** as well as an extension covering **subsequent years and external shocks.** Another extension could address decisions of reduced input purchase for agricultural production if cash is short. However, if sale of assets as a buffer against income shocks is considered, one needs to keep in mind that such a sale may reduce households' income-generating capacity in the long run.

9 Summary

Chapter one outlines the analytic approach to the problem and the objectives and leading research questions of this study. In the rural areas of Zimbabwe, poverty and periodical food shortages are common problems that hamper development. Indigenous fruits are a natural resource used in times of need to overcome food insecurity and also, increasingly, for purposes of sale. Due to several factors, deforestation reduces the availability of indigenous fruit tree resources. The 'Domestication of Indigenous Fruit Trees Programme' of the World Agroforestry Centre (ICRAF, formerly the International Centre for Research in Agroforestry) addresses this problem by improving indigenous fruit trees for farmer-led on-farm planting of the trees with the aim of alleviating poverty and conserving biodiversity. Improvements target the development of appropriate propagation techniques for early fruit production and for improving fruit yields and quality. However, information on the economic value and the role of indigenous fruit tree products within the rural household economy is scarce. As a supplement to the biological research, this study assesses the economics of current indigenous fruit collection, use and sale. Second, it quantifies the contribution of indigenous fruit trees towards reducing the vulnerability to poverty of rural households in Zimbabwe. Third, it analyses the option to invest in planting of domesticated indigenous fruit trees. *U. kirkiana*, *S. cocculoides* and *P. curatellifolia* are the target species of this study. They are the three most popular species as determined by ICRAF's previous research in the Southern African region. Overall, this study aims at giving recommendations for further research and adaptation of the domestication programme.

Chapter 2 presents detailed background information on the farming system, land tenure and environmental conditions in rural Zimbabwe. It further describes the role of woodland resources in the rural household economy and the institutional arrangements for woodland use as analysed by previous studies. Finally, the chapter provides insights in the link between biodiversity, domestication and the rationale for public investment in domestication.

The Miombo zone is an eco-zone that covers seven countries in Southern Africa and is home to a variety of indigenous fruit trees that are used by rural households. These fruit trees are a common property resource. Two driving forces have previously been identified to induce active management of trees, i.e. growing scarcity and the potential income from the trees. However, currently the fruits are mostly collected from naturally occurring trees in the Communal Areas and trees that have been preserved in farmers' fields. Over the past years, markets have emerged for the fruits, but so far enhanced market demand has not led to on-farm planting of the trees.

Domestication of trees is a long-term process. The gain from domestication, i.e. expected on-farm conservation of the trees and thus conservation of the genetic diversity, is expected to outweigh the costs of the biodiversity loss if deforestation continues. Biodiversity has an insurance function and constitutes a potential source of innovation in the R&D sector. External effects like poverty alleviation and enhanced food security as a result of enhanced incomes from domesticated trees justify the public expenditure and spillover effects are expected with respect to domestication of other tree crops.

The theoretical background is outlined in **chapter three**. The current status of indigenous fruit tree use is analysed within the framework of farm household theory. Households are assumed to maximise utility and follow multiple objectives like food security and/or cash income maximisation, etc. They pursue a variety of farm, household and off-farm activities and assess each activity based on its contribution to household utility. Resource availability, e.g. land, labour and capital, can be a production constraint. The chapter further presents definitions of poverty, food security and vulnerability to poverty or food insecurity. Poverty is a static concept that includes several dimensions. It is often measured in one dimension only, i.e. by income or consumption. In contrast, vulnerability is a dynamic concept. It refers to the risk that people will fall short of their food requirements or below the poverty line, depending on which framework is applied. Risk-management or risk-coping strategies can mitigate vulnerability. The former refers to an ex ante and the latter to an ex post perspective. Indigenous fruit tree collection is a risk-coping strategy and tree planting would constitute a risk-management strategy. Finally, the chapter compares the net present value and the real option approach to investment analysis. It

shows that sunk cost, uncertain returns on investment and flexible timing of investment result in a higher hurdle rate than 'discounted net benefits exceeding initial investment cost' in order to initiate investment.

Chapter four presents the research locations and describes the methodology of data collection. Research was conducted in Murehwa Communal Area, which is about 80 km east of Harare and Takawira Resettlement Area, which is about 200 km south of Harare. Income, expenditure and labour data were collected by detailed case studies of 39 households that were visited monthly from August 1999 to August 2000. Additionally, a socio-economic random survey of 300 households was conducted to collect data for assessing factors associated with indigenous fruit sale. The chapter further outlines the methods used for collecting physical information like the age-yield function on the indigenous fruit trees, which is the basic piece of information required for the investment analysis.

In **chapter five,** the role of indigenous fruit trees in the household economy in rural Zimbabwe is assessed. The chapter starts with the definition of the household income and activities that contribute to it. Then the resource base of rural households is presented.

The results show that households produce agricultural and horticultural crops and keep livestock. Rain-fed agricultural production covers subsistence needs, whereas off-farm and household activities and remittances are important sources of cash income. Indigenous and exotic fruits are used for home consumption and sale. All households consume *U. kirkiana*. Children consume higher amounts of exotic and indigenous fruits than do adults. Indigenous fruit sale is more prevalent in Murehwa than in Takawira and provides cash income at a time when cash is required for agricultural inputs like fertiliser. Households that receive fewer remittances and households that live close to the market sell indigenous fruits more often than other households. Indigenous fruits are mostly consumed as a snack. However, in years following a poor maize harvest, households of Takawira switch to consuming the fruits for a main meal, especially with regards to *P. curatellifolia*. Labour productivity of indigenous fruit tree product collection is high and higher than labour productivity of the other income-generating activities like agricultural and vegetable production.

Chapter six assesses the impact of indigenous fruit trees on food security and on reduction of vulnerability to poverty in Takawira. The analysis concentrates on this site because a higher share of households here indicated the use of fruits as a main meal in times of food shortages. In this study, vulnerability to poverty is defined as the probability of falling below the poverty line. In Takawira, 25% of the sample households were below the poverty threshold. Based on distributions of gross margins and household expenditure, the household income is stochastically simulated over the course of the year. Five different scenarios -- depending on availability of a surplus from the previous cropping season and availability of indigenous fruits -- are assessed.

Cropping and income-generating activities follow seasonal fluctuations and therefore the household income also fluctuates in the course of the year. It is lowest between August and January and reaches a peak in April/May. Vulnerability to poverty is also subject to seasonal fluctuations. It is highest between August and January. The higher the resource stocks, i.e. the surplus from the previous season, that can be carried over to the new cropping season, the higher the household income. Additionally, the higher indigenous fruit availability and therefore the amount of minimum food requirements that can be replaced by indigenous fruits, the higher the household income. Although indigenous fruits contribute to reduction of vulnerability, other sources of income show higher influence on the household income that is available. The highest influence stems from production of agricultural crops, which constitute a major share of rural incomes. Overall, indigenous fruits can reduce vulnerability to poverty by roughly 10-30%. Moreover, they are available at a time when cash inputs to agricultural production and energy requirements for labour in agricultural production are high.

In **chapter seven,** investment in planting indigenous fruit trees is assessed by using the real options approach. Currently, collection of indigenous fruits from trees preserved in the Communal Areas and in farmers' fields yields higher returns than planting. The analysis investigates to which degree indigenous fruit trees have to be improved or costs of collection have to rise so that planting becomes economically attractive. Improvements made to the trees aim to induce precocity, i.e. early fruit production, to increase the yield level and to improve fruit quality. The latter is assumed to result in higher fruit prices for domesticated fruits. The risk-adjusted discount rate is computed based on farmers' household portfolio and tree enterprises. The value of immediate investment and the value of waiting to invest are modelled as the incremental benefit from planting domesticated trees.

Under the prevailing conditions, trees have to be improved significantly, e.g. maturity at two years in comparison to 11 to 16 for non-improved trees plus yield increases of about nine times the current level. Alternatively, a rise in collection costs and/or fruit quality improvements trigger investment. The implications of the investment analysis are that inducing precocity seems to be a pre-condition for making the investment economically attractive. Enhanced fruit quality seems to have a relatively stronger effect than increased yield.

In **chapter eight,** conclusions are drawn and recommendations for further research are given. Further analysis of the deforestation process is recommended to assess indigenous fruit availability and thus the prospects of the domestication programme in other regions where abundance of IFT is lower than in Zimbabwe. With respect to the domestication programme, tree improvements necessary to initiate immediate investment need to be assessed with respect to technical feasibility. Furethermore, market research is recommended to estimate consumers' potential willingness to pay for enhanced fruit quality. Conservation constitutes an alternative to planting, so further research in order to analyse the decision to conserve indigenous fruit trees is also recommended.

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Appendix

Appendix 1. Crops mentioned in the text.

Common name	**Scientific name**
Avocado	*Persea americana* Mill.
Beans	*Phaseolus vulgaris*
Bush Orange (Shona: Matamba)	*Strychnos* sp. (*S. cocculoides* Baker & *S. spinosa* Lam.)
Cabbage	*Brassica oleracea* var. *capitata*
Cowpea (Shona: Nyemba)	*Vigna unguiculata* subsp. *unguiculata*
Fever Tree (Shona: Muhacha)	*Parinari curatellifolia* Plance. ex Benth.
Finger millet (Rapoko)	*Eleusine coracana* L.
Groundnuts	*Arachis hypogaea* L.
Guava	*Psidium guajava* Linn.
Kale	*Brassica oleracea*, variety *acephala*
Maize	*Zea mays* L.
Mango	*Mangifera indica* Blume
Orange	*Citrus sinensis* Osbeck
Peach	*Prunus persica* Rehder
Pumpkin	*Cucurbita* sp.
Roundnuts	*Vigna subterranea*
Sorghum	*Sorghum bicolour* L.
Tomato	*Lycopersicon esculentum* Mill.
Wild Loquat (Shona: Mazhanje)	*Uapaca kirkiana* Muell. Arg.

Appendix 2. IFT contribution towards counteracting vulnerability to poverty: model description.

Item	Period	Distribution	P-Value
Remittances	1	=RiskBetaGeneral(0.11642; 0.41166; 0; 2552.7)	< 0.1
	2	=RiskExpon(43.864; RiskShift(-2.1932))	< 0.1
	3	=RiskExtvalue(26.344; 65.097)	< 0.1
	4	=RiskTriang(0; 0; 201.66)	< 0.1
	5	=RiskExpon(77.29; RiskShift(-3.8645))	< 0.1
	6	=RiskExpon(54.125; RiskShift(-2.7062))	< 0.1
	7	=RiskExpon(164.68; RiskShift(-8.2338))	0.4235
	8	=RiskBetaGeneral(0.10245; 0.36398; 0; 251.68)	< 0.1
Off-farm	1	=RiskBetaGeneral(0.1179; 0.45644; 0; 3132.9)	< 0.1
	2	=RiskBetaGeneral(0.1091; 0.39442; 0; 163.02)	< 0.1
	3	=RiskBetaGeneral(0.11082; 0.40681; 0; 311.9)	< 0.1
	4	=RiskBetaGeneral(0.10563; 0.41788; 0; 280.89)	< 0.1
	5	=RiskExtvalue(18.4; 42.784)	< 0.1
	6	=RiskLogistic(68.553; 43.523)	0.9402
	7	=RiskLoglogistic(-18.987; 84.542; 2.4637)	0.9402
	8	=RiskExpon(37.384; RiskShift(-1.8692))	< 0.1
Garden	1	=RiskExpon(334.38; RiskShift(-53.095))	0.9402
	2	=RiskNormal(18.6; 27.51)	0.1577
	3	=RiskLogistic(-1.5363; 4.3309)	< 0.1
	4	=RiskLogistic(-0.90826; 8.4918)	< 0.1
	5	=RiskLogistic(-0.16921; 8.5567)	< 0.1
	6	=RiskUniform(-99.852; 99.105)	< 0.1
	7	=RiskLogistic(20.251; 22.038)	0.4235
	8	=RiskPearson5(1.084; 40.78; RiskShift(-10.682))	< 0.1
Field	1	=RiskLogistic(-1606.09; 752.7)	1
	2	=RiskLogistic(-18.225; 22.49)	< 0.1
	3	=RiskLogistic(231.84; 215.77)	0.8495
	4	=RiskLognorm(2281.4; 1305.9; RiskShift(-593.44))	1
	5	=RiskExtvalue(1193.8; 1289)	0.8495
	6	=RiskBetaGeneral(0.16617; 0.5164; -9.8594; 6361.9)	< 0.1
	7	=RiskExpon(83.833; RiskShift(-4.1916))	< 0.1
	8	=RiskBetaGeneral(5.3546; 0.82527; -2865.6; 298.05)	0.1577
Livestock	1	=RiskExtvalue(479.36; 677.02)	0.5724
	2	=RiskExtvalue(177.46; 255.01)	0.9402
	3	=RiskExtvalue(162.66; 247.28)	0.753
	4	=RiskLognorm(5376.9; 223.16; RiskShift(-5236))	0.4235
	5	=RiskNormal(293.79; 331.61)	0.6594
	6	=RiskNormal(458.11; 395.29)	0.308
	7	=RiskExpon(505.56; RiskShift(-190.76))	< 0.1
	8	=RiskLoglogistic(-870.84; 1093.9; 4.6905)	0.753

Appendix 3. IFT contribution towards counteracting vulnerability to poverty (cont.).

Item	Period	Distribution	P-Value
EFT	1	=RiskNormal(16.972; 23.864)	0.5724
	2	=RiskLogistic(15.088; 32.873)	0.5724
	3	=RiskBetaGeneral(0.10777; 0.43633; 0; 247.75)	< 0.1
	4	=RiskExtvalue(3.4841; 16.96)	< 0.1
	5	=RiskExpon(25.778; RiskShift(-16.316))	< 0.1
	6	=RiskBetaGeneral(0.1132; 0.39092; 0; 42.724)	< 0.1
	7	=RiskUniform(-0.50771; 10.154)	< 0.1
	8	0 exotic fruits are out of season	-
IFT		if surplus t_0 > (HHexpenditure+MFR+CashRequirementsProduction)	
	1	=RiskUniform(38.969; 272.91)	0.9402
	2	=RiskExtvalue(96.724; 58.425)	0.9402
	3	=RiskLoglogistic(1.8381; 14.372; 1.15)	0.8495
	4	=RiskBetaGeneral(0.1357; 0.41906; 0; 87.941)	< 0.1
	5	=RiskLoglogistic(-10.777; 21.122; 4.859)	0.6594
	6	=RiskLogistic(8.069; 5.0933)	0.4235
	7	=RiskExtvalue(19.056; 17.422)	0.753
	8	=RiskLoglogistic(-17.002; 28.495; 6.1134)	0.4235
		if surplus t_0 < (HHexpenditure+MFR+CashRequirementsProduction)	
	1	=RiskUniform(38.969; 272.91, RiskShift(IFT share MFR * MFR))	as above
	2	=RiskExtvalue(96.724; 58.425, RiskShift(IFT share MFR * MFR))	as above
	3-8	as above	
Credit	1-8	=RiskPareto(1.1; 64.516)	0.8013
Surplus, t_0	1	=RiskBetaGeneral(6.2261; 11.911; -10968; 25286)	0.9402
HH expenditure incl. school fees	1	=RiskExpon(646.49; RiskShift(109.9))	0.9402
	2	=RiskTriang(98.934; 98.934; 472.21)	0.8964
	3	=RiskExtvalue(168.24; 120.82)	0.9402
	4	=RiskExpon(78.653; RiskShift(43.421))	0.8495
	5	=RiskLoglogistic(2.0053; 96.53; 2.5365)	0.9402
	6	=RiskLogistic(122.68; 30.118)	0.6594
	7	=RiskExtvalue(111.368; 61.462)	0.753
	8	=RiskLoglogistic(24.571; 68.21; 1.7843)	0.5724
Cash requirements for production, ALL ACTIVITIES[1)]	1	=RiskExtvalue(353.64; 262.7)	1
	2	=RiskExtvalue(14.389; 28.869)	0.4235
	3	=RiskBetaGeneral(0.19378; 0.48498; 0; 443.37)	0.4235
	4	=RiskBetaGeneral(0.12522; 0.4661; 0; 304.4)	< 0.1
	5	=RiskBetaGeneral(0.10367; 0.41016; 0; 87.085)	< 0.1
	6	=RiskBetaGeneral(0.10872; 0.3787; 0; 54.774)	< 0.1
	7	=RiskExpon(21.335; RiskShift(-1.0667))	< 0.1
	8	=RiskBetaGeneral(0.18322; 0.42043; 0; 220.22)	0.753

Source: Own calculation based on household survey 1999/ 2000, Takawira Resettlement Area, N = 20 (BestFit (Palisade, 2000)).

1) Distributions, which define cash requirements, are employed to define whether the household substitutes minimum food requirements by enhanced indigenous fruit use. Indigenous fruits are available during period 1 and 2 only.

Appendix 4. Input requirements for indigenous fruit tree seedling production and grafting.

Item	Input requirements	
	Quantity	Unit
Seedling production		
Collecting fruits	920	fruits person-day^{-1}
Extracting seeds	200	fruits person-day^{-1}
Treatment of seeds	600	seeds person-day^{-1}
Soil collection & transport	0.1	person-day wheelbarrow^{-1}
Filling tubes & seeding	200	tubes person-day^{-1}
Transport	0.1	person-day 200 tubes^{-1}
Watering	0.12	person-day 200 tubes^{-1} & every 2nd day^{-1}
Weeding	0.1	person-day 200 tubes^{-1} & every 2nd month^{-1}
Other labour (e.g. standing pots upright, etc.)	0.1	person-day 200 tubes^{-1} & week^{-1}
Seeds	3	seeds fruit^{-1}
Space requirements	2	m^2 200tubes^{-1}
Grafting		
Labour		
Collection of scion material	0.14	person-day tree^{-1}
Grafting	0.03	person-day tree^{-1}

Source: Labour requirements according to Maghembe (1999) and own information.

Appendix 5. Scenario 1 & 2: Parameter values of the option to invest in planting domesticated indigenous fruit trees – maturity at two years.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta\text{-}1)$	V^*[5)]	V[5)]	B
2	1	1	1	22.90	0.00	15.64	-0.946	0.023	1.103	97.214	1.01	**23.14**	-299.19	5.575E-134
2	1	1	2	22.89	0.00	15.64	-0.253	0.023	0.409	36.486	1.03	**23.54**	-46.04	5.733E-51
2	1	1	2.5	22.90	0.00	15.64	-0.029	0.023	0.185	17.145	1.06	**24.32**	4.81	2.453E-24
2	1	1	2.6	22.89	0.00	15.64	0.010	0.023	0.146	13.634	1.08	**24.70**	12.71	1.861E-19
2	1	1	2.7	22.89	0.00	15.64	0.047	0.023	0.109	10.392	1.11	**25.32**	19.94	6.320E-15
2	1	1	2.8	22.89	0.00	15.64	0.084	0.023	0.072	7.311	1.16	26.51	26.64	1.421E-10
2	1	1	2.9	22.90	0.00	15.64	0.120	0.023	0.036	4.210	1.31	30.03	33.03	4.294E-06
2	1	1	3	22.90	0.00	15.64	0.154	0.022	0.003	1.234	5.27	**120.81**	38.57	2.640E-01
2	1	1	3.1	22.90	0.00	15.64	0.186	0.023	-	-	-	∞	43.94	-
2	1	1	1	22.90	0.00	15.64	-0.946	0.023	1.103	97.214	1.01	**23.14**	-299.19	5.575E-134
2	1	8	1	8.26	0.00	15.64	-0.032	0.016	0.189	24.123	1.04	**8.62**	6.57	9.754E-24
2	1	9	1	7.64	0.00	15.64	-0.007	0.017	0.163	20.669	1.05	8.03	19.99	7.805E-20
2	1	10	1	7.09	0.00	15.64	0.015	0.016	0.142	18.379	1.06	7.50	31.21	3.348E-17
2	1	12	1	6.21	0.00	15.64	0.050	0.016	0.107	14.601	1.07	6.67	49.86	4.258E-13
2	1	16	1	5.06	0.00	15.64	0.092	0.016	0.065	9.013	1.12	5.70	74.21	9.787E-08
2	1	18	1	4.66	0.00	15.64	0.107	0.016	0.049	7.180	1.16	5.41	82.89	4.092E-06
2	1	20	1	4.26	0.00	15.64	0.119	0.016	0.038	5.674	1.21	5.17	90.79	8.147E-05
2	1	22	1	4.03	0.00	15.64	0.128	0.016	0.029	4.548	1.28	5.16	95.43	6.509E-04
2	1	24	1	3.80	0.00	15.64	0.138	0.016	0.019	3.369	1.42	5.40	101.27	5.471E-03
2	1	26	1	3.56	0.00	15.64	0.145	0.016	0.012	2.488	1.67	5.96	105.46	2.823E-02
2	1	28	1	3.38	0.00	15.64	0.150	0.016	0.006	1.797	2.25	7.61	109.14	1.104E-01
2	1	30	1	3.21	0.00	15.64	0.157	0.016	-	-	-	∞	113.16	-

Appendix 6. Scenario 1 & 2: Parameter values of the option to invest in planting domesticated indigenous fruit trees – maturity at four years.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta\text{-}1)$	V^*[5)]	V[5)]	B
4	1	1	1	24.82	0.00	15.64	-1.162	0.025	1.319	106.158	1.01	**25.05**	-340.28	7.523E-150
4	1	1	2	24.80	0.00	15.64	-0.469	0.025	0.626	50.948	1.02	**25.30**	-86.28	1.615E-72
4	1	1	3	24.81	0.00	15.64	-0.063	0.025	0.220	18.402	1.06	**26.23**	-1.47	1.105E-26
4	1	1	3.2	24.79	0.00	15.64	0.001	0.025	0.155	13.372	1.08	**26.80**	9.23	1.601E-19
4	1	1	3.5	24.80	0.00	15.64	0.090	0.025	0.067	6.261	1.19	**29.51**	22.66	2.948E-09
4	1	1	3.6	24.81	0.00	15.64	0.118	0.026	0.039	4.023	1.33	**33.01**	26.77	6.373E-06
4	1	1	3.7	24.81	0.00	15.64	0.145	0.025	0.011	1.875	2.14	**53.17**	30.53	1.650E-02
4	1	1	3.72	24.81	0.00	15.64	0.151	0.026	0.006	1.459	3.18	**78.85**	31.21	9.226E-02
4	1	1	4	24.81	0.00	15.64	0.223	0.025	-	-	-	∞	40.73	-
4	1	1	1	24.82	0.00	15.64	-1.162	0.025	1.319	106.158	1.01	**25.05**	-340.28	7.523E-150
4	1	4	1	15.12	0.00	15.64	-0.360	0.018	0.516	59.408	1.02	**15.38**	-137.25	8.038E-72
4	1	8	1	10.10	0.00	15.64	-0.110	0.016	0.266	33.323	1.03	**10.41**	-31.73	3.860E-35
4	1	10	1	8.69	0.00	15.64	-0.050	0.017	0.207	25.985	1.04	**9.03**	-2.45	5.054E-26
4	1	12	1	7.71	0.00	15.64	-0.007	0.016	0.164	21.384	1.05	8.08	19.10	1.476E-20
4	1	16	1	6.23	0.00	15.64	0.047	0.016	0.110	14.499	1.07	6.69	48.87	4.936E-13
4	1	20	1	5.32	0.00	15.64	0.081	0.016	0.076	10.227	1.11	5.90	68.14	7.575E-09
4	1	24	1	4.66	0.00	15.64	0.106	0.016	0.051	7.349	1.16	5.39	82.32	3.068E-06
4	1	28	1	4.16	0.00	15.64	0.123	0.016	0.033	5.181	1.24	5.15	92.79	2.039E-04
4	1	32	1	3.78	0.00	15.64	0.138	0.015	0.018	3.410	1.41	5.35	101.02	5.146E-03
4	1	36	1	3.50	0.00	15.64	0.147	0.016	0.009	2.165	1.86	6.51	107.13	5.209E-02
4	1	40	1	3.19	0.00	15.64	0.156	0.016	0.000	1.022	46.61	**148.64**	113.01	8.769E-01
4	1	44	1	3.05	0.00	15.64	0.162	0.016	-	-	-	∞	115.98	-

Appendix 7. Scenario 1 & 2: Parameter values of the option to invest in planting domesticated indigenous fruit trees – maturity at six years.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta\text{-}1)$	V^*[5)]	V[5)]	B
6	1	1	1	26.47	0.00	15.64	-1.399	0.029	1.555	108.439	1.01	**26.71**	-375.10	4.799E-156
6	1	1	2	26.46	0.00	15.64	-0.706	0.029	0.862	60.288	1.02	**26.91**	-121.23	2.772E-87
6	1	1	3	26.47	0.00	15.64	-0.299	0.029	0.456	32.873	1.03	**27.30**	-36.29	5.142E-48
6	1	1	4	26.46	0.00	15.64	-0.013	0.029	0.170	12.768	1.08	**28.71**	5.99	5.442E-19
6	1	1	4.1	26.46	0.00	15.64	0.012	0.029	0.144	10.891	1.10	**29.14**	9.23	3.006E-16
6	1	1	4.5	26.46	0.00	15.64	0.104	0.029	0.053	4.618	1.28	**33.78**	19.93	6.390E-07
6	1	1	4.6	26.46	0.00	15.64	0.127	0.029	0.029	3.019	1.50	**39.56**	22.71	1.971E-04
6	1	1	4.8	26.47	0.00	15.64	0.170	0.028	-	-	-	∞	27.24	-
6	1	1	5	26.46	0.00	15.64	0.211	0.029	-	-	-	∞	31.69	-
6	1	1	1	26.47	0.00	15.64	-1.399	0.029	1.555	108.439	1.01	**26.71**	-375.10	4.799E-156
6	1	8	1	12.14	0.00	15.64	-0.205	0.017	0.361	43.821	1.02	**12.43**	-74.97	3.118E-49
6	1	12	1	9.40	0.00	15.64	-0.079	0.016	0.236	29.738	1.03	**9.72**	-17.16	1.370E-30
6	1	16	1	7.70	0.00	15.64	-0.010	0.016	0.167	21.425	1.05	8.08	18.23	1.370E-20
6	1	20	1	6.59	0.00	15.64	0.035	0.016	0.122	16.225	1.07	7.02	41.92	8.058E-15
6	1	24	1	5.74	0.00	15.64	0.066	0.016	0.090	12.458	1.09	6.24	59.40	6.154E-11
6	1	28	1	5.19	0.00	15.64	0.088	0.016	0.068	9.684	1.12	5.79	71.83	2.460E-08
6	1	32	1	4.68	0.00	15.64	0.105	0.016	0.051	7.304	1.16	5.42	82.42	3.240E-06
6	1	36	1	4.28	0.00	15.64	0.119	0.016	0.037	5.701	1.21	5.20	90.58	7.578E-05
6	1	40	1	3.98	0.00	15.64	0.129	0.016	0.027	4.398	1.29	5.15	96.18	8.690E-04
6	1	48	1	3.50	0.00	15.64	0.146	0.016	0.010	2.296	1.77	6.20	106.67	4.092E-02
6	1	54	1	3.21	0.00	15.64	0.155	0.016	0.001	1.142	8.05	25.88	112.17	5.521E-01
6	1	56	1	3.12	0.00	15.64	0.159	0.016	-	-	-	∞	114.16	-

Appendix 8. Scenario 1 & 2: Parameter values of the option to invest in planting domesticated indigenous fruit trees – maturity at eight years.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta$-1)	V^*[5)]	V[5)]	B
8	1	1	1	27.86	0.00	15.64	-1.652	0.034	1.808	108.055	1.01	28.12	-404.38	7.043E-158
8	1	1	2	27.86	0.00	15.64	-0.959	0.034	1.115	66.820	1.02	28.28	-150.44	4.352E-98
8	1	1	3	27.85	0.00	15.64	-0.551	0.033	0.708	43.333	1.02	28.51	-65.98	5.879E-64
8	1	1	4	27.85	0.00	15.64	-0.265	0.034	0.422	26.093	1.04	28.96	-23.19	7.956E-39
8	1	1	5	27.85	0.00	15.64	-0.041	0.033	0.197	12.942	1.08	30.19	2.30	1.645E-19
8	1	1	5.5	27.86	0.00	15.64	0.054	0.034	0.103	7.134	1.16	32.40	11.49	7.600E-11
8	1	1	6	27.85	0.00	15.64	0.138	0.034	0.018	2.064	1.94	54.05	19.12	6.960E-03
8	1	1	6.1	27.85	0.00	15.64	0.155	0.035	0.002	1.100	10.97	305.58	20.46	5.120E-01
8	1	1	7	27.85	0.00	15.64	0.294	0.034	-	-	-	∞	31.36	-
8	1	0	1	27.86	0.00	15.64	-1.652	0.034	1.808	108.055	1.01	28.12	-404.38	7.043E-158
8	1	8	1	14.41	0.00	15.64	-0.320	0.017	0.477	57.193	1.02	14.66	-122.01	5.109E-68
8	1	16	1	9.49	0.00	15.64	-0.082	0.017	0.239	29.659	1.03	9.82	-18.51	1.245E-30
8	1	24	1	7.15	0.00	15.64	0.013	0.016	0.144	18.594	1.06	7.56	30.29	1.878E-17
8	1	32	1	5.77	0.00	15.64	0.064	0.016	0.093	12.535	1.09	6.27	58.25	5.028E-11
8	1	40	1	4.91	0.00	15.64	0.096	0.016	0.061	8.534	1.13	5.56	77.00	2.863E-07
8	1	48	1	4.30	0.00	15.64	0.118	0.016	0.039	5.886	1.20	5.18	89.35	5.485E-05
8	1	56	1	3.85	0.00	15.64	0.133	0.016	0.023	3.870	1.35	5.19	99.17	2.290E-03
8	1	64	1	3.51	0.00	15.64	0.145	0.016	0.011	2.374	1.73	6.06	106.55	3.540E-02
8	1	72	1	3.20	0.00	15.64	0.155	0.016	0.001	1.155	7.45	23.82	112.67	5.298E-01
8	1	80	1	2.98	0.00	15.64	0.163	0.016	-	-	-	∞	117.13	-

Appendix 9. Scenario 1 & 2: Parameter values of the option to invest in planting domesticated indigenous fruit trees – maturity at ten years.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	$I^{5)}$	$r^{6)}$	$\mu^{6)}$	α	σ	δ	β	$\beta/(\beta\text{-}1)$	$V^{*5)}$	$V^{5)}$	B
10	1	1	1	28.99	0.00	15.64	-1.923	0.043	2.079	98.095	1.01	29.29	-427.16	3.912E-145
10	1	1	2	28.99	0.00	15.64	-1.229	0.043	1.385	65.853	1.02	29.44	-174.40	8.251E-98
10	1	1	3	29.00	0.00	15.64	-0.824	0.043	0.980	46.557	1.02	29.63	-89.28	1.912E-69
10	1	1	4	29.00	0.00	15.64	-0.535	0.042	0.691	33.839	1.03	29.89	-47.07	1.043E-50
10	1	1	5	29.00	0.00	15.64	-0.312	0.043	0.469	22.972	1.05	30.32	-21.74	1.214E-34
10	1	1	6	28.99	0.00	15.64	-0.132	0.043	0.288	14.382	1.07	31.16	-4.78	7.173E-22
10	1	1	7	28.99	0.00	15.64	0.024	0.042	0.132	7.228	1.16	33.65	7.42	4.279E-11
10	1	1	7.5	29.00	0.00	15.64	0.091	0.043	0.065	4.031	1.33	38.57	12.04	3.869E-06
10	1	1	8	29.00	0.00	15.64	0.158	0.041	-	-	-	∞	16.41	-
10	1	0	1	28.99	0.00	15.64	-1.923	0.043	2.079	98.095	1.01	29.29	-427.16	3.912E-145
10	1	8	1	16.73	0.00	15.64	-0.458	0.018	0.615	69.612	1.01	16.98	-171.35	5.973E-87
10	1	16	1	11.45	0.00	15.64	-0.171	0.016	0.327	40.822	1.03	11.73	-60.15	6.336E-45
10	1	24	1	8.80	0.00	15.64	-0.054	0.017	0.211	26.158	1.04	9.15	-4.45	2.455E-26
10	1	32	1	7.17	0.00	15.64	0.011	0.016	0.145	19.024	1.06	7.57	29.49	7.530E-18
10	1	48	1	5.34	0.00	15.64	0.080	0.016	0.076	10.577	1.10	5.89	67.83	3.965E-09
10	1	64	1	4.29	0.00	15.64	0.117	0.016	0.040	6.010	1.20	5.14	89.17	4.542E-05
10	1	80	1	3.73	0.00	15.64	0.140	0.016	0.017	3.099	1.48	5.51	102.59	8.992E-03
10	1	96	1	3.25	0.00	15.64	0.156	0.016	0.001	1.083	13.03	42.37	112.10	6.763E-01
10	1	104	1	3.05	0.00	15.64	0.160	0.016	-	-	-	∞	115.41	-

Appendix 10. Scenario 3 & 4: Parameter values of the option to invest in planting domesticated indigenous fruit trees – higher fruit quality.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta\text{-}1)$	V^*[5)]	V[5)]	B
2	1-3	1	1	22.45	0.00	15.64	-0.305	0.145	0.461	7.364	1.16	25.98	-86.88	1.350E-10
2	1-3	1	1.1	22.45	0.00	15.64	-0.211	0.147	0.367	5.999	1.20	26.94	-40.37	1.177E-08
2	1-3	1	1.3	22.45	0.00	15.64	-0.043	0.145	0.199	3.751	1.36	30.61	31.03	2.181E-05
2	1-3	1	1.5	22.45	0.00	15.64	0.099	0.146	0.057	1.782	2.28	51.16	83.19	2.589E-02
2	1-3	1	1.6	22.44	0.00	15.64	0.1687	0.1428	-	-	-	∞	105.21	-
2	1-3	1	1	22.45	0.00	15.64	-0.305	0.145	0.461	7.364	1.16	25.98	-86.88	1.350E-10
2	1-3	1.3	1	20.72	0.00	15.64	-0.145	0.142	0.301	5.255	1.24	25.59	-13.92	1.939E-07
2	1-3	1.5	1	19.71	0.00	15.64	-0.065	0.144	0.222	4.083	1.32	26.10	27.89	1.050E-05
2	1-3	1.7	1	18.79	0.00	15.64	0.005	0.143	0.152	3.123	1.47	27.64	66.61	2.790E-04
2	1-3	2	1	17.56	0.00	15.64	0.094	0.138	0.062	1.901	2.11	37.05	118.99	2.032E-02
2	1-3	2.2	1	16.84	0.00	15.64	0.1386	0.1377	0.0178	1.26	4.86	81.85	146.68	2.539E-01
2	1-3	6	1	9.45	0.00	15.64	1.092	0.370	-	-	-	∞	453.07	-

Appendix 11. Scenario 5 & 6: Parameter values of the option to invest in planting domesticated indigenous fruit trees – risk-free rate of return 3%.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta$-1)	V^*[5)]	V[5)]	B
2	1	1	1	20.56	3.00	14.06	-0.887	0.022	1.028	90.069	1.01	20.79	-288.32	4.655E-120
2	1	1	2	20.56	3.00	14.06	-0.194	0.022	0.335	28.339	1.04	21.31	-33.72	1.670E-38
2	1	1	2.6	20.56	3.00	14.06	0.069	0.022	0.072	5.316	1.23	25.33	25.01	1.647E-07
2	1	1	2.7	20.58	3.00	14.06	0.108	0.022	0.033	2.399	1.71	35.28	32.48	2.849E-03
2	1	1	2.8	20.56	3.00	14.06	0.143	0.022	-	-	-	∞	39.16	-
2	1	1	1	20.56	3.00	14.06	-0.887	0.022	1.028	90.069	1.01	20.79	-288.32	4.655E-120
2	1	6	1	8.76	3.00	14.06	-0.082	0.016	0.222	24.548	1.04	9.13	-18.54	9.890E-25
2	1	8	1	7.19	3.00	14.06	-0.012	0.016	0.153	16.645	1.06	7.65	16.63	8.960E-16
2	1	12	1	5.39	3.00	14.06	0.063	0.016	0.078	7.485	1.15	6.22	57.38	9.495E-07
2	1	16	1	4.35	3.00	14.06	0.1036	0.0158	0.0370	3.11	1.47	6.41	81.08	6.402E-03
2	1	20	1	3.71	3.00	14.06	0.1284	0.0158	0.0122	1.42	3.37	12.50	95.62	2.426E-01
2	1	24	1	3.25	3.00	14.06	0.1449	0.0158	-	-	-	∞	105.81	-

Appendix 12. Scenario 5 & 6: Parameter values of the option to invest in planting domesticated indigenous fruit trees – risk-free rate of return 5%.

Maturity[1)]	Fruit price[2)]	Yield [3)]	Collection costs[4)]	I[5)]	r[6)]	μ[6)]	α	σ	δ	β	$\beta/(\beta\text{-}1)$	V^*[5)]	V[5)]	B
2	1	1	1	19.17	5.00	13.00	-0.854	0.022	0.984	85.445	1.01	19.40	-279.23	2.071E-111
2	1	1	2	19.18	5.00	13.00	-0.160	0.022	0.290	22.628	1.05	20.07	-25.93	2.979E-30
2	1	1	2.5	19.17	5.00	13.00	0.064	0.022	0.066	3.709	1.37	26.25	24.99	3.855E-05
2	1	1	2.6	19.17	5.00	13.00	0.103	0.022	0.027	1.644	2.55	48.92	32.83	4.958E-02
2	1	1	2.7	19.17	5.00	13.00	0.142	0.022	-	-	-	∞	40.15	-
2	1	1	1	19.17	5.00	13.00	-0.854	0.022	0.984	85.445	1.01	19.40	-279.23	2.071E-111
2	1	6	1	7.99	5.00	13.00	-0.069	0.016	0.199	19.410	1.05	8.42	-11.72	4.699E-19
2	1	8	1	6.54	5.00	13.00	-0.002	0.017	0.132	11.402	1.10	7.17	**22.66**	1.111E-10
2	1	12	1	4.91	5.00	13.00	0.071	0.016	0.059	3.803	1.36	6.67	**62.10**	1.290E-03
2	1	16	1	4.01	5.00	13.00	0.1088	0.0162	0.0213	1.52	2.93	11.76	**84.08**	1.837E-01
2	1	20	1	3.37	5.00	13.00	0.1338	0.0157	-	-	-	∞	99.22	-

1) years
2) times the non-domesticated level
3) times the non-domesticated level
4) times the current level
5) ZWD day^{-1}
6) %