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

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Abstract

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

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1. Introduction

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

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

Another strategy to halt loss of tree resources and thus to conserve biodiversity is tree domestication, i.e. advancing favorable traits of the trees so that farmer-led planting leads to a higher abundance of the trees. Such an approach is the World Agroforestry Centre's (ICRAF) domestication program, which aims to enhance planting of indigenous fruit trees with improved fruit quality and higher yields and thus to alleviate poverty by enhancing farmers' income and at the same time to conserve biodiversity (ICRAF, 1996). This program has emerged as a result of the on-going debate on the future direction of rural development efforts in Africa. Some approaches favor biotechnology and an expansion of the green revolution technologies; others call for conserving and enhancing the diversity of the crops available (Leakey et al., 2004). The domestication program is part of the latter strategy. The untapped potential of wild plants is seen as a source of growth for the rural economies in tropical countries, as a means to motivate improved conservation of the wild areas, which supply these crops (Evans and Sengdala, 2002), and as a means to enhance productivity and sustainability of agroforestry systems (Simons, 1996).

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

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

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

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[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.

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

- ⇨ What is the extent of improvement in tree performance that is necessary to induce farmers to invest?
- ⇨ By how much have the costs of natural resource use to increase to trigger on-farm investment in domesticated trees?

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

The article is organized as follows. First, we derive the value of an investment in planting of domesticated indigenous fruit trees using the real option approach and contingent claim analysis. Then, the study area and data are presented and applied to the investment question. A numerical example from a village in Zimbabwe is used to illustrate the results with respect to the most popular indigenous fruit tree species, Uapaca kirkiana, as determined by Maghembe et al. (1998). At the end, conclusions are drawn for the indigenous fruit tree domestication program and the prospects of farmer-led planting to conserve indigenous fruit trees.

2. The investment model

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

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

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

V_{DT1} is the present value of planting indigenous fruit trees, where the subscript indicates the number of rotations. In year $t=0$, costs include initial irreversible investment cost, I. In year T, the end of the optimal life span of the orchard, the costs of uprooting the plantation and benefits from harvest of timber are included via R. During the lifetime of the orchard, costs, c_t, occur due to management of the orchard and harvesting the fruits. Benefits from the multiple tree products are accounted for in b_t. Costs and benefits are discounted by the risk-adjusted discount rate, μ. If opportunity costs of land are lower than expected returns from the orchard, the farmer can be expected to continuously replant the orchard. The optimal rotation rate, *T*, is found where the marginal benefit of the plantation left growing for an additional period equals the marginal opportunity cost of this choice, i.e. site value and capital tied up (Hartman, 1976; Perman et al., 1999). The maximum net present value over an infinite sequence of orchard rotations is given by $\frac{V_{DT1} - I}{1 - e^{\mu T}}$ (Perman et al., 1999). In the following, the subscript ∞ is omitted and NPV always indicates the maximum net present value of an infinite investment sequence in domesticated indigenous fruit trees. The incremental benefit of an investment in planting domesticated indigenous fruit trees is given by $V = (NPV + I)_{DT\infty} - (NPV_{C\infty})$, where $NPV_{C\infty} = V_C$ constitutes the net present value of collecting the fruits from the communal areas. Collection of indigenous fruit tree products from the wild constitutes an alternative to obtaining the fruits by planting trees. Opportunity costs of land for planted IFT are assumed to be zero, as in the area under consideration space for planting a few trees is no constraint.

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

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

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

δ is the convenience yield and equivalent to the dividend in financial economics; it is a benefit that accrues from holding the project. The relationship between convenience 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).

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

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

3. Study area and data

Data was collected in ward 16, Murehwa District, which is a major collection area for U. kirkiana fruits in Zimbabwe. The area is located along the road to Mozambique and Malawi, about 80 km east of Harare and close to a thriving market and bus stop. A sample of 19 households was monitored from August 1999 to August 2000. Monitoring of case study households on a monthly basis allowed detailed data collection. Price information, cash income, in-kind income, and expenditure as well as labor flows were monitored with respect to indigenous and exotic fruit trees, cultivation of horticultural and agricultural crops, keeping of livestock, household and off-farm activities (further referred to as 'Survey').

3.1. Management and production parameters

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

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

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

3.2. The age yield function

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

From farmers' yield estimates and expert information, age yield functions[3] for the minimum, the maximum and the modal yield were approximated using the Hoerl Function, $u = \upsilon g^{\zeta} e^{\kappa g}$, as commonly done (Haworth and Vincent, 1977). Yield in a given year, *u*, solely depends on age, *g* (here productive period); the coefficients υ, ζ, κ are estimated via linear regression. Fruit yield for each age is defined as a triangular distribution, with the minimum and maximum as lower and upper boundary, from which data are drawn stochastically. Figure 1 shows the age yield production functions used. Year zero is the age at which the tree bears fruits for the first time. Fruiting sets in 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.

One draw in the simulation for the realization of the yield serves as yield estimate for all trees within the orchard. Alternate fruit production[4] is not explicitly considered.

Insert Figure 1

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

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

3.3. Identification of the risk-adjusted rate of return

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

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

$E[r_a]$ is the expected rate of return on activity a, which is the average over the sample of households. The weight of activity a in the portfolio, ω_a, is given by $\frac{1}{N}\sum_{n=1}^{N} \frac{C_{an} + LC_{an} + D_{an}}{\sum_{a=1}^{A} C_{an} + LC_{an} + D_{an}}$ with N as the number of farmers in the sample.

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

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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.

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

The variance of the market portfolio can be described through a linear combination of the variances and covariances of the rates of return of its titles, r_a and r_k: $Var[r_m] = \sum_{a=1}^{A}\sum_{k=1}^{A}\omega_a\omega_k Cov[r_a, r_k]$. The covariance between the market rate of return and the rate of return of planting domesticated trees is estimated via the covariance between the rates of return of the tree use sector, r_{trees}, i.e. collection of indigenous fruits and production of exotic fruits, and the rates of return on the market portfolio. r_{trees} is computed analogously to the rate of return on the titles of the market portfolio.

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

The systematic risk of the tree sector can be expressed by the so-called beta factor, $\frac{Cov[r_m r_V]}{Var[r_m]}$, which is 1.53. The market portfolio has a beta factor of one; thus, in comparison, the tree sector amplifies the overall movements of the market portfolio. The risk-adjusted rate of return is at 15.64% for a risk-free rate of return of zero percent. It is higher than the rate of return of the market portfolio, which shows a positive risk premium for using trees due to the characteristics of the beta factor of the tree sector.

3.4. The opportunity costs – Collecting fruits from communal land

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

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

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

The first term of the numerator on the right-hand-side of equation 3 refers to the value per man-day from planting domesticated trees and the second term to the value per man-day from collecting fruits from the wild. L_{DT} and L_C are the annual number of mandays and LC_{DT} and LC_C the labor costs per man-day for planting improved trees and collection from the wild, respectively.

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

3.5. Investment scenarios

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

4. Results

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

Table 1 explores the interaction between tree improvements, i.e. advancing age at first fruiting and increasing collection costs of fruit from the communal areas. Simulation results show that a shift of first fruiting to two years of age is not sufficient to trigger investment. Additionally, the costs of collecting fruits from the communal areas have to rise, if the yield function remains the same as for non-domesticated IFT. As the growth rate grows closer to the risk-adjusted discount rate, the hurdle rate increases, thus waiting turns out to be of higher value. Once the growth rate exceeds the risk-adjusted discount rate, it would always pay to wait. However, not only the hurdle rate and thus the trigger value, but also the present value of investment increases with increasing collection cost. Investment in planting improved indigenous fruit trees according to the conventional NPV approach would require the present value of investment to exceed initial investment cost, i.e. ZWD 23 per man-day. When collection costs increase by 2.8 to 2.9 times and first fruiting sets in at an age of two years, farmers can be expected to invest immediately. At a threefold increase of collection costs, waiting becomes the profit maximizing strategy.

Insert Table 1

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

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

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

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

Insert Table 2

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

Since it is not quite clear whether advancing first fruiting to an age of two years is a feasible improvement, trigger and present values of yield increases in combination with older age at first fruiting are calculated. In addition to inducing first fruiting at an age of four years, a yield increase of between 10 and 40 times the non-domesticated level would be required to trigger immediate investment. Yield increases of 40 times and more imply that waiting to invest would be a better strategy. This result is mainly driven by the high growth rate of the incremental benefit of investment. Thus, the older the trees are at the first yield, the higher the required improvement of the yield level to initiate adoption of planting.

4.3. Improving fruit quality (Scenario 3 and 4)

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

Insert Table 3

The effect of fruit quality improvement in combination with yield improvements on the value of immediate investment and the value of waiting to invest is similar to the effect of the combination of fruit quality improvements and enhanced natural resource use costs. Furthermore, fruit quality improvements plus yield increases require lower levels of yield increases to trigger immediate investment than the scenario without enhanced fruit quality does. Higher prices for domesticated fruits lead to an increase of the variance rate of *V*. This increases the hurdle rate and also the trigger value. This increased variance also leads to a higher value of the option to invest, since "an increase in variance increases the spread of possible future values for *V*/*I*, and hence the maximum possible gain, while leaving unchanged the maximum possible loss" (McDonald and Siegel, 1986, p. 714). Investment still commences on a lower level of improvement compared to the case of no fruit quality improvements, as the present value of investment grows relatively stronger than the trigger value.

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

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

The influence of the risk-free rate of return on the investment decision is manifold. An increasing *r* that could result from changes in the economic conditions in Zimbabwe results in a decreasing risk-adjusted rate of return, which influences the optimal rotation period. Overall, the higher the risk-free interest rate, the lower the trigger value and the higher the present value as shown in table 4. This is surprising, since the hurdle rate grows with increasing *r*. However, the decline in the optimal rotation period also reduces labor input and thus the initial investment cost per man-day. For scenario 5, a rise in collection costs does not trigger investment since the trigger value grows relatively stronger than the present value of investment.

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

Insert Table 4

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

5. Conclusions

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

Our results suggest that under the current conditions in Zimbabwe the prospects of the domestication strategy for biodiversity conservation and poverty alleviation are dim. It is shown that improvements of trees have to be substantial and ecological conditions have to change dramatically to trigger immediate investment in planting. These are shown by the critical values that were derived for advancing the time of first fruiting, increasing yields and improving fruit quality. It can be concluded that under different conditions, e.g. Malawi, where deforestation is more pronounced and collection costs are high, adoption of tree planting could be faster. Generally, planting IFT could be economical for areas with a lower abundance of the IFT and therefore higher collection costs. To further validate these findings, research should be carried out in areas where the abundance of IFT is lower. Hence, data need to be collected from other Southern African countries, which have shown higher deforestation rates than Zimbabwe in the past.

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

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

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Appendix

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

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

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

Instead of holding the portfolio, the farmer can buy the right to plant trees and produce the products herself to generate V for the same short interval dt. If she produces the products herself she has to spend $F(V,t)$, which is the market value of the trees that entitles her to future profits from the trees. Over the short time period, dt, this value will change by *dF*. The change is uncertain. The random capital gains, *dF*, can be calculated using Ito's Lemma (Dixit and Pindyck, 1994)[8] [9]:

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

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

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

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

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[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).

$$xV/(1+xV) = VF_V(V,t)/F(V,t)\,, \tag{A4}$$

and

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

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

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

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

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

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

$$F(V) = \begin{cases} BV^{\beta} & \text{for } V \le V^* \\ V - I & \text{for } V \ge V^* \end{cases} \tag{A7}$$

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

with

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

and

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

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

$$V^* = \frac{\beta}{\beta - 1} I . \tag{A10}$$

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

Tables

Table 1

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

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

Table 2

Scenario 2: Parameter values of the option to invest in planting of domesticated indigenous fruit trees[1)]

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

[1)] Same legend as for table 1.

Table 3

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

			Scenario 3[1)]				
First fruiting	Fruit price	Yield	Collection costs	*r*	*I*	*V**	*V*
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

[1)] Same legend as for table 1.

Table 4

Scenario 5 and 6: Parameter values of the option to invest in planting of domesticated indigenous fruit trees

			Scenario 5[1)]				
First fruiting	Fruit price	Yield	Collection costs	*r*	*I*	*V**	*V*
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	*r*	*I*	*V**	*V*
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

[1)] Same legend as for table 1.

Figures

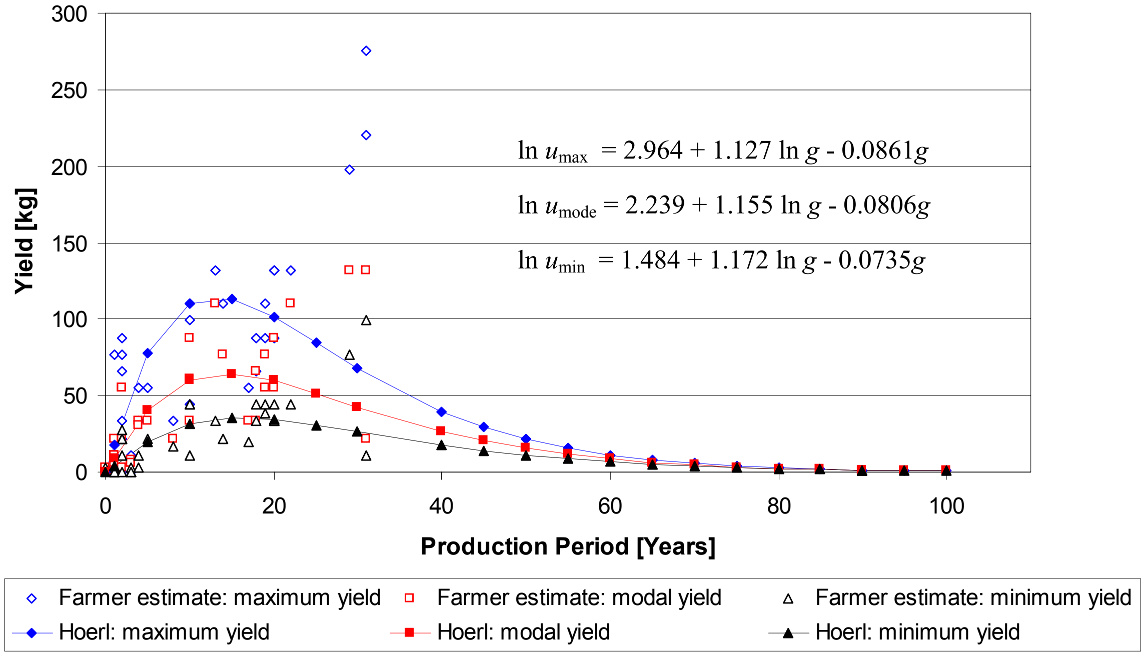

Figure 1. Age yield function of Uapaca kirkiana.

Tables in Appendix

Table A1

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

[1] These figures take the germination rate of 80% into account; [2] 3 seeds per fruit; [3] Space requirements $1m^2$/100tubes; [4] Orchard of five trees.

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

Table A2

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

[1] Mean; [2] Mode, [3] DS dry season, WS wet season.

Source: Survey.

Table A3

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

Source: Survey.

Table A4

Rates of return on the tree sector for households of Murehwa

Household	EFT	P. curatellifolia & Strychnos sp.	U. kirkiana	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

Source: Survey.

Table A5

Variance-covariance matrix of the market portfolio, Murehwa

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

Source: Survey.

Table A6

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%

Table A7

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

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

Table A8

Scenarios assessed in the investment analysis[1)]

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	↑	–	–	↑

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