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

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

3
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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.

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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-farm¹.

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).

¹ 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, μ . 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 ∞ 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, $\mu = r + \phi Cov[r_m r_V]$. μ 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)². 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 α being the growth rate, σ 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 δ 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 $\delta = \mu - \alpha$.

² 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, α and σ 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 functions³ 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 υ , ζ , κ 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.

³ 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 production⁴ is not explicitly considered.

226

227

Insert Figure 1

228

229 Fruit prices are considered to follow a uniform distribution between ZWD⁵/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 club⁶, which is zero⁷. The

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

⁵ USD 1 = ZWD 38, December 1999.

⁶ 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, ω_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).

⁷ 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.

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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 Anegbeh, 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: 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 $dV = \alpha Vdt + \sigma Vdz$. α constitutes the growth rate, e.g. from price appreciation, and σ 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)^{8 9}:

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

⁸ 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.

⁹ 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 β 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 ¹⁾	Fruit price ²⁾	Yield ³⁾	Collection costs ⁴⁾	r ⁵⁾	I ⁶⁾	V^* ⁶⁾	V ⁷⁾
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	26.64
2	1	1	2.9	0	22.90	30.03	33.03
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 ¹⁾ Years; ²⁾ Times the non-domesticated level: 1: same as non-domesticated fruits; 1-3:
 672 stochastically 1-3 times the non-domesticated level; ³⁾ 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; ⁴⁾ Times the labor input to collect the
 675 same amount of fruits compared to the survey: 1 same level as for the survey; ⁵⁾ %; ⁶⁾ ZWD/day; ⁷⁾
 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 trees¹⁾

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	19.99
2	1	28	1	0	3.38	7.61	109.14
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	19.10
4	1	40	1	0	3.19	148.64	113.01
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	18.23
6	1	44	1	0	3.72	5.35	101.55
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	30.29
8	1	40	1	0	4.91	5.56	77.00
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	29.49
10	1	96	1	0	3.25	42.37	112.10
10	1	104	1	0	3.05	-	115.41

680 ¹⁾ 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 ¹⁾							
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	31.03
2	1-3	1	1.5	0	22.45	51.16	83.19
2	1-3	1	1.6	0	22.44	-	105.21
Scenario 4 ¹⁾							
2	1-3	1.3	1	0	20.72	25.59	-13.92
2	1-3	1.5	1	0	19.71	26.10	27.89
2	1-3	2.2	1	0	16.84	81.85	146.68
2	1-3	6	1	0	9.45	-	453.07

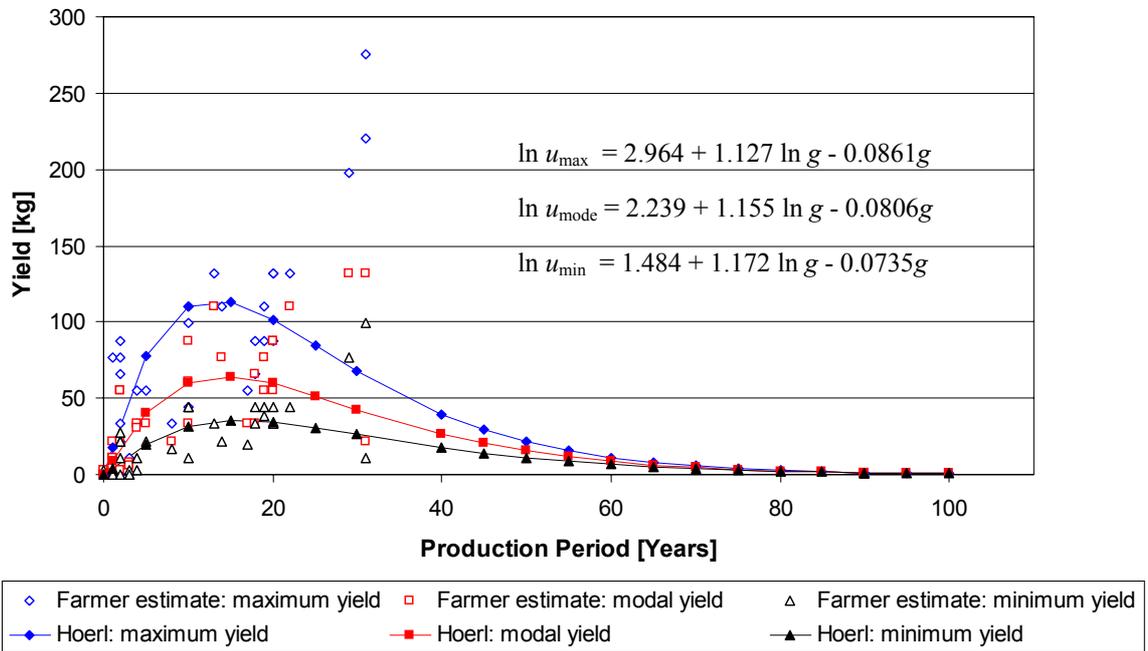
684 ¹⁾ Same legend as for table 1.

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 ¹⁾							
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 ¹⁾							
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	16.63
2	1	16	1	3	4.35	6.41	81.08
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	22.66
2	1	16	1	5	4.01	11.76	84.08
2	1	20	1	5	3.37	-	99.22

688 ¹⁾ 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 ¹⁾ (ZWD/seedling)
Seedlings	
Labor	
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 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 ⁴⁾	92.3

695 ¹⁾ These figures take the germination rate of 80% into account; ²⁾ 3 seeds per fruit; ³⁾ Space
696 requirements 1m²/100tubes; ⁴⁾ 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 ¹⁾ (hour/tree)	Frequency ²⁾ (#/year)	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
Fertilizing	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

701 ¹⁾ Mean; ²⁾ Mode, ³⁾ 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 & 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, 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

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, ϕ	Risk-adjusted rate of return, μ
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 ¹⁾ (ZWD/day)
Collecting IFT products from the communal areas	Survey	222 (228)
Collecting IFT products from the communal areas	Uniform (0.4;18) ²⁾	506 (255)
Planting non-domesticated IFT	Uniform (0.4;18) ²⁾	52 (34)

719 ¹⁾ Figures in parentheses give the standard deviation; ²⁾ Distribution defined by the minimum and
720 maximum farm gate price found in the survey.

721 Table A8

722 Scenarios assessed in the investment analysis¹⁾

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