

Waibel, Hermann; Wesseler, Justus; Mithöfer, Dagmar

**Conference Paper**

## R&D and private investment: How to conserve indigenous fruit biodiversity of Southern Africa

Proceedings of the German Development Economics Conference, Kiel 2005, No. 35

**Provided in Cooperation with:**

Research Committee on Development Economics (AEL), German Economic Association

*Suggested Citation:* Waibel, Hermann; Wesseler, Justus; Mithöfer, Dagmar (2005) : R&D and private investment: How to conserve indigenous fruit biodiversity of Southern Africa, Proceedings of the German Development Economics Conference, Kiel 2005, No. 35, Verein für Socialpolitik, Ausschuss für Entwicklungsländer, Hannover

This Version is available at:

<https://hdl.handle.net/10419/19826>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

1 R&D and private investment: How to conserve indigenous fruit biodiversity  
2 of Southern Africa

3  
4 Dagmar Mithöfer<sup>\*</sup>, Justus Wesseler<sup>+</sup> and Hermann Waibel<sup>\*</sup>

5  
6 **Abstract**

7 Indigenous fruits contribute widely to rural incomes in Southern Africa but their  
8 availability is declining. A domestication program aims to increase farm-household  
9 income and conserve biodiversity through farmer-led tree planting. Planting domesticated  
10 indigenous fruit trees is an uncertain, irreversible but flexible investment. Our analysis  
11 applies the real option approach using contingent claims analysis, which allows solving  
12 the discounting problem. The article analyses (1) to what level fruit collection cost and/or  
13 (2) the necessary technical change, i.e. breeding progress, have to rise in order to render  
14 tree planting economical, using data from income portfolios of rural households in  
15 Zimbabwe. Results currently show that collecting indigenous fruits is more profitable  
16 than planting the trees. A combination of technical change and decrease in resource  
17 abundance can provide incentives for farmer-led planting of domesticated trees and  
18 biodiversity conservation. However, breeding progress must be significant for investment  
19 in tree planting to be economically attractive.

---

*\* Department of Economics and Business Administration, University of Hannover, Königsworther Platz 1, 30167 Hannover, Germany, Tel.: ++49-511-7622666; fax: ++49-511-7622667, E-mail address: mithoefer@ifgb.uni-hannover.de (D. Mithöfer).*

*+ Department of Social Sciences, University of Wageningen, IMAG building, Mansholtlaan 10-12, 6708 PG Wageningen, The Netherlands.*

20

21 *JEL classification:* Q16, Q01, Q23, O13

22 *Keywords:* indigenous fruits; real option; technology adoption; uncertainty; ex ante

23 impact assessment; Zimbabwe.

24

## 25 **1. Introduction**

26 The countries of Southern Africa possess rich plant biodiversity especially in the  
27 ecozone of the Miombo woodlands. A wide variety of indigenous fruit trees (IFT) has  
28 long been a natural resource available in common forest land. Their fruits are extensively  
29 used for home consumption and are increasingly being commercialized by the rural  
30 population (Chidari et al., 1992; Maghembe et al., 1994; Maghembe et al., 1998;  
31 Cavendish, 2000).

32 Declining per capita income and a number of other factors (Chipika and Kowero,  
33 2000; Deininger and Minten, 2002) have accelerated deforestation at an estimated annual  
34 rate of 1.5% (FAO, 2001) and have consequently caused biodiversity loss with a negative  
35 impact on rural poverty (Scherr, 2003). Often, protected areas are created for biodiversity  
36 conservation. However, as Adams et al. (2004) show in their review, trade-offs between  
37 biodiversity conservation via protected areas and poverty alleviation exist and win-win  
38 solutions are difficult to achieve.

39 Another strategy to halt loss of tree resources and thus to conserve biodiversity is tree  
40 domestication, i.e. advancing favorable traits of the trees so that farmer-led planting leads  
41 to a higher abundance of the trees. Such an approach is the World Agroforestry Centre's  
42 (ICRAF) domestication program, which aims to enhance planting of indigenous fruit  
43 trees with improved fruit quality and higher yields and thus to alleviate poverty by  
44 enhancing farmers' income and at the same time to conserve biodiversity (ICRAF, 1996).  
45 This program has emerged as a result of the on-going debate on the future direction of  
46 rural development efforts in Africa. Some approaches favor biotechnology and an  
47 expansion of the green revolution technologies; others call for conserving and enhancing  
48 the diversity of the crops available (Leakey et al., 2004). The domestication program is

49 part of the latter strategy. The untapped potential of wild plants is seen as a source of  
50 growth for the rural economies in tropical countries, as a means to motivate improved  
51 conservation of the wild areas, which supply these crops (Evans and Sengdala, 2002), and  
52 as a means to enhance productivity and sustainability of agroforestry systems (Simons,  
53 1996).

54 However, domestication as a means of enhancing biodiversity can be contradictory,  
55 since selection may reduce genetic variability (Perman et al., 1999). On the other hand, it  
56 can also promote widespread distribution of the plant due to its now enhanced favorable  
57 characteristics (Pollan, 2002).

58 In order to contribute to biodiversity conservation by farmer-led tree planting, a  
59 domestication program must render tree planting economically attractive. The question is  
60 when do rural households switch from fruit collection in communal areas to cultivating  
61 them on-farm<sup>1</sup>.

62 Farm investment in planting IFT can be seen as a decision under irreversibility,  
63 flexibility and uncertainty and hence the real option approach applies. Several  
64 applications of the real option approach for investments under uncertainty in agriculture  
65 exist (Purvis et al., 1995; Winter-Nelson and Amegbeto, 1998; Price and Wetzstein,  
66 1999; Carey and Zilberman, 2002; Demont et al., 2004). The real option value can be  
67 identified either by dynamic programming or contingent claim analysis. The dynamic  
68 programming approach requires the knowledge of risk and time preference of the  
69 decision maker, whereas an application of the contingent claim analysis is independent of  
70 these individual preferences under a quadratic utility function (Dixit and Pindyck, 1994).

---

<sup>1</sup> Simons and Leakey (2004) distinguish non-timber forest products that are usually extracted from the forest from agroforestry tree products that may be the same products but stem from domesticated trees.

71 Previous studies either assume a discount rate or assume that the underlying risk of the  
72 investment can be hedged without explicitly deriving the risk-adjusted rate of return. In  
73 this article we use contingent claims analysis and derive the risk-adjusted rate of return  
74 from a portfolio of farmers' investment opportunities. Our analysis is a first attempt to  
75 model ex-ante decisions explicitly in the real option context using farm households'  
76 investment opportunities to construct riskless portfolios. We argue that this approach is  
77 feasible as farmers in Southern Africa use a diversity of investment activities and in the  
78 context of an African village do have equal access to information. We use the results of  
79 our model to answer the following questions:

80     ⇒ What is the extent of improvement in tree performance that is necessary to induce  
81         farmers to invest?

82     ⇒ By how much have the costs of natural resource use to increase to trigger on-farm  
83         investment in domesticated trees?

84     The first aspect is modeled as technical change by shifting the age of first fruiting,  
85     increasing the yield, and increasing fruit quality. The latter aspect is modeled by  
86     increasing the labor costs of collecting fruits from the communal areas. Furthermore, the  
87     prospects of the domestication strategy for biodiversity conservation and poverty  
88     alleviation are discussed by relating the model results to the economic, institutional and  
89     ecological changes likely to take place in Southern Africa.

90     The article is organized as follows. First, we derive the value of an investment in  
91     planting of domesticated indigenous fruit trees using the real option approach and  
92     contingent claim analysis. Then, the study area and data are presented and applied to the  
93     investment question. A numerical example from a village in Zimbabwe is used to  
94     illustrate the results with respect to the most popular indigenous fruit tree species, Uapaca

95 kirkiana, as determined by Maghembe et al. (1998). At the end, conclusions are drawn for  
 96 the indigenous fruit tree domestication program and the prospects of farmer-led planting  
 97 to conserve indigenous fruit trees.

98

## 99 **2. The investment model**

100 Expected returns from planting trees depend on time, quantity and price of tree  
 101 products. These are determined by physical factors and can be formalized by age-yield  
 102 functions. Alternatives of allocating land and labor, such as extending agricultural  
 103 production or collecting fruits from the wild, may exist; hence planting of trees includes  
 104 opportunity costs.

105 The net present value,  $NPV_{DT}$ , of profits from an orchard of domesticated indigenous  
 106 fruit trees,  $DT$ , providing multiple product benefits,  $b_t$ , planted at  $t=0$  is:

107

$$108 \quad NPV_{DT1} = V_{DT1} - I = \int_{t=0}^T (b_t - c_t) e^{-\mu t} dt - R_T \cdot e^{-\mu T} - I. \quad (1)$$

109

110  $V_{DT1}$  is the present value of planting indigenous fruit trees, where the subscript  
 111 indicates the number of rotations. In year  $t=0$ , costs include initial irreversible investment  
 112 cost,  $I$ . In year  $T$ , the end of the optimal life span of the orchard, the costs of uprooting the  
 113 plantation and benefits from harvest of timber are included via  $R$ . During the lifetime of  
 114 the orchard, costs,  $c_t$ , occur due to management of the orchard and harvesting the fruits.  
 115 Benefits from the multiple tree products are accounted for in  $b_t$ . Costs and benefits are  
 116 discounted by the risk-adjusted discount rate,  $\mu$ . If opportunity costs of land are lower  
 117 than expected returns from the orchard, the farmer can be expected to continuously

118 replant the orchard. The optimal rotation rate,  $T$ , is found where the marginal benefit of  
 119 the plantation left growing for an additional period equals the marginal opportunity cost  
 120 of this choice, i.e. site value and capital tied up (Hartman, 1976; Perman et al., 1999). The  
 121 maximum net present value over an infinite sequence of orchard rotations is given by  
 122  $\frac{V_{DT1} - I}{1 - e^{\mu T}}$  (Perman et al., 1999). In the following, the subscript  $\infty$  is omitted and NPV  
 123 always indicates the maximum net present value of an infinite investment sequence in  
 124 domesticated indigenous fruit trees. The incremental benefit of an investment in planting  
 125 domesticated indigenous fruit trees is given by  $V = (NPV + I)_{DT\infty} - (NPV_{C\infty})$ , where  
 126  $NPV_{C\infty} = V_C$  constitutes the net present value of collecting the fruits from the communal  
 127 areas. Collection of indigenous fruit tree products from the wild constitutes an alternative  
 128 to obtaining the fruits by planting trees. Opportunity costs of land for planted IFT are  
 129 assumed to be zero, as in the area under consideration space for planting a few trees is no  
 130 constraint.

131 If one assumes that the option to invest is owned by well-diversified farmers who  
 132 hold efficient portfolios, then they need only to be compensated for the systematic  
 133 component of the investment risk. According to the Capital Asset Pricing Model, the  
 134 expected risk premium in a competitive market varies in direct proportion to the  
 135 systematic risk. The price for one unit of the non-diversifiable risk of the investment  $V$  is  
 136 the risk-adjusted discount rate,  $\mu = r + \phi Cov[r_m r_V]$ .  $\mu$  is determined by the risk-free rate  
 137 of return,  $r$ , the market price of risk,  $\phi = \frac{E[r_m] - r}{Var[r_m]}$ , the market rate of return,  $r_m$ , and the  
 138 rate of return of  $V$ ,  $r_V$  (Trigeorgis, 1998).



139 As mentioned in the introduction, farmers do not face a dichotomous choice of  
 140 planting now or never, but are flexible in carrying out the investment in IFT. They also  
 141 face uncertainty about future benefits and costs of their investment in domesticated  
 142 indigenous fruit trees, which influences their optimal timing of investment (McDonald  
 143 and Siegel, 1986)<sup>2</sup>. The farmers' aim can be described as to maximize the value of the  
 144 option to invest,  $F(V,t)$ .  $F(V,t)$  can be derived by replicating the costs and benefits under  
 145 uncertainty using alternative investment opportunities with known values (spanning  
 146 assets). By assuming the value  $V$  of the investment follows a geometric Brownian motion  
 147 of the form  $dV = \alpha V dt + \sigma V dz$ , with  $\alpha$  being the growth rate,  $\sigma$  the variance rate,  $dz$  a  
 148 Wiener process, and solving for the critical value,  $V^*$ , using the smooth pasting and value  
 149 matching conditions and the information that the value of an option to invest is zero,  
 150  $F(V,t) = 0$ , if the value of the investment  $V = 0$ , provides the following result (Dixit and  
 151 Pindyck, 1994):

152

$$153 \quad V^* = \frac{\beta}{\beta - 1} I, \text{ with } \beta = \frac{1}{2} - (r - \delta) / \sigma^2 + \sqrt{\left[ (r - \delta) / \sigma^2 - \frac{1}{2} \right]^2 + 2r / \sigma^2}. \quad (2)$$

154

155  $\delta$  is the convenience yield and equivalent to the dividend in financial economics; it is  
 156 a benefit that accrues from holding the project. The relationship between convenience  
 157 yield, risk-adjusted discount rate and growth rate is given through  $\delta = \mu - \alpha$ .

---

<sup>2</sup> In the literature on real option valuations, the opportunity to invest is valued in analogy to a call option in financial markets. The investor has the right but not the obligation to exercise his investment. This right has a value, which is a result of the option owner's flexibility and is similar to the quasi-option value developed earlier by Arrow and Fisher (1974) and Henry (1974) (Fisher, 2000).

158 Equation 2 implies that the value of immediate investment  $V$  should be at least as  
159 high as the irreversible investment times the hurdle rate, which is the ratio of  $\beta/(\beta-1)$ . If  
160 the current level of  $V$  is less than  $V^*$  it is worthwhile to postpone the planting of  
161 domesticated IFT. If  $V$  exceeds  $V^*$  then immediate investment would be the right  
162 decision (Dixit and Pindyck, 1994; see appendix for the details).

163 For the calculation of  $V$  and  $V^*$ , information about the NPV of planting IFT is  
164 required, as well as the growth and variance rate,  $\alpha$  and  $\sigma$  of the geometric Brownian  
165 motion. Similar to the application of Purvis et al. (1995) and Winter-Nelson and  
166 Amegbeto (1998), the discrete change of  $V$  between  $V_{DT}$  and  $V_C$  can be defined as the  
167 difference between their natural logarithms. Through Monte Carlo simulation values for  
168  $V_{DT}$  and  $V_C$  are generated (using @risk, Palisade (2000) and Excel software) and used to  
169 estimate the growth rate and the variance rate. The benefits and costs of planting trees  
170 and information about investment alternatives are collected from the field and are  
171 explained in more detail in the following section.

172

### 173 **3. Study area and data**

174 Data was collected in ward 16, Murehwa District, which is a major collection area for  
175 U. kirkiana fruits in Zimbabwe. The area is located along the road to Mozambique and  
176 Malawi, about 80 km east of Harare and close to a thriving market and bus stop. A  
177 sample of 19 households was monitored from August 1999 to August 2000. Monitoring  
178 of case study households on a monthly basis allowed detailed data collection. Price  
179 information, cash income, in-kind income, and expenditure as well as labor flows were  
180 monitored with respect to indigenous and exotic fruit trees, cultivation of horticultural

181 and agricultural crops, keeping of livestock, household and off-farm activities (further  
182 referred to as ‘Survey’).

183

### 184 *3.1. Management and production parameters*

185 The investment analysis is carried out for an orchard with initially 35 seedlings  
186 planted, of which only seven trees survive due to low germination (80%) and seedling  
187 survival (20%) rate (Chidumayo, 1997). With a grafting success rate of 70% for a skilled  
188 grafter (Mhango et al., 2002), the orchard finally consists of five improved trees. Grafting  
189 is assumed to take place in situ. It is assumed that once trees have survived the first year  
190 mortality drops down to zero percent. It is further assumed that farmers buy each seedling  
191 at its production cost that includes labor valued at the local wage rate and material inputs.  
192 Labor requirements for seedling production are available from the ICRAF Research  
193 Station in Makoka, Malawi (Maghembe, 1999; Appendix table A1).

194 Experience with orchards of deliberately planted indigenous fruit trees is scarce,  
195 therefore it is assumed that an orchard of planted indigenous fruit trees requires, on  
196 average, management strategies that are similar to those of exotic fruit trees (Appendix  
197 table A2).

198 Opportunity costs of labor are subject to seasonal fluctuations. They also vary  
199 depending on the extent of kinship and of neighborhood-ties between employer and  
200 employee. Labor costs accounted for in the investment model are valued at the average  
201 wage rate over the year as well as over varying labor tasks. The wage rate also includes  
202 payments in-kind.

203

204

205 3.2. *The age yield function*

206 A pre-requisite for analysis of investment into indigenous fruit tree planting is  
 207 knowledge about the respective age-yield functions. Data on growth and yield  
 208 characteristics of indigenous fruit trees is not available from trials. Thus, indigenous fruit  
 209 trees preserved by the farmers who participated in the survey were recorded in tree  
 210 inventories. For U. kirkiana 38 trees were included in the inventory. The farm owners  
 211 estimated the minimum, the maximum and modal yield the trees produced per year and  
 212 provided information about the age at first fruiting. Additionally, experts from ICRAF  
 213 and other research institutions in the region were informally interviewed with respect to  
 214 the age-yield relationship in order to supplement the farmer information.

215 From farmers' yield estimates and expert information, age yield functions<sup>3</sup> for the  
 216 minimum, the maximum and the modal yield were approximated using the Hoerl  
 217 Function,  $u = \upsilon g^{\zeta} e^{\kappa g}$ , as commonly done (Haworth and Vincent, 1977). Yield in a given  
 218 year,  $u$ , solely depends on age,  $g$  (here productive period); the coefficients  $\upsilon$ ,  $\zeta$ ,  $\kappa$  are  
 219 estimated via linear regression. Fruit yield for each age is defined as a triangular  
 220 distribution, with the minimum and maximum as lower and upper boundary, from which  
 221 data are drawn stochastically. Figure 1 shows the age yield production functions used.  
 222 Year zero is the age at which the tree bears fruits for the first time. Fruiting sets in  
 223 between 11 and 16 years of age for non-improved IFT according to farmers' observation.

---

<sup>3</sup> 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, instead of age yield functions productive production yield functions are established. Observations on the tree's productive period are found to be more reliable than information on the age of the tree.

224 One draw in the simulation for the realization of the yield serves as yield estimate for all  
225 trees within the orchard. Alternate fruit production<sup>4</sup> is not explicitly considered.

226

227

### **Insert Figure 1**

228

229 Fruit prices are considered to follow a uniform distribution between ZWD<sup>5</sup>/kg 0.4  
230 and ZWD/kg 18, which are the minimum and maximum farm gate price households  
231 received in 1999/ 2000. Harvesting labor estimates are based on data for harvesting time  
232 of indigenous fruits from trees that farmers preserved in their fields and around the  
233 homestead.

234 In addition to the revenues from fruit production, income obtained from leaf- and  
235 wood-products is considered. Leaf and wood production functions are found in  
236 Chidumayo (1997). Those products have been priced by either using market prices or  
237 prices of surrogates.

238

### 239 *3.3. Identification of the risk-adjusted rate of return*

240 The risk-adjusted rate of return is determined via returns on the farm-household's  
241 market portfolio using the Capital Asset Pricing Model. The risk-free interest rate is  
242 specified through the interest rate on membership in a savings club<sup>6</sup>, which is zero<sup>7</sup>. The

---

<sup>4</sup> Biannual fruit production is a well-known phenomenon in fruit production and tree management (Mwamba, 1996).

<sup>5</sup> USD 1 = ZWD 38, December 1999.

<sup>6</sup> Savings clubs consist of a group of households who contribute cash or storable goods in-kind towards the club at regular intervals. At pre-defined dates the items are distributed back amongst the club

243 market portfolio is defined as the portfolio of all agricultural, horticultural, livestock-  
 244 keeping and off-farm activities that small-scale farmers pursue. Variability in the rates of  
 245 return on the portfolio titles over the cross section is assumed to project variability of the  
 246 market portfolio (see appendix table A3 and A4 for rates of return of farm household  
 247 activities). The expected rate of return on the market portfolio,  $E[r_m]$ , is the sum over the  
 248 weighted expected rates of return on each title in the portfolio,  $\sum_{a=1}^A \omega_a E[r_a]$ . The rate of  
 249 return of activity  $a$ ,  $r_a = \frac{O_a}{C_a + LC_a + D_a} - 1$ , is defined as depending on the gross income,  
 250  $O_a$ , variable cost,  $C_a$ , opportunity cost of land,  $D_a$ , and labor cost,  $LC_a$ , of activity  $a$ .  
 251 Labor costs include family labor, which is valued at the average wage rate.

252  $E[r_a]$  is the expected rate of return on activity  $a$ , which is the average over the sample  
 253 of households. The weight of activity  $a$  in the portfolio,  $\omega_a$ , is given by

254 
$$\frac{1}{N} \sum_{n=1}^N \frac{C_{an} + LC_{an} + D_{an}}{\sum_{a=1}^A C_{an} + LC_{an} + D_{an}}$$
 with  $N$  as the number of farmers in the sample.

255 Costs and revenues of all activities considered for constructing the portfolio are  
 256 valued at the average price over the period August 1999 – August 2000. Thus, rates of

---

members and thus protect them from inflation. These payments can also be interpreted as informal loans that are handed out and received on a rotating principle. 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 detailed discussion) or they are a means to cover lumpy expenditure (Besley et al., 1993).

<sup>7</sup> 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, but most are members of savings clubs.

257 return for farming activities are adjusted for inflation by using 50% of the GDP deflator  
 258 (59.9%) provided by the World Bank (2003).

259 The variance of the market portfolio can be described through a linear combination of  
 260 the variances and covariances of the rates of return of its titles,  $r_a$  and  $r_k$ :

261  $Var[r_m] = \sum_{a=1}^A \sum_{k=1}^A \omega_a \omega_k Cov[r_a, r_k]$ . The covariance between the market rate of return and

262 the rate of return of planting domesticated trees is estimated via the covariance between  
 263 the rates of return of the tree use sector,  $r_{trees}$ , i.e. collection of indigenous fruits and  
 264 production of exotic fruits, and the rates of return on the market portfolio.  $r_{trees}$  is  
 265 computed analogously to the rate of return on the titles of the market portfolio.

266 Comparison between the rates of return on titles in the market portfolio and rates of  
 267 return on the trees use sector shows that the latter provides relatively high rates of return.  
 268 The expected rate of return on the market portfolio is 10.24%. The variance of the market  
 269 portfolio is at 0.1671, which is relatively low (Appendix table A5). The resulting market  
 270 price of risk is about 0.6125 when using the risk-free rate of return of zero percent. When  
 271 the risk-free rate of return increases, the market risk premium,  $E[r_m] - r$ , decreases and  
 272 consequently the market price of risk also decreases. In the present case, this results in an  
 273 overall decrease of the risk-adjusted rate of return given the covariance of returns on trees  
 274 and returns on the market portfolio (0.2554) (Appendix table A6).

275 The systematic risk of the tree sector can be expressed by the so-called beta factor,

276  $\frac{Cov[r_m r_V]}{Var[r_m]}$ , which is 1.53. The market portfolio has a beta factor of one; thus, in

277 comparison, the tree sector amplifies the overall movements of the market portfolio. The  
 278 risk-adjusted rate of return is at 15.64% for a risk-free rate of return of zero percent. It is

279 higher than the rate of return of the market portfolio, which shows a positive risk  
 280 premium for using trees due to the characteristics of the beta factor of the tree sector.

281

### 282 3.4. The opportunity costs – Collecting fruits from communal land

283 Revenue from collecting indigenous fruit tree products from the wild net of  
 284 collection cost can be interpreted as annuity. The revenue ranges from ZWD 262 – ZWD  
 285 6528 with a mean of ZWD 1285. If the annuity of collection is simulated based on  
 286 stochastic prices following a uniform distribution with the minimum and maximum farm  
 287 gate price as lower and upper bound, respectively, the average value is equal to ZWD  
 288 3187 with a standard deviation (SD) of ZWD 1935. The annuity of planting non-  
 289 domesticated fruit trees, which mature between 11 and 16 years of age, is, on average  
 290 ZWD -158 (SD 208).

291 The costs and benefits of IFT products from planted trees are difficult to compare  
 292 with the collection of IFT products from the communal areas. In order to conduct such  
 293 comparison,  $V$  is established on the basis of returns to labor,  $V_L$ :

294

$$295 \quad V_L = \frac{\left[ \frac{(NPV_{DT} + \int_{t=0}^T (LC_{DT,t}) e^{-\mu t} dt + I)}{\int_{t=0}^T (L_{DT,t}) e^{-\mu t} dt} \right] - \left[ \frac{NPV_C + \int_{t=0}^T (LC_{C,t}) e^{-\mu t} dt}{\int_{t=0}^T (L_{C,t}) e^{-\mu t} dt} \right]}{1 - e^{-\mu T}}. \quad (3)$$

296

297 The first term of the numerator on the right-hand-side of equation 3 refers to the  
 298 value per man-day from planting domesticated trees and the second term to the value per  
 299 man-day from collecting fruits from the wild.  $L_{DT}$  and  $L_C$  are the annual number of man-



300 days and  $LC_{DT}$  and  $LC_C$  the labor costs per man-day for planting improved trees and  
301 collection from the wild, respectively.

302 Returns to labor from planting non-domesticated species are below returns to  
303 collecting the fruits from the wild (Appendix table A7), thus, the option to plant non-  
304 domesticated IFT equals zero. The question therefore remains how much collection costs  
305 have to rise or trees have to be improved so that the option to plant trees is of value.

306

### 307 *3.5. Investment scenarios*

308 The expected economic gain from planting domesticated indigenous fruit trees  
309 depends on the level of tree improvements and the relative level of opportunity costs, i.e.  
310 collection of the fruits from the communal areas. Improvements of the domesticated trees  
311 can occur with respect to selection (breeding) of superior species, e.g. taste and fruit size  
312 can be improved, and through establishing appropriate vegetative propagation methods.  
313 The latter is a pre-requisite for shortening the period to reach the first fruiting. Two main  
314 scenarios, an improvement in economic IFT fruit productivity due to technical change,  
315 subdivided in reduced time period until fruiting, increased yield level and higher fruit  
316 quality and a decrease in the returns to labor for collection of fruits from communal areas  
317 are analyzed and compared (Appendix table A8).

318

## 319 **4. Results**

### 320 *4.1. Age of first fruiting and rising natural resource use cost (Scenario 1)*

321 Table 1 explores the interaction between tree improvements, i.e. advancing age at  
322 first fruiting and increasing collection costs of fruit from the communal areas. Simulation  
323 results show that a shift of first fruiting to two years of age is not sufficient to trigger

324 investment. Additionally, the costs of collecting fruits from the communal areas have to  
325 rise, if the yield function remains the same as for non-domesticated IFT. As the growth  
326 rate grows closer to the risk-adjusted discount rate, the hurdle rate increases, thus waiting  
327 turns out to be of higher value. Once the growth rate exceeds the risk-adjusted discount  
328 rate, it would always pay to wait. However, not only the hurdle rate and thus the trigger  
329 value, but also the present value of investment increases with increasing collection cost.  
330 Investment in planting improved indigenous fruit trees according to the conventional  
331 NPV approach would require the present value of investment to exceed initial investment  
332 cost, i.e. ZWD 23 per man-day. When collection costs increase by 2.8 to 2.9 times and  
333 first fruiting sets in at an age of two years, farmers can be expected to invest immediately.  
334 At a threefold increase of collection costs, waiting becomes the profit maximizing  
335 strategy.

336

337

### **Insert Table 1**

338

339 However, if the costs of natural resource use increase and also age at which planted  
340 improved trees produce the first fruits, the increase in the trigger value is relatively  
341 stronger than the present value of investment. Thus farmers will wait to invest.

342 The gap between the trigger value and the present value increases the older the trees  
343 are at the first fruiting. Without increasing the level of yield in addition to inducing  
344 precocity, the minimum improvement to initiate investment is a start of fruit production  
345 at two years of age, even with increasing costs of IF collection from the communal areas.

346

347

348 *4.2. Age of first fruiting and increased yield (Scenario 2)*

349 Table 2 shows the results of Scenario 2, which analyses the effects of a yield increase  
350 in addition to a shift of the first fruiting. The yield increase is modeled as a shift of the  
351 modal yield while the difference between the minimum and maximum yield and the  
352 modal yield level is kept constant. Thus the variance of the yield remained constant.  
353 Otherwise, a yield increase could be expected to result in larger hurdle rates due to the  
354 increased variance.

355

356

**Insert Table 2**

357

358 Results presented in table 2 show with increasing yield level, labor input into  
359 harvesting of the fruits also increases, thus initial investment costs per man-day decrease.  
360 Overall, this results in a declining trigger value. As the present value of investment  
361 grows, investment is triggered at a ninefold yield increase compared to the level of non-  
362 domesticated trees. At this level of improvement, the present value also exceeds initial  
363 investment cost. Such a yield increase implies that instead of producing between 35 and  
364 113 kg of fruits per tree (modal yield 64 kg per tree), improved trees bear between 547  
365 and 624 kg per tree (modal yield 576 kg per tree). Of course, with respect to the  
366 implications of these results, it has to be discussed amongst breeders whether this is a  
367 feasible improvement; e.g. is the tree structure strong enough to bear the additional load?

368 Since it is not quite clear whether advancing first fruiting to an age of two years is a  
369 feasible improvement, trigger and present values of yield increases in combination with  
370 older age at first fruiting are calculated. In addition to inducing first fruiting at an age of  
371 four years, a yield increase of between 10 and 40 times the non-domesticated level would

372 be required to trigger immediate investment. Yield increases of 40 times and more imply  
373 that waiting to invest would be a better strategy. This result is mainly driven by the high  
374 growth rate of the incremental benefit of investment. Thus, the older the trees are at the  
375 first yield, the higher the required improvement of the yield level to initiate adoption of  
376 planting.

377

#### 378 *4.3. Improving fruit quality (Scenario 3 and 4)*

379 In addition to increasing yield and inducing precocity, fruit quality could be  
380 improved by selection of appropriate genotypes from the wild. It is assumed that such an  
381 improvement would result in a higher fruit price. Results reported in table 3 show that  
382 with heightened fruit quality a relatively lower growth in natural resource use cost  
383 triggers immediate investment, i.e. immediate investment would commence for collection  
384 cost increases by 1.3 to less than 2 times the current level. However, not only immediate  
385 investment but also waiting to invest turns the optimal strategy at lower levels of  
386 increased natural resource use costs as compared to the case where fruit quality is not  
387 improved.

388

389

#### **Insert Table 3**

390

391 The effect of fruit quality improvement in combination with yield improvements on  
392 the value of immediate investment and the value of waiting to invest is similar to the  
393 effect of the combination of fruit quality improvements and enhanced natural resource  
394 use costs. Furthermore, fruit quality improvements plus yield increases require lower  
395 levels of yield increases to trigger immediate investment than the scenario without

396 enhanced fruit quality does. Higher prices for domesticated fruits lead to an increase of  
397 the variance rate of  $V$ . This increases the hurdle rate and also the trigger value. This  
398 increased variance also leads to a higher value of the option to invest, since “an increase  
399 in variance increases the spread of possible future values for  $V/I$ , and hence the maximum  
400 possible gain, while leaving unchanged the maximum possible loss” (McDonald and  
401 Siegel, 1986, p. 714). Investment still commences on a lower level of improvement  
402 compared to the case of no fruit quality improvements, as the present value of investment  
403 grows relatively stronger than the trigger value.

404 With higher fruit prices, one could expect the risk-adjusted discount rate to adjust and  
405 this would also influence the covariance between the rate of return on the market  
406 portfolio and the rate of return of the spanning asset. Since the rate of return on the tree  
407 use sector is the weighted average return on all trees used, i.e. exotic and indigenous fruit  
408 trees, one can still claim that spanning holds and our model is still valid due to the  
409 domesticated (here: exotic) fruit trees in the portfolio.

410

#### 411 *4.4. Influence of the risk-free discount rate (Scenario 5 and 6)*

412 The influence of the risk-free rate of return on the investment decision is manifold.  
413 An increasing  $r$  that could result from changes in the economic conditions in Zimbabwe  
414 results in a decreasing risk-adjusted rate of return, which influences the optimal rotation  
415 period. Overall, the higher the risk-free interest rate, the lower the trigger value and the  
416 higher the present value as shown in table 4. This is surprising, since the hurdle rate  
417 grows with increasing  $r$ . However, the decline in the optimal rotation period also reduces  
418 labor input and thus the initial investment cost per man-day. For scenario 5, a rise in

419 collection costs does not trigger investment since the trigger value grows relatively  
420 stronger than the present value of investment.

421 With respect to scenario 6, as shown by results in Table 4, an increase of yield of  
422 more than six times is, *ceteris paribus*, sufficient to initiate investment.

423

424

#### **Insert Table 4**

425

426 Thus, the higher the risk-adjusted discount rate, the lower the yield improvements  
427 that trigger investment have to be.

428

#### **429 5. Conclusions**

430 Results show that under current conditions collecting the fruits from the wild is the  
431 profit maximizing strategy. Collection of the IFT products from forests and the common  
432 lands yields higher returns to labor as compared to planting unimproved trees. The real  
433 option approach shows that only a narrow range of technical change and natural resource  
434 use costs triggers immediate investment. This may explain why farmers do not  
435 immediately adopt many technologies but would rather wait. Even highly profitable  
436 technologies may not be adopted immediately due to a high option value. Option values  
437 in addition to net present values should be considered when evaluating R&D projects. In  
438 the present case, the analysis offers guidance to the domestication strategy in relation to  
439 resource allocation and *ex ante* impact assessment.

440 Our results suggest that under the current conditions in Zimbabwe the prospects of  
441 the domestication strategy for biodiversity conservation and poverty alleviation are dim.

442 It is shown that improvements of trees have to be substantial and ecological conditions

443 have to change dramatically to trigger immediate investment in planting. These are  
444 shown by the critical values that were derived for advancing the time of first fruiting,  
445 increasing yields and improving fruit quality. It can be concluded that under different  
446 conditions, e.g. Malawi, where deforestation is more pronounced and collection costs are  
447 high, adoption of tree planting could be faster. Generally, planting IFT could be  
448 economical for areas with a lower abundance of the IFT and therefore higher collection  
449 costs. To further validate these findings, research should be carried out in areas where the  
450 abundance of IFT is lower. Hence, data need to be collected from other Southern African  
451 countries, which have shown higher deforestation rates than Zimbabwe in the past.

452 Including externalities like the conservation of biodiversity, reduced soil erosion, and  
453 carbon sequestration can expand our analysis. This would provide the value of the option  
454 to plant from society's perspective. Hence, the conclusions can change if the effects of  
455 tree planting on regional and global commons are significant.

456 Furthermore, intra-household income distribution, gender aspects and property rights  
457 over planted trees and their products can change the value of the option to plant. The  
458 distribution of income within the household can influence total household welfare. For  
459 example, additional income to women has been shown to be beneficial to children's well-  
460 being (Alderman et al., 1995). On the other hand, divorce causes women to lose rights to  
461 land and the trees planted (Fortmann and Bruce, 1993; Fortmann et al., 1997). With  
462 respect to poverty alleviation the value of the option to plant may change if intra-  
463 household distributional weights are heterogeneous.

464 **Acknowledgements**

465 We thank the ICRAF team in Zimbabwe and Malawi, in particular Freddie Kwesiga,  
466 Elias Ayuk and Festus Akinnifesi for their comments and support during data collection.  
467 We also thank David Zilberman for his useful comments on this work. The German  
468 Ministry for Economic Cooperation and Development (BMZ) provided funds through  
469 ICRAF's 'Domestication of Indigenous Fruit Trees Programme'.

470

471 **References**

- 472 Adams, W. M., R. Aveling, D. Brockington, B. Dickson, J. Elliott, J. Hutton, D. Roe, B.  
473 Vira, and W. Wolmer, "Biodiversity Conservation and the Eradication of  
474 Poverty," *Science* 306 (2004), 1146–1149.
- 475 Alderman, H., P. A. Chiappori, L. Haddad, J. Hoddinott, and R. Kanbur, "Unitary Versus  
476 Collective Models of the Household: Is it Time to Shift the Burden of Proof?" *The*  
477 *World Bank Research Observer* 10 (1995), 1–19.
- 478 Arrow, K. J., and A. C. Fisher, "Environmental Preservation, Uncertainty and  
479 Irreversibility," *Quarterly Journal of Economics* 88 (1974), 312–319.
- 480 Besley, T., S. Coate, and G. Loury, "The Economics of Rotating Savings and Credit  
481 Associations," *The American Economic Review* 83 (1993), 792–810.
- 482 Carey, J.M., and D. Zilberman, "A Model of Investment under Uncertainty: Modern  
483 Irrigation Technology and Emerging Markets in Water," *American Journal of*  
484 *Agricultural Economics* 84, no. 1 (2002), 171–183.
- 485 Cavendish, W., "Empirical Regularities in the Poverty-Environment Relationship of  
486 Rural Households: Evidence from Zimbabwe," *World Development* 28, no. 11  
487 (2000), 1979–2003.



- 488 Chidari, G., F. Chirambaguwa, P. Matsvimbo, A. Mhiripiri, P. Kamanya, W. Muza, T.  
489 Muyombo, H. Chanakira, J. Chanakira, X. Mutsvangwa, A. Mvumbe, P.  
490 Nyamadzawo, L. Fortmann, R. B. Drummond, and N. Nabane, “The Use of  
491 Indigenous Fruit Trees in Mhondoro District,” Centre for Applied Social  
492 Sciences, University of Zimbabwe, Working Paper vol. 5 (1992).
- 493 Chidumayo, E., *Miombo Ecology and Management. An Introduction* (IT Publications:  
494 London, 1997).
- 495 Chipika, J. T., and G. Kowero, “Deforestation of Woodlands in Communal Areas of  
496 Zimbabwe: Is It Due to Agricultural Policies?” *Agriculture, Ecosystems and*  
497 *Environment* 79 (2000), 175–185.
- 498 Deininger, K., and B. Minten, “Determinants of Deforestation and the Economics of  
499 Protection: An Application to Mexico,” *American Journal of Agricultural*  
500 *Economics* 84 (2002), 943–960.
- 501 Demont, M., Wesseler, J., Tollens, E., “Biodiversity versus Transgenic Sugar Beet: The  
502 One Euro Question,” *European Review of Agricultural Economics* 31, no. 1 (2004),  
503 1–18.
- 504 Dixit, A. K., and R. S. Pindyck, *Investment under Uncertainty* (Princeton University  
505 Press: Princeton, New Jersey, 1994).
- 506 Evans, T. D., and K. Sengdala, “The Adoption of Rattan Cultivation for Edible Shoot  
507 Production in Lao PDR and Thailand - From Non-Timber Forest Product to Cash  
508 Crop,” *Economic Botany* 56 (2002), 147–153.
- 509 Fafchamps, M., and S. Lund, “Risk-Sharing Networks in Rural Philippines,” *Journal of*  
510 *Development Economics* 71 (2002), 261–287.

- 511 FAO, *Global Forest Resources Assessment 2000* (Food and Agriculture Organization of  
512 the United Nations: Rome, 2001).
- 513 Fisher, A. C., “Investment under Uncertainty and Option Value in Environmental  
514 Economics,” *Resource and Energy Economics* 22 (2000), 197–204.
- 515 Fortmann, L., C. Antinori, and N. Nabane, “Fruits of Their Labors: Gender, Property  
516 Rights, and Tree Planting in Two Zimbabwe Villages,” *Rural Sociology* 62  
517 (1997), 295–314.
- 518 Fortmann, L., and J. Bruce, “Tenure and Gender Issues in Forest Policy,” in P. N.  
519 Bradley, and K. McNamara, eds., *Living with Trees. Policies for Forestry  
520 Management in Zimbabwe* (The World Bank and the Stockholm Environment  
521 Institute: Washington and Stockholm, 1993), pp. 199–210.
- 522 Hartman, R., “The Harvesting Decision when a Standing Forest has Value,” *Economic  
523 Inquiry* 14 (1976), 52–58.
- 524 Haworth, J. M., and P. J. Vincent, “Medium Term Forecasting of Orchard Fruit  
525 Production in the EEC: Methods and Analysis,” *Agricultural Statistical Studies*  
526 19 (European Communities Commission: Brussels, 1977).
- 527 Henry, C., “Investment Decisions under Uncertainty: the “Irreversibility Effect”,” *The  
528 American Economic Review* 64 (1974), 1006–1012.
- 529 Hull, J. C., *Options, Futures and other Derivatives* (Prentice Hall International: New  
530 Jersey, 2003).
- 531 ICRAF, “Domestication of Indigenous Fruit Trees of the Miombo Woodlands of  
532 Southern Africa,” Project Proposal for the Restricted Core Program to the German  
533 Ministry for Economic Cooperation and Development (BMZ) (International  
534 Centre for Research in Agroforestry: Nairobi, 1996).

- 535 Leakey, R., Z. Tchoundjeu, R. I. Smith, R. C. Munro, J.-M. Fondoun, J. Kengue, P. O.  
536 Anegbah, A. R. Atangana, A. N. Waruhiu, E. Asaah, C. Usoro, and V. Ukafor,  
537 “Evidence that Subsistence Farmers have Domesticated Indigenous Fruits  
538 (*Dacyodes edulis* and *Irvingia gabonensis*) in Cameroon and Nigeria,”  
539 *Agroforestry Systems* 60 (2004), 101–111.
- 540 Maghembe, J. A., Personal Communication (International Centre for Research in  
541 Agroforestry: Malawi, 1999).
- 542 Maghembe, J. A., Y. Ntupanyama, and P. W. Chirwa, eds., *Proceedings of the*  
543 *Conference ‘Improvement of Indigenous Fruit Trees of the Miombo Woodlands of*  
544 *Southern Africa’, Club Makokola, Mangochi, Malawi* (International Centre for  
545 Research in Agroforestry: Nairobi, 1994).
- 546 Maghembe, J. A., A. J. Simons, F. Kwesiga, and M. Rarieya, eds., *Selecting Indigenous*  
547 *Trees for Domestication in Southern Africa* (International Centre for Research in  
548 Agroforestry: Nairobi, 1998).
- 549 McDonald, R., and D. Siegel, “The Value of Waiting to Invest,” *The Quarterly Journal*  
550 *of Economics* 101 (1986), 707–728.
- 551 Mhango, J., A. Mkonda, and F. Akinnifesi, “Vegetative Propagation as a Tool for the  
552 Domestication of Indigenous Fruit Trees in Southern Africa,” Paper presented at  
553 the Regional Agroforestry Conference ‘Agroforestry Impacts on Livelihoods in  
554 Southern Africa: Putting Research into Practice,’ May 20-24, Warmbaths, South  
555 Africa (International Centre for Research in Agroforestry: Nairobi, 2002).
- 556 Mwamba, C. K., “Status Report on Domestication and Commercialization of Non-Timber  
557 Forest Products in Agroforestry Systems, Zambia,” Proceedings of the  
558 Conference ‘Sustainable Management of Indigenous Forests in the Dry Tropics,’

- 559 Kadoma Ranch Motel (Division of Research and Development, Forestry  
560 Commission: Harare, 1996), pp. 211–222.
- 561 Palisade, *Guide to using @RISK, Version 4, November 2000* (Palisade Corporation: New  
562 York, 2000).
- 563 Perman, R., Y. Ma, J. McGilvray, and M. Common, *Natural Resource and*  
564 *Environmental Economics* (Pearson Education Limited, Longman: Harlow, 1999).
- 565 Pollan, M., *The Botany of Desire - A Plant's-Eye View of the World* (Random House  
566 Paperback Edition: New York, 2002).
- 567 Price, T. J., and M. E. Wetzstein, “Irreversible Investment Decisions in Perennial Crops  
568 with Yield and Price Uncertainty,” *Journal of Agricultural and Resource*  
569 *Economics* 24 (1999), 173–185.
- 570 Purvis, A., W. G. Boggess, C. B. Moss, and J. Holt, “Technology Adoption Decisions  
571 under Irreversibility and Uncertainty: An *Ex Ante* Approach,” *American Journal*  
572 *of Agricultural Economics* 77 (1995), 541–551.
- 573 Scherr, S., “Hunger, Poverty and Biodiversity in Developing Countries,” Paper presented  
574 at the Mexico Action Summit, June 2-3, Mexico City, Mexico,  
575 ([http://www.futureharvest.org/pdf/hunger\\_poverty.pdf](http://www.futureharvest.org/pdf/hunger_poverty.pdf): 2003).
- 576 Simons, A. J., “ICRAF’s Strategy for Domestication of Non-Wood Tree Products,” in  
577 FAO, *Domestication and Commercialization of Non-Timber Forest Products in*  
578 *Agroforestry Systems* (Food and Agriculture Organization of the United Nations:  
579 Rome, 1996).
- 580 Simons, A. J., and R. R. B. Leakey, “Tree Domestication in Tropical Agroforestry,”  
581 *Agroforestry Systems* 61 (2004), 167–181.
- 582 Trigeorgis, L., *Real Options* (The MIT Press: Cambridge, Massachusetts, 1998).

- 583 Winter-Nelson, A., and K. Amegbeto, “Option Values to Conservation and Agricultural  
584 Price Policy: Application to Terrace Construction in Kenya,” *American Journal of*  
585 *Agricultural Economics* 80 (1998), 409–418.
- 586 World Bank, *World Development Indicators* (The World Bank: Washington, D.C, 2003).

587 **Appendix**

588 Suppose a farmer considers whether to buy the products of a domesticated  
589 indigenous fruit tree at the market or to produce the products by planting the tree. The  
590 farmer can buy  $n$  units of bundles of the products from one tree,  $nV$ , the so-called  
591 spanning asset, and invests 1 Dollar in the riskless asset, i.e. a savings account. Thus, the  
592 portfolio costs  $1+nV$  Dollar. All the values of the portfolio are known. If this portfolio is  
593 held for a short interval  $dt$  it will generate the following return: the riskless asset will pay  
594 an interest of  $rdt$  and the return on the spanning asset will be given by the gain from  
595 owning products of the tree, the convenience yield  $n\delta Vdt$ , and the random capital gain  
596  $n\alpha Vdt + n\sigma Vdz$ , which are assumed to follow a geometric Brownian motion of the form  
597  $dV = \alpha Vdt + \sigma Vdz$ .  $\alpha$  constitutes the growth rate, e.g. from price appreciation, and  $\sigma$  is  
598 the standard deviation of returns on the spanning asset. The total return from holding the  
599 portfolio over the short time interval for each dollar invested is:

600

$$601 \quad \frac{1}{1+nV} \cdot (rdt + n\delta Vdt + n\alpha Vdt + n\sigma Vdz) = \frac{r + n(\alpha + \delta)V}{1+nV} dt + \frac{\sigma nV}{1+nV} dz. \quad (A1)$$

602

603 The return can be split up into the riskfree return, which is the first term on the right  
604 hand side of equation (1) and in return, which is stochastically influenced, the second  
605 term on the right hand side of equation (A1).

606 Instead of holding the portfolio, the farmer can buy the right to plant trees and  
607 produce the products herself to generate  $V$  for the same short interval  $dt$ . If she produces  
608 the products herself she has to spend  $F(V,t)$ , which is the market value of the trees that  
609 entitles her to future profits from the trees. Over the short time period,  $dt$ , this value will

610 change by  $dF$ . The change is uncertain. The random capital gains,  $dF$ , can be calculated  
 611 using Ito's Lemma (Dixit and Pindyck, 1994)<sup>8 9</sup>:

612

$$613 \quad dF = \left[ F_t(V, t) + \alpha V F_V(V, t) + \frac{1}{2} \sigma^2 V^2 F_{VV}(V, t) \right] dt + \sigma V F_V(V, t) dz . \quad (A2)$$

614

615 The total return per dollar invested in this option is given through equation (A3),  
 616 which is derived equivalently to equation (A1):

617

$$618 \quad \frac{F_t(V, t) + \alpha V F_V(V, t) + \frac{1}{2} \sigma^2 V^2 F_{VV}(V, t)}{F(V, t)} dt + \frac{\sigma V F_V(V, t)}{F(V, t)} dz . \quad (A3)$$

619

620 Similarly to returns on the replicating portfolio, returns on holding the option to  
 621 invest are also separated into riskfree and stochastic returns, which are the first and the  
 622 second term of equation (A3). Since the replicating portfolio (consisting of one dollar's  
 623 worth of the riskless asset and  $n$  units of the spanning asset,  $V$ ) has to replicate the risk  
 624 and return of owning the option to avoid arbitrage opportunities the following conditions  
 625 must be met (Dixit and Pindyck, 1994):

626

---

<sup>8</sup> With respect to a stock option, the option price is a function of the underlying stock 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.

<sup>9</sup> The subscripts denote the partial derivatives; thus  $F_{VV}(V, t)$  denotes the second partial derivative of  $F$  with respect to  $V$ . With an infinite time horizon,  $F$  becomes independent of time and only depends on  $V$  (Dixit and Pindyck, 1994).

$$627 \quad xV/(1+xV) = VF_V(V, t) / F(V, t), \quad (A4)$$

628 and

$$629 \quad \frac{F_t(V, t) + \alpha VF_V(V, t) + \frac{1}{2} \sigma^2 V^2 F_{VV}(V, t)}{F(V, t)} = \frac{r + x(\alpha + \delta)V}{1 + xV}. \quad (A5)$$

630

631 Equation (A4) ensures that both assets are of equal risk (the  $dz$ -terms must equal each  
632 other) and as they are of the same risk they must also yield the same return, which leads  
633 to equation (A5).

634 After some transformation the return for holding the option to invest can be  
635 expressed as a partial differential equation (A6):

636

$$637 \quad \frac{1}{2} \sigma^2 V^2 F_{VV}(V, t) + (r - \delta)VF_V(V, t) + F_t(V, t) - rF(V, t) = 0. \quad (A6)$$

638

639  $F(V)$  must hold the following conditions: When  $V = 0$ , the value of the option to  
640 invest is also 0 ( $F(0) = 0$ ). The value matching condition determines that when the  
641 investor carries out investment, she will receive  $V^* - I$ , where  $V^*$  is the return received at  
642 the optimal time of investment ( $F(V^*) = V^* - I$ ). The last condition makes sure that at the  
643 critical return  $V^*$ ,  $F(V^*)$  has to be continuous and smooth (smooth pasting condition)  
644 ( $F'(V^*) = 1$ ) (see also Trigeorgis, 1998).

645 After solving equation (A6) according to these conditions the function for the value  
646 of the option to invest is given by (A7):

647

$$648 \quad F(V) = \begin{cases} BV^\beta & \text{for } V \leq V^* \\ V - I & \text{for } V \geq V^* \end{cases} \quad (A7)$$



649 The upper function gives the value of waiting to invest and the lower part gives the  
 650 value of immediate investment.

651

652 with

$$653 \quad B = (V^* - I)/(V^*)^\beta = (\beta - 1)^{\beta-1} / (\beta^\beta I^{\beta-1}), \quad (\text{A8})$$

654 and

$$655 \quad \beta = \frac{1}{2} - (r - \delta) / \sigma^2 + \sqrt{\left[ (r - \delta) / \sigma^2 - \frac{1}{2} \right]^2 + 2r / \sigma^2}. \quad (\text{A9})$$

656

657  $B$  is a shift parameter, and  $\beta$  is the positive solution to Equation (A6) which is used to  
 658 establish the hurdle rate  $V^*$ , which is the critical level of return that will trigger off  
 659 investment:

660

$$661 \quad V^* = \frac{\beta}{\beta - 1} I. \quad (\text{A10})$$

662

663 Equation A10 states the value of immediate investment  $V$  should be at least as high as  
 664  $V^*$  (Dixit and Pindyck, 1994). If the current level of  $V$  is less than  $V^*$  it is worthwhile to  
 665 postpone the planting of domesticated indigenous fruit trees.

666

667 **Tables**

## 668 Table 1

669 Scenario 1: Parameter values of the option to invest in planting of domesticated indigenous fruit  
670 trees

| First fruiting <sup>1)</sup> | Fruit price <sup>2)</sup> | Yield <sup>3)</sup> | Collection costs <sup>4)</sup> | $r$ <sup>5)</sup> | $I$ <sup>6)</sup> | $V^*$ <sup>6)</sup> | $V$ <sup>7)</sup> |
|------------------------------|---------------------------|---------------------|--------------------------------|-------------------|-------------------|---------------------|-------------------|
| 2                            | 1                         | 1                   | 1                              | 0                 | 22.90             | 23.14               | -299.19           |
| 2                            | 1                         | 1                   | 2.7                            | 0                 | 22.89             | 25.32               | 19.94             |
| 2                            | 1                         | 1                   | 2.8                            | 0                 | 22.89             | 26.51               | <b>26.64</b>      |
| 2                            | 1                         | 1                   | 2.9                            | 0                 | 22.90             | 30.03               | <b>33.03</b>      |
| 2                            | 1                         | 1                   | 3                              | 0                 | 22.90             | 120.81              | 38.57             |
| 2                            | 1                         | 1                   | 3.1                            | 0                 | 22.90             | -                   | 43.94             |
| 4                            | 1                         | 1                   | 1                              | 0                 | 24.82             | 25.05               | -340.28           |
| 4                            | 1                         | 1                   | 3                              | 0                 | 24.81             | 26.23               | -1.47             |
| 4                            | 1                         | 1                   | 3.5                            | 0                 | 24.80             | 29.51               | 22.66             |
| 4                            | 1                         | 1                   | 4                              | 0                 | 24.81             | -                   | 40.73             |
| 6                            | 1                         | 1                   | 1                              | 0                 | 26.47             | 26.71               | -375.10           |
| 6                            | 1                         | 1                   | 4                              | 0                 | 26.46             | 28.71               | 5.99              |
| 6                            | 1                         | 1                   | 4.7                            | 0                 | 26.47             | 74.35               | 25.01             |
| 6                            | 1                         | 1                   | 4.8                            | 0                 | 26.47             | -                   | 27.24             |
| 8                            | 1                         | 1                   | 1                              | 0                 | 27.86             | 28.12               | -404.38           |
| 8                            | 1                         | 1                   | 6.1                            | 0                 | 27.85             | 305.58              | 20.46             |
| 8                            | 1                         | 1                   | 6.2                            | 0                 | 27.86             | -                   | 21.84             |
| 10                           | 1                         | 1                   | 1                              | 0                 | 28.99             | 29.29               | -427.16           |
| 10                           | 1                         | 1                   | 7                              | 0                 | 28.99             | 33.65               | 7.42              |
| 10                           | 1                         | 1                   | 8                              | 0                 | 29.00             | -                   | 16.41             |

671 <sup>1)</sup> Years; <sup>2)</sup> Times the non-domesticated level: 1: same as non-domesticated fruits; 1-3:  
672 stochastically 1-3 times the non-domesticated level; <sup>3)</sup> Times the modal yield of the non-  
673 domesticated fruit trees: 1 same as non-domesticated fruit trees. The difference between  
674 minimum, modal and maximum yield remains constant; <sup>4)</sup> Times the labor input to collect the  
675 same amount of fruits compared to the survey: 1 same level as for the survey; <sup>5)</sup> %; <sup>6)</sup> ZWD/day; <sup>7)</sup>  
676 ZWD/day; mean over  $V = (NPV_{DT\infty} + I) - (NPV_{C\infty})$ .

677 Table 2

678 Scenario 2: Parameter values of the option to invest in planting of domesticated indigenous fruit

679 trees<sup>1)</sup>

| First fruiting | Fruit price | Yield | Collection costs | $r$ | $I$   | $V^*$  | $V$           |
|----------------|-------------|-------|------------------|-----|-------|--------|---------------|
| 2              | 1           | 8     | 1                | 0   | 8.26  | 8.62   | 6.57          |
| 2              | 1           | 9     | 1                | 0   | 7.64  | 8.03   | <b>19.99</b>  |
| 2              | 1           | 28    | 1                | 0   | 3.38  | 7.61   | <b>109.14</b> |
| 2              | 1           | 30    | 1                | 0   | 3.21  | -      | 113.16        |
| 4              | 1           | 8     | 1                | 0   | 10.10 | 10.41  | -31.73        |
| 4              | 1           | 10    | 1                | 0   | 8.69  | 9.03   | -2.45         |
| 4              | 1           | 12    | 1                | 0   | 7.71  | 8.08   | <b>19.10</b>  |
| 4              | 1           | 40    | 1                | 0   | 3.19  | 148.64 | <b>113.01</b> |
| 4              | 1           | 44    | 1                | 0   | 3.05  | -      | 115.98        |
| 6              | 1           | 8     | 1                | 0   | 12.14 | 12.43  | -74.97        |
| 6              | 1           | 12    | 1                | 0   | 9.40  | 9.72   | -17.16        |
| 6              | 1           | 16    | 1                | 0   | 7.70  | 8.08   | <b>18.23</b>  |
| 6              | 1           | 44    | 1                | 0   | 3.72  | 5.35   | <b>101.55</b> |
| 6              | 1           | 56    | 1                | 0   | 3.12  | -      | 114.16        |
| 8              | 1           | 8     | 1                | 0   | 14.41 | 14.66  | -122.01       |
| 8              | 1           | 16    | 1                | 0   | 9.49  | 9.82   | -18.51        |
| 8              | 1           | 24    | 1                | 0   | 7.15  | 7.56   | <b>30.29</b>  |
| 8              | 1           | 40    | 1                | 0   | 4.91  | 5.56   | <b>77.00</b>  |
| 8              | 1           | 80    | 1                | 0   | 2.98  | -      | 117.13        |
| 10             | 1           | 8     | 1                | 0   | 16.73 | 16.98  | -171.35       |
| 10             | 1           | 24    | 1                | 0   | 8.80  | 9.15   | -4.45         |
| 10             | 1           | 32    | 1                | 0   | 7.17  | 7.57   | <b>29.49</b>  |
| 10             | 1           | 96    | 1                | 0   | 3.25  | 42.37  | <b>112.10</b> |
| 10             | 1           | 104   | 1                | 0   | 3.05  | -      | 115.41        |

680 <sup>1)</sup> Same legend as for table 1.

681 Table 3  
 682 Scenario 3 and 4: Parameter values of the option to invest in planting of domesticated indigenous  
 683 fruit trees

| Scenario 3 <sup>1)</sup> |             |       |                  |          |          |            |               |
|--------------------------|-------------|-------|------------------|----------|----------|------------|---------------|
| First fruiting           | Fruit price | Yield | Collection costs | <i>r</i> | <i>I</i> | <i>V</i> * | <i>V</i>      |
| 2                        | 1-3         | 1     | 1                | 0        | 22.45    | 25.98      | -86.88        |
| 2                        | 1-3         | 1     | 1.1              | 0        | 22.45    | 26.94      | -40.37        |
| 2                        | 1-3         | 1     | 1.3              | 0        | 22.45    | 30.61      | <b>31.03</b>  |
| 2                        | 1-3         | 1     | 1.5              | 0        | 22.45    | 51.16      | <b>83.19</b>  |
| 2                        | 1-3         | 1     | 1.6              | 0        | 22.44    | -          | 105.21        |
| Scenario 4 <sup>1)</sup> |             |       |                  |          |          |            |               |
| 2                        | 1-3         | 1.3   | 1                | 0        | 20.72    | 25.59      | -13.92        |
| 2                        | 1-3         | 1.5   | 1                | 0        | 19.71    | 26.10      | <b>27.89</b>  |
| 2                        | 1-3         | 2.2   | 1                | 0        | 16.84    | 81.85      | <b>146.68</b> |
| 2                        | 1-3         | 6     | 1                | 0        | 9.45     | -          | 453.07        |

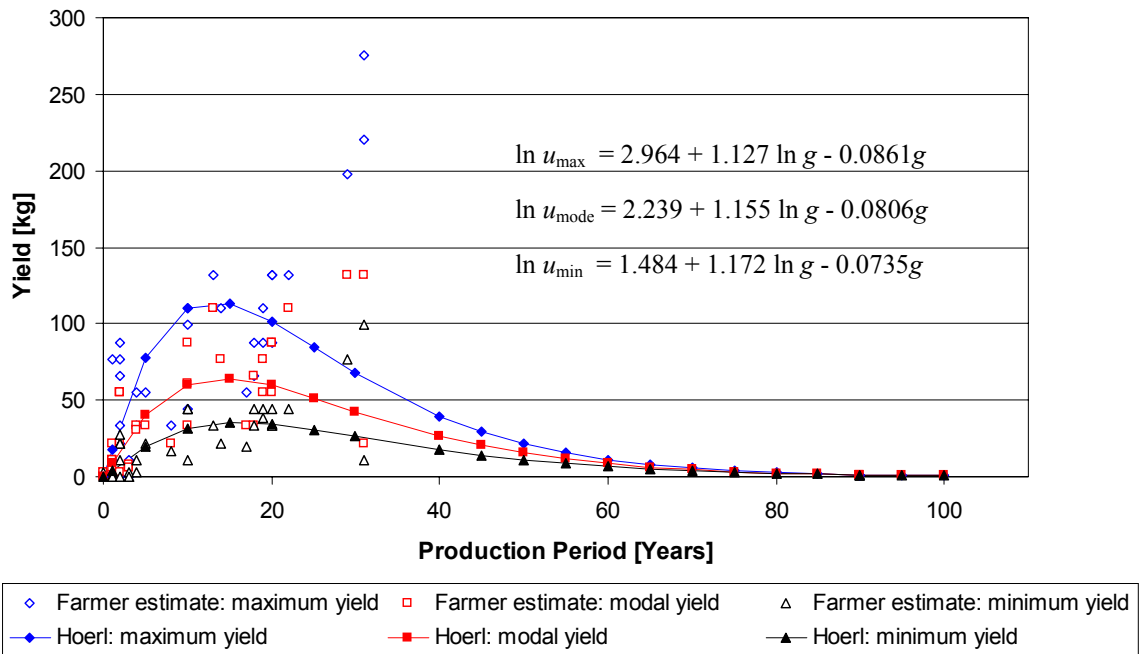
684 <sup>1)</sup> Same legend as for table 1.

685 Table 4  
 686 Scenario 5 and 6: Parameter values of the option to invest in planting of domesticated indigenous  
 687 fruit trees

| Scenario 5 <sup>1)</sup> |             |       |                  |          |          |            |              |
|--------------------------|-------------|-------|------------------|----------|----------|------------|--------------|
| First fruiting           | Fruit price | Yield | Collection costs | <i>r</i> | <i>I</i> | <i>V</i> * | <i>V</i>     |
| 2                        | 1           | 1     | 1                | 3        | 20.56    | 20.79      | -288.32      |
| 2                        | 1           | 1     | 2.7              | 3        | 20.58    | 35.28      | 32.48        |
| 2                        | 1           | 1     | 2.8              | 3        | 20.56    | -          | 39.16        |
| 2                        | 1           | 1     | 1                | 5        | 19.17    | 19.40      | -279.23      |
| 2                        | 1           | 1     | 2.6              | 5        | 19.17    | 48.92      | 32.83        |
| 2                        | 1           | 1     | 2.7              | 5        | 19.17    | -          | 40.15        |
| Scenario 6 <sup>1)</sup> |             |       |                  |          |          |            |              |
| First fruiting           | Fruit price | Yield | Collection costs | <i>r</i> | <i>I</i> | <i>V</i> * | <i>V</i>     |
| 2                        | 1           | 6     | 1                | 3        | 8.76     | 9.13       | -18.54       |
| 2                        | 1           | 8     | 1                | 3        | 7.19     | 7.65       | <b>16.63</b> |
| 2                        | 1           | 16    | 1                | 3        | 4.35     | 6.41       | <b>81.08</b> |
| 2                        | 1           | 24    | 1                | 3        | 3.25     | -          | 105.81       |
| 2                        | 1           | 6     | 1                | 5        | 7.99     | 8.42       | -11.72       |
| 2                        | 1           | 8     | 1                | 5        | 6.54     | 7.17       | <b>22.66</b> |
| 2                        | 1           | 16    | 1                | 5        | 4.01     | 11.76      | <b>84.08</b> |
| 2                        | 1           | 20    | 1                | 5        | 3.37     | -          | 99.22        |

688 <sup>1)</sup> Same legend as for table 1.

689 **Figures**



690

691

Figure 1. Age yield function of Uapaca kirkiana.

692 **Tables in Appendix**

693 Table A1

694 Costs of Uapaca kirkiana seedling production

| Type of input  | Costs <sup>1)</sup> (ZWD/seedling) |
|--|------------------------------------|
| Seedlings  |                                    |
| Labor  |                                    |
| Collecting fruits <sup>2)</sup>                              | 0.03                               |
| Extracting seeds   | 0.12                               |
| Treatment of seeds   | 0.12                               |
| Soil collection & transport                                  | 0.13                               |
| Filling tubes & seeding <sup>3)</sup>                        | 0.36                               |
| Transport  | 0.04                               |
| Watering   | 8.01                               |
| Weeding  | 0.22                               |
| Other labor (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)              | 391.0                              |
| Grafting (labor costs only)                                  |                                    |
| 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)       | 461.7                              |
| Seedling plus grafting costs per tree survived <sup>4)</sup> | 92.3                               |

695 <sup>1)</sup> These figures take the germination rate of 80% into account; <sup>2)</sup> 3 seeds per fruit; <sup>3)</sup> Space  
696 requirements 1m<sup>2</sup>/100tubes; <sup>4)</sup> Orchard of five trees.

697 Source: Labor requirements according to Maghembe (1999) and own information, valued at the  
698 average wage rate of Murehwa.

699 Table A2

700 Management of exotic fruit trees in Zimbabwe and application in the investment model

| Exotic fruit tree orchards     |                                     |                                     |                      | Specification for IFT orchards                                     |
|--------------------------------|-------------------------------------|-------------------------------------|----------------------|--|
| Task                           | Labour <sup>1)</sup><br>(hour/tree) | Frequency <sup>2)</sup><br>(#/year) | Season <sup>3)</sup> |  |
| Watering                       | 0.8                                 | 1-18                                | DS                   | trees < 4 years: once a week, DS<br>trees > 4 years: once per year |
| Weeding                        | 0.6                                 | 2                                   | WS                   | as exotic fruit trees  |
| Fertilizing                    | 0.6                                 | 1                                   | before WS            | as exotic fruit trees  |
| Pruning                        | 0.7                                 | 1                                   | DS                   | as exotic fruit trees  |
| Cut dead &<br>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<br>fences       |                                     |                                     |                      | included in miscellaneous  |
| Micro-catchments               | 0.4                                 | 1                                   | WS                   | as exotic fruit trees  |

701 <sup>1)</sup> Mean; <sup>2)</sup> Mode, <sup>3)</sup> DS dry season, WS wet season.

702 Source: Survey.

703



704 Table A3

705 Rates of return on titles of the market portfolio for households of Murehwa

| Household | Off-farm | Horticulture | Agriculture | Livestock | Market portfolio, $r_m$ |
|-----------|----------|--------------|-------------|-----------|-------------------------|
| 21        | -0.20    | -0.09        | 0.52        | 0.11      | 0.21                    |
| 22        | 0.01     | 2.14         | 1.57        | 0.82      | 1.23                    |
| 23        | 2.14     | 0.95         | -0.32       | -0.27     | 0.05                    |
| 24        | 0.49     | 0.82         | -0.67       | 0.31      | 0.08                    |
| 25        | 0.40     | -0.87        | 0.44        | 0.20      | -0.03                   |
| 26        | 0.63     | -0.10        | 1.04        | -0.19     | 0.62                    |
| 27        | -0.13    | -0.77        | 1.15        | -0.38     | -0.01                   |
| 28        | 0.19     | -1.00        | -0.18       | -0.15     | -0.11                   |
| 29        | 0.82     | -0.44        | 0.59        | 0.15      | 0.17                    |
| 30        | -0.04    | 1.56         | 1.96        | 0.02      | 0.64                    |
| 31        | 1.33     | -0.18        | -0.40       | 0.07      | 0.17                    |
| 32        | -0.28    | 1.53         | -0.18       | -0.12     | 0.10                    |
| 33        | 1.74     | -0.48        | -0.62       | -0.31     | 0.15                    |
| 34        | -0.23    | 1.06         | 0.40        | -0.41     | -0.11                   |
| 35        | -0.33    | -0.08        | 0.38        | -0.33     | -0.15                   |
| 36        | -0.45    | -0.80        | -0.51       | -0.14     | -0.52                   |
| 37        | -0.22    | -0.18        | -0.77       | -1.00     | -0.46                   |
| 38        | 0.24     | -0.24        | -0.01       | 0.68      | 0.23                    |
| 39        | -0.85    | -0.60        | -0.56       | -0.11     | -0.32                   |

706 Source: Survey.

707 Table A4

708 Rates of return on the tree sector for households of Murehwa

| Household | EFT   | <u>P. curatellifolia &amp; Strychnos sp.</u> | <u>U. kirkiana</u> | Tree sector, $r_V$ |
|-----------|-------|--|--------------------|--------------------|
| 21        | 5.47  | 5.89   | 1.69               | 4.66               |
| 22        | 2.53  | 8.13   | 1.65               | 2.21               |
| 23        | 8.43  | 16.96  | 0.14               | 4.89               |
| 24        | 0.72  | 1.81   | 3.30               | 0.85               |
| 25        | 0.88  | 0.19   | 0.97               | 0.85               |
| 26        | -1.00 | 3.38   | 0.35               | -0.04              |
| 27        | -1.00 | 11.66  | 1.18               | 0.13               |
| 28        | 7.77  | -0.35  | 0.52               | 4.77               |
| 29        | 4.77  | 9.81   | 0.29               | 2.61               |
| 30        | 8.75  | 18.78  | 13.60              | 11.11              |
| 31        | 1.08  | 2.80   | 2.62               | 1.64               |
| 32        | 0.59  | 15.15  | 0.82               | 0.71               |
| 33        | 0.04  | 0.63   | 0.12               | 0.21               |
| 34        | 6.18  | 11.92  | 1.22               | 5.40               |
| 35        | 3.85  | 2.37   | 2.56               | 3.34               |
| 36        | -0.55 | 2.35   | 2.29               | -0.03              |
| 37        | 1.83  | 1.52   | 1.25               | 1.66               |
| 38        | 2.75  | -0.06  | -0.84              | 0.94               |
| 39        | -0.84 | 2.26   | 2.84               | 0.61               |

709 Source: Survey.

710 Table A5

711 Variance-covariance matrix of the market portfolio, Murehwa

| Titles of the market portfolio, Murehwa |          |              |             |           |                   |
|---|----------|--------------|-------------|-----------|-------------------|
|   | Off-farm | Horticulture | Agriculture | Livestock | Weights, $\omega$ |
| 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            |

712 Source: Survey.

713 Table A6

714 Risk-free interest rate, market price of risk and risk-adjusted rate of return, Murehwa

| Risk-free interest rate, $r$ | Market price of risk, $\phi$ | Risk-adjusted rate of return, $\mu$ |
|------------------------------|------------------------------|-------------------------------------|
| 0.00%                        | 0.6125                       | 15.64%                              |
| 3.00%                        | 0.4330                       | 14.06%                              |
| 5.00%                        | 0.3133                       | 13.00%                              |

715

716 Table A7

717 Returns to labor from collecting indigenous fruits from the wild in comparison to returns to labor

718 from planting non-domesticated IFT

| Access to fruits via ...                        | Farm gate price of fruits      | Returns to labour <sup>1)</sup><br>(ZWD/day) |
|---|--------------------------------|--|
| Collecting IFT products from the communal areas | Survey                         | 222 (228)                                    |
| Collecting IFT products from the communal areas | Uniform (0.4;18) <sup>2)</sup> | 506 (255)                                    |
| Planting non-domesticated IFT                   | Uniform (0.4;18) <sup>2)</sup> | 52 (34)                                      |

719 <sup>1)</sup> Figures in parentheses give the standard deviation; <sup>2)</sup> Distribution defined by the minimum and

720 maximum farm gate price found in the survey.

721 Table A8

722 Scenarios assessed in the investment analysis<sup>1)</sup>

| Scenario | First fruiting | 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        | ↑           | –             | –                | ↑                        |

723 <sup>1)</sup> ↓ = decrease, ↑ = increase, – = no change in comparison to the survey.