PRIVATE INVESTMENT IN BIODIVERSITY CONSERVATION: A REAL OPTION APPROACH.

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Abstract

In the 1990's, the World Agroforestry Centre (ICRAF) initiated a domestication programme of indigenous fruit trees (IFTs) in Southern Africa to increase farm-household income through farmer-led tree planting and thus conserve bio-diversity. From the farmer's point of view planting domesticated IFTs is an investment under uncertainty and irreversibility. As timing of planting is flexible, real options theory suggests that waiting to invest may be a profit maximising strategy. Applying the real option theory the critical value of an investment in planting IFTs is derived using contingent claim analysis. As previous studies on ex-ante assessments investments in agriculture have used dynamic optimisation, we use contingent claims and explicitly derive the risk adjusted rate of return from the Consumer Capital Asset Pricing Model by using the different sources of farm-household income. Our analysis investigates to what level (1) fruit collection cost and/or (2) the necessary technical change, i.e. breeding progress, have to rise that will render tree planting economical. Results show a combination of technical change and decrease in resource abundance provides scope for farmer-led planting of domesticated IFTs and bio-diversity conservation. However, breeding progress must be significant for investment in tree planting to be economically attractive and thus to contribute towards on-farm preservation of the IFTs.

Keywords: indigenous fruits, CAPM, real option, R&D, technology adoption, Zimbabwe.

Introduction

Indigenous fruits are extensively used for home consumption and are increasingly being commercialised by the rural population in Southern Africa (Cavendish, 2000; Maghembe *et al.*, 1994; Maghembe *et al.*, 1998)). They are available in times of drought thus sustaining food security and are appreciated for their nutritional value (Rukuni *et al.*, 1998). Due to increasing population pressure and other factors, land deforestation continues and, although traditionally indigenous fruit trees (IFTs) have to be preserved when clearing woodland in favour of agricultural production (Clarke *et al.*, 1996), nowadays, IFTs are also being felled (Rukuni *et al.*, 1998).

In 1997, the International Centre for Research in Agroforestry (ICRAF) initiated a domestication programme of IFTs of Southern Africa to halt loss of biodiversity due to clear cutting. By improving quality and quantity of fruits per tree, the programme aims to encourage IFT planting by farmers thus enhancing indigenous fruits supply. In 1998, Maghembe *et al.* conducted a priority setting exercise, in which farmers identified their most popular indigenous fruit tree species, which is *Uapaca kirkiana* for Zimbabwe. However, until now, farmers have rarely planted the IFTs but continued collecting from the communal areas (Campbell, 1996). ADD ADOPTION early adopters versus real option

A necessary but not sufficient condition for adoption of tree planting at farm level for a profit-maximizing farmer is a positive economic gain. The assessment of ex-ante benefits is a valuation problem under uncertainty as future prices and quantities of inputs and outputs are not known with certainty. From a theoretical point of view, the problem of an ex-ante adoption decision of a long-term investment is the identification of the relevant discount rate and the risk preferences of the decision maker. If irreversibility is excluded, the individual rate of time preference can be used as the discount rate and elicited from the decision maker by using dichotomous choice models; attitudes towards risk can be considered by ranking alternatives by using first and higher degrees of stochastic dominance (Wesseler, 1997).

But, generally, an investment in planting domesticated indigenous fruit trees is irreversible and thereby the real option value of postponing the decision to plant trees has to be considered as well. Several applications of the real option approach for investments under uncertainty in agriculture exist (e.g. Carey and Zilberman, 2002; Price and Wetzstein, 1999; Purvis *et al.*, 1995; Wesseler, 2002; Winter-Nelson and Amegbeto, 1998). The real option value can be identified either by dynamic programming or contingent claim analysis (Dixit & Pindyck, 1994). 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 (Dixit and Pindyck, 1994). Most studies use the contingent claim analysis and assume that the underlying risk of the investment can be hedged without explaining the derivation of the risk free portfolio and the risk adjusted rate of return (e.g. Purvis *et al.*, 1995; Winter-Nelson and Amegbeto, 1998).

In this paper we use contingent claims analysis and derive the risk adjusted rate of return from a portfolio of farmers investment opportunities. We argue that this approach is feasible as farmers in rural Africa use a diversity of investment activities and do have equal access to information. We use the results of our model to answer the following questions:

1. What is the level of natural resource use cost increase that triggers on-farm investment in domesticated trees?
2. What level of tree improvement is necessary to induce farmers to invest?

The latter aspect is modelled as (a) a shift towards trees bearing fruits at an earlier age, (b) as a yield increase as compared to non-domesticated fruit trees, and (c) a quality change of the fruits of domesticated trees, which is modelled as a price increase as compared to non-improved fruits. Answering these questions can help to improve the success of the domestication programme and hence contribute to biodiversity conservation.

The paper is organized as follows. First, we derive the value of an investment into domesticated indigenous fruit trees using the real option approach and contingent claim analysis. Then, a numerical example from a village in Zimbabwe is used to illustrate the results. At the end, conclusions are drawn for the domestication programme.

The theoretical model

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

The net-present-value of an infinite sequence of rotations from an orchard of domesticated trees, $NPV_{DT\infty}$, providing multiple products planted at t=0 is given through equation (1):

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

with R_T the residual value in T, that is timber value minus cost of uprooting, μ the risk adjusted discount rate, I the initial irreversible investment outlays, T the rotation period, b_t the vector of benefits, and c_t the vector of costs. We call **Error! Objects cannot be created from editing field codes.** the present value of an investment in planting domesticated IFTs, whereby $NPV_{C\infty} = V_C$ constitutes the net present value of collecting the fruits from the communal areas. Hence, V measures the incremental benefit of planting domesticated IFTs.

The costs and benefits of the investment can be observed on the market but the discount rate cannot. If one assumes that the option to invest is owned by investors with well-diversified, efficient portfolios, then they need only to be compensated for the systematic component of the risk of the option to invest. According to the Capital Asset Pricing Model (CAPM) the expected risk premium in a competitive market varies in direct proportion to the market risk, that is the non-diversifiable (systematic) risk. The price for the non-diversifiable risk of the title V is the risk adjusted discount rate, μ, which can be established through the equilibrium equation of the CAPM $\mu = r + \lambda Cov[r_m r_V]$ (Brealey & Myers, 2000). μ is determined by the risk free rate of return, r, the market price of risk $\lambda = \frac{E[r_m] - r}{Var[r_m]}$, the market rate of return, r_m and the rate of return of V.

Farmers do not face a dichotomous choice of planting now or never, but are flexible in carrying out investment. They also face uncertainty about future benefits and costs of their investment in domesticated indigenous fruit trees, which influences optimal timing of an investment (this has been analysed by e.g. McDonald and Siegel 1986; Pindyck 1991; Dixit and Pindyck 1994)[1]. The value of the option to invest, $F(V,t)$, can be derived by replicating the costs and benefits under uncertainty using traded assets. By assuming the value V of the investment follows a geometric Brownian motion of the form $dV = \alpha V dt + \sigma V dz$ 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 well know result (Dixit and Pindyck, 1994):

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

The interpretation of equation 2 is, 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 $\beta/(\beta\text{-}1)$. If the current level of V is less than V^* it is worthwhile to postpone the planting of domesticated IFTs, thus the value of the option to invest, $F(V)$ is given through the value of waiting, BV^{β}. If V exceeds V^* then $F(V)$ is given by the value of immediate investment $V - I$.

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[1] 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, the option to invest (real option) has a value, which is a result of the option owner's flexibility

Data and application

Data was collected in ward 16, Murehwa District, which is a major collection area for *U. kirkiana* fruits in Zimbabwe. A sample of 19 households was monitored from August 1999 to August 2000 to collect data on income generating activities, indigenous fruit tree use and price information. Additionally, a farmer workshop and expert interviews were held to gather information on physical characteristics of *U. kirkiana* trees and fruit production.

The risk adjusted rate of return, μ, is derived from the portfolio of the 19 farm-households monitored by using the capital asset pricing model. The portfolio consists of agricultural, horticultural (mainly vegetable production), livestock keeping and off-farm activities (Mithöfer & Waibel, 2003). The expected rate of return, $E[r_m]=\sum_{a=1}^{A}\omega_a E[r_a]$ and the variance of the rate of return, $Var[r_m]=\sum_{a=1}^{A}\sum_{k=1}^{A}\omega_a\omega_k Cov[r_a, r_k]$ of the market portfolio are determined by the linear combination of its titles (a, k, ... A), whereby ω gives the relative share of each title. Due to the high rate of inflation in Zimbabwe in 1999/ 2000, rates of return for farming activities were adjusted for inflation, using 50 % of the GDP deflator (59.9 %) provided by the World Bank (2002). Opportunity cost of land are assumed to be nil, as farmers can borrow land from neighbours or are allocated additional land from the chief free of charge. The cost of capital input are valued at the risk free interest rate, which in our case is specified through the interest rate on membership in a savings club. For a savings club several farmers join together and

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and is similar to the quasi-option value developed earlier by Arrow and Fisher (1974) and Henry (1974) (Fisher 2000).

monthly pay in storable goods. At a pre-defined date, a party is held, where the paid in items are distributed back to their owners. Since every farmer receives back the same item he paid in and the fact that product prices rise according to the rate of inflation the risk free interest rate is set to nil[2]. The covariance between the market rate of return and the rate of return on planting domesticated trees is estimated via the covariance between the rates of return of the tree use sector, i.e. collection of indigenous fruits and production of exotic fruits, and the rates of return on the market portfolio (Household Survey 1999/ 2000).

The value of IFT products through planting of an orchard is difficult to compare with collection of fruits from the communal areas as the scale of both enterprises may differ. Consequently, V is established on the basis of returns to labour (see equation (3)). The first term refers to the value per labour-day, L_{DT}, of domesticated trees, V_{DT}, and the second term to the value per labour-day of collecting fruits, L_C, from the wild, V_C. LC_{DT} and LC_C give labour cost for orchard management of improved trees and collection from the wild respectively.

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

For establishment of an orchard of five domesticated trees, 35 trees have to be planted, because of poor survival after planting (20%, Chidumayo, 1997) and poor success of

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

grafting (70%, Mhango *et al.*, 2002). The latter is assumed to take place in situ. Initial investment cost are based on seedling production costs, which are ZWD 267, and labour cost of planting (ZWD 507) for an orchard of 5 non-domesticated trees and ZWD 462 (seedling production cost) plus ZWD 709 (planting labour) for establishment of an orchard of 5 domesticated trees. During the life cycle of the trees first the yield increases, then starts to decline after 35 to 45 years of production (Mwamba, 2000). Yield is variable among years and individual trees. Fruit yield for each age is modelled randomly as a triangular distribution based on the Hoerl function[3] (Haworth & Vincent, 1977) using information on minimum, mode and maximum yield from farmers and fruit experts. One draw for the realisation of the yield serves as yield estimate for all trees within the orchard. Fruit yield in a given year is assumed to be independent from the yield of previous years. Improvement of the domesticated trees can occur regarding selection (breeding) of superior species, e.g. taste and fruit size improved, and through establishing appropriate vegetative propagation methods. The latter is a pre-requirement of shortening the period to maturity, which for the unimproved species with a period of 11 to 16 years is rather long (farmer estimates; Household Survey 1999/ 2000).

Fruit prices are considered to follow a uniform distribution using the range of farm gate prices found in the survey (0.4 – 18 ZWD kg^{-1}). Prices of other tree products are either market prices or prices of substitutes. Labour input for orchard management is based on the lowest level of labour input for the cultivation of alternative trees (Household Survey 1999/ 2000). The optimal life span of the orchard, T^*, is found, where return to

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[3] The Hoerl Function allows to model the age yield function of a fruit tree with the following properties: "An individual orchard tree will have the following biological curve: zero production during the initial years; rapid rise to maximum yield, constant over a number of years, dependent on species and variety; with a final period of declining yield" (Haworth & Vincent, 1977, p. 20).

labour is maximised, accounting for multiple products the trees provide. Factors determining *T** are the fruit-, leaf- and wood-production functions of *U. kirkiana* (the latter two functions are specified according to Chidumayo, 1997) as well as the prices for these products.

V is not constant; *dV*, is modelled as a geometric Brownian motion. Then the discrete change of *V* between V_{DT} and V_C can be defined as the difference of the natural logarithms between V_{DT} and V_C. Through Monte Carlo simulation values for V_{DT} and V_C are generated (using @risk and Excel software) and the difference between V_{DT} and V_C is calculated by $\Delta(\ln V_j) \equiv \ln(V_{DT}) - \ln(V_C)$[4]. The subscript *j* denotes the sample size over which the difference is calculated, which is computed over 50000 iterations. The drift rate $\hat{\alpha}$ of *dV* is the arithmetic mean over all $\Delta(\ln V_j)$, and the variance rate $\hat{\sigma}$ is the standard deviation over all $\Delta(\ln V_j)$.[5]

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[4] If *V* follows the Geometric Brownian Motion, then $d\ln V = \left(\alpha - \frac{\sigma^2}{2}\right)dt + \sigma dz$. From this $\ln V_{t+1} - \ln V_t \sim \phi\left[\left(\alpha - \frac{\sigma^2}{2}\right)(t+1), \sigma\sqrt{t+1}\right]$. The term on the right hand side stands for a normal distribution with mean $\left(\alpha - \frac{\sigma^2}{2}\right)(t+1)$ and standard deviation $\sigma\sqrt{t+1}$. Thus the expected value of V_{t+1} $E(V_{t+1}) = V_t e^{\alpha(t+1)}$ (Hull, 2003), from which equation $\Delta(\ln V_j) \equiv \ln(V_{DT}) - \ln(V_C)$ can be derived (*t*+1 refers to domesticated trees, *DT* and *t* refers to collection of the fruits, *C*).

[5] The growth rate, α, would come from price appreciation. The relationship between convenience yield, growth rate and risk adjusted interest rate (= total expected rate of return) is given through $\delta=\mu-\alpha$. The convenience yield is equivalent to the dividend in financial economics; it is a benefit that accrues just from holding the project (Dixit & Pindyck, 1994).

Evaluated scenarios

The expected economic gain from planting domesticated indigenous fruit trees depends on the level of tree improvements and the relative level of opportunity cost, which is collection of the fruits from the communal areas. Thus the following scenarios are assessed Table 1.

Table 1. Scenarios assessed in the investment analysis.

Improvement of domesticated trees in terms of					
		Maturity	Yield level	Fruit quality	Collection cost
			Scenario number		
Maturity	First fruit yield after planting (years).	-	1	2	3
Yield level	In comparison to non-domesticated IFT.	-	-	4	-
Fruit quality, i.e. fruit price	Stochastically 1 to 3 times higher than price of non-domesticated fruits	-	-	-	5
Opportunity cost increase					
Collection cost	Increase of labour input to collect the fruits from the communal areas (compared to survey findings).	-	-	-	-

Results and discussion

Characteristics of non-domesticated trees

Yield, u is determined through productive age, i.e. time from maturity onwards, of the tree, g[6]. Yield functions for minimum, mode and maximum yield are given through equation (4) – (6).

$$\ln u_{\min} = 1.484 + 1.172 \ln g - 0.0732 g \tag{4}$$

$$\ln u_{\mathrm{mod}\,e} = 2.239 + 1.155 \ln g - 0.08057 g \tag{5}$$

$$\ln u_{\max} = 2.964 + 1.127 \ln g - 0.08607 g \tag{6}$$

The risk adjusted rate of return is at 15.64%. It is based on the expected rate of return on the market portfolio (10.24%), its variance (0.1671), and the covariance between the market portfolio and the tree sector (0.26). In order to estimate rates of return on the titles of the portfolio, labour inputs were valued at the average daily wage rate of ZWD 58 for agricultural, horticultural and off-farm activities. Labour input into livestock keeping were valued at the prevailing daily wage rate for the livestock sector, which was at ZWD 10 (Household survey 1999/ 2000). Revenue of collecting indigenous fruits tree products from the wild net off collection cost can be interpreted as annuity. It ranges from ZWD 262 – ZWD 6528, with a mean of ZWD 1285 (Household survey 1999/ 2000). If the annuity of collection is simulated based on stochastic prices following an uniform distribution with the minimum and maximum farm gate price as lower and upper bound, it is on average ZWD 3187 (SD 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). Table 2 shows the comparison of returns to labour for planting wild fruit trees versus collection of their products.

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[6] Usually, age-yield-function are established but due to the limited recall abilities of the farmers and the fact that they tend to notice more when a tree starts bearing fruits than the time it germinates, data on the tree’s productive period was considered as more reliable than information on the age of the tree.

Table 2. Returns to labour for collecting indigenous fruits from the wild in comparison to returns to labour for planting of not improved IFT's

	Farm gate price of fruits	Returns to labour [ZWD day^{-1}]
Collecting IFT products from the communal areas	1999/ 2000 Survey1)	222 (228)
Collecting IFT products from the communal areas	Uniform (0.4;18)2)	506 (255)
Planting not improved IFT's maturing between 11-16 years3)	Uniform (0.4;18)2)	52 (34)

1) Data over 19 households from Murehwa District, Ward 19 (Household Survey 1999/ 2000). Figures give average over all households. Figures in parentheses give the standard deviation.

2) Distribution, defined by the minimum and maximum farm gate price of the 1999/ 2000 survey.

3) For an orchard of 5 trees. Figures give present value of planting non-domesticated trees, $V_{nonDT\infty,}$, which is determined analogously to $V_{DT\infty,}$.

As returns to labour for planting of not improved species is on average below the average wage rate and thus the annuity is negative, one can conclude that also the option to plant non-domesticated IFTs equals nil. The question therefore remains, how much collection costs have to rise or trees have to be improved so that the option to plant is of value.

Domestication, natural resource use cost and adoption of IFT planting

Simulation results show, that a shift in maturity to two years of age is not sufficient to trigger investment. Additionally, cost of collecting fruits from the communal areas have to rise, while the yield function remains the same as for non-domesticated IFTs (scenario 3) (Table 3 and 4) or the yield function has to increase while collection cost remain at the current level (scenario 1) (Table 5 and 6).

Table 3. Maturity at 2 years: Parameter values of the option to invest for different levels of collection cost.

	Level of collection cost [times the current level]							
	1999/2000 survey	2.0	2.5	2.7	2.8	2.9	3.0	3.1
α	-0.946	-0.253	-0.029	0.047	0.084	0.120	0.154	0.186
σ^2	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
$\beta/(\beta-1)$	1.0104	1.03	1.06	1.11	1.16	1.31	5.27	-

As α grows closer to the risk adjusted discount rate the hurdle rate increases, thus waiting turns out to be of higher value. Once α exceeds the risk adjusted discount rate farmers would wait to invest indefinitely. However, not only the hurdle rate and thus the trigger value but also the present value of investment increases with increasing collection cost (table 4).

Table 4. Maturity at 2 years: Trigger and present values of the option to invest for different levels of collection cost [ZWD[1] day^{-1}].

Maturity at 2 years.	Level of collection cost[2] [times the current level]							
	1999/2000 survey	2.0	2.5	2.7	2.8	2.9	3.0	3.1
Trigger value, V*	23.1	23.5	24.3	25.3	26.5	30.0	120.8	-
Present value, V[3]	-299.2	-46.0	4.8	19.9	**26.6**	**33.0**	38.6	43.9

[1] 1 USD = 38 ZWD, December 1999.

[2] The increase in the level of collection cost was modelled as an increase in labour days to collect the same amount of fruits as compared to the 1999/ 2000 survey data.

[3] Mean over $V = (NPV_{DT\infty} + I) - (NPV_{C\infty})$.

Figures in table 4 can be interpreted as follows: investment into planting of improved indigenous fruit trees according to the conventional NPV approach would require the present value of investment, V to exceed ZWD 23 per labour-day. This would be the case for a collection cost increase of between 2.7 to 2.8 times higher than the current level. However, depending on the level to which collection cost rise, the trigger value V^* and the present value V also rise. When collection cost increase 2.8 to 2.9 times higher as they are currently farmers can be expected to immediately invest as the present value then exceeds the trigger value. For a collection cost increase to the threefold level as compared to today, waiting turns the profit maximising strategy, because in this area the growth rate of the present value of investment turns closer to the risk adjusted rate of return.

Scenario 1 shows the yield increase in addition to a shift in maturity to two years of age (table 4 and 5). Again, the hurdle rate grows with increasing improvements of the domesticated trees (table 5).

Table 5. Maturity at 2 years: Parameter values of the option to invest for different levels of yield increase.

	Yield increase of domesticated trees in comparison to non-domesticated IFTs[1)]				
	8 times	9 times	10 times	12 times	16 times
α	-0.032	-0.007	0.015	0.050	0.092
σ^2	0.016	0.017	0.016	0.016	0.016
$\beta/(\beta$-1)	1.04	1.05	1.06	1.07	1.12

[1)] The yield increase was modelled by a shift of the mode yield. The difference between minimum, mode and maximum yield remained constant.

With increasing yield level, labour input into harvesting of the fruits also increase, thus initial investment cost per labour-day decrease (Table 6). This effect exceeds the effect of the increasing hurdle rate and results in a declining trigger value. As also the present value of investment increases, investment would be triggered at an eightfold yield increase as compared to the level of non-domesticated trees.

Table 6. Maturity at 2 years: Initial investment cost, trigger and present values for different levels in yield increase [ZWD[1)] day^{-1}].

	Yield increase of domesticated trees in comparison to non-domesticated IFTs[2)]				
	8 times	9 times	10 times	12 times	16 times
Initial investment cost, *I*	8.3	7.6	7.1	6.2	5.1
Trigger value, *V**	8.6	8.0	7.5	6.7	5.7
Present value, *V*[3)]	6.6	**20.0**	**31.2**	**49.9**	**74.2**

[1)] 1 USD = 38 ZWD, December 1999.

[2)] The yield increase was modelled by a shift of the mode yield. The difference between minimum, mode and maximum yield remained constant.

[3)] Mean over $V = (NPV_{DT\infty} + I) - (NPV_{C\infty})$.

The present value of investment exceeds the trigger value for a yield increase of about nine times; at this level of improvement the present value also exceeds initial investment cost.

Since it is not quite clear, whether a shift in maturity to an age of two years is a feasible improvement, trigger and present values of yield increases and increases in collection cost in combination with older age at maturity are evaluated. Table 7 shows the changes necessary to initiate investment for those maturity ages. Inducing maturity at an age of four years would require in addition a yield increase of greater than 10 times of the non-domesticated level, but lower than 40 times. From then on waiting to invest would commence due to the high growth rate, α of the incremental benefit of investment. Thus the older the trees are for producing the first yield, the higher the improvements of the yield level have to be for adoption of the new technology. However, if natural resource use cost increase in combination with older age at maturity farmers cannot be expected to adopt planting. This is caused by relatively stronger increases of the trigger value than the present value of investment.

Table 7. Adoption of domesticated IFT planting depending on age at maturity, yield increases and increasing natural resource use cost.

	Maturity [years]				
	2	4	6	8	10
Yield increase [times the non-domesticated level]	9 - 30	10 - 40	12 - 56	16 - 80	24 - 104
Collection cost [times the level of the survey year]	2.7 - 3.0	-	-	-	-

In addition to increasing yield and inducing precocity, fruit quality could be improved in terms of size and taste by selection of appropriate genotypes from the wild (SOURCE). It is assumed that such an improvement would result in higher fruit prices, which is addressed in scenario 4 and 5 in combination with increased yield and increased collection cost respectively. Results show that for this scenario lower increases in natural resource use cost trigger adoption, i.e. adoption would commence for collection cost increases of 1.3 to less than 2 times the current level (Table 8).

Table 8. Maturity at 2 years: Trigger and present values of the option to invest for different levels of collection cost and higher fruit prices for domesticated trees [ZWD day^{-1}].

.	Level of collection cost				
	1999/2000 survey	1.1	1.3	1.5	2
Trigger value, V^*	26.0	26.9	30.6	51.2	-
Present value, V	-86.8	-40.4	**31.0**	**83.2**	166.9

The effect of fruit quality improvement in combination with yield increases is similar. Regarding the latter much lower levels are required as compared to the case without fruit quality improvements (Table 9).

Table 9. Maturity at 2 years: Initial investment cost, trigger and present values for different levels in yield increase and higher fruit prices for domesticated trees [ZWD day^{-1}].

	Yield increase of domesticated trees in comparison to wild fruit trees			
	1999/2000 survey	1.5 times	2 times	6 times
Initial investment cost, I	22.5	19.7	17.6	9.5
Trigger value, V^*	26.0	26.1	37.1	-
Present value, V	-86.9	27.9	119.0	453.1

Differences in the risk free discount rate

We also evaluated the effect of a higher risk free discount rate, r on the option to invest. In our case higher r results in a lower risk adjusted discount rate, μ. Assuming r = 5 % instead of 0 %, then μ = 13.0%. In this case, scenario 1 (maturity at 2 years, collection cost constant) and a yield increase of greater than 6 times is sufficient to initiate adoption. For scenario 3 (maturity at 2 years, yield remains at the non-domesticated level), a rise in collection cost does not trigger investment since the trigger value grows relatively stronger than the present value of investment.

Conclusion

The present study focuses on the analysis of investment into planting of domesticated IFTs in Zimbabwe using a real options approach. Currently, farmers mostly collect IFT products from the communal areas. However, due to diminishing resource base (SOURCE) and increased competition over the fruits (SOURCE) IFT product availability per household is declining. Five scenarios for investment analysis are considered. Scenario 1, 2 and 4 evaluate the effect of improvement of the domesticated trees in terms of inducing precocity, increasing the yield per tree and improving fruit quality (fruit price) on the decision to plant the trees. Scenario 3 and 5 evaluate the investment decision for a combination of increasing natural resource use cost and tree improvements. Inducing precocity could be achieved through invention of an appropriate vegetative propagation technology (SOURCE), whereas improvements in fruit quality and yield increases would result from a combination of selecting superior genotypes and appropriate vegetative propagation technology. Increases in collection cost for trees products from the wild addresses the situation in areas, where the fruit trees are less abundant than in the research area *ceteris paribus*. It would also be the case for a situation, where deforestation increases and indigenous fruit trees are also cut *c.p.*. Regarding the latter actual decision making processes regarding selective tree cutting would also have to be taken into account.

The risk adjusted discount rate using the portfolio of farm-household income generating activities provided a real risk adjusted discount rate of 15.64%, which was used to evaluate the option to invest. It shows that under current conditions farmer maximise utility by collecting the fruits from the wild. Currently, farmers cannot be expected to plant unimproved indigenous fruit trees for reasons of income generation since collection of the IFT products from forests and the common lands yields comparably high returns to labour. Other reasons, e.g. taking pleasure in growing the trees or incentives from the domestication programme other than providing trees, have to be analysed separately.

Even advancing maturity to two years after planting through breeding does not induce investment. In addition to such an improvement collection cost for IFT products from the forests and the common lands and/ or fruit yield have to increase substantially to trigger investment. Farmers can be expected to switch to planting of IFTs, when collection costs have risen by 2.8 to 2.9 times of the present level, *ceteris paribus*. This would be the case, when deforestation continues. However, planting IFTs could be an alternative for areas with a lower abundance of the IFTs, *c. p.*. The switch to on-farm planting would also take place if breeding efforts on IFTs not only reduces age at maturity but also increases the yield level although the latter would have to rise by nine times or even higher levels *c. p.*. For trees, that mature at older ages than two years, fruit yield has to increase on a larger scale to trigger investment, here waiting to invest commences if not the yield but opportunity cost of planting, i.e. natural resource use cost, increase. However, if improvements address fruit quality and the domestication program can translate this into a higher fruit prices, e.g. by appropriate marketing strategies (SOURCE), then additional improvements in terms of precocity and yield increase have to be relatively smaller to initiate investment. However, increased natural resource use cost result in a large value of waiting to which the offsets adoption.

Overall results show that effect of tree improvements and/ or natural resource use cost increases on the decision to adopt move in very narrow boundaries. Both result in larger present values of investment but also increased trigger values. The switch from not planting because $V<V^*$ to not planting because growth rate α exceeds the risk adjusted rate of return, μ moves in a very close range of assumption changes. In order to induce immediate investment, the domestication program would have to reach an improvement level within those boundaries. The domestication program would have to assess the feasibility of achieving the level of technical changes or to target areas with lower abundance of the IFTs. In the latter case in order to overcome the large value of waiting to invest, the program would have to communicate, that tree improvements resulting in large growth rates of the incremental benefit of planting domesticated trees would not be sustained indefinitely.

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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 Euro in the riskless asset, i.e. a savings account. Thus, the portfolio costs $1+nV$ Euro. 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[2]. The total return from holding the portfolio over the short time interval for each dollar invested is:

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

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 (1).

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 the future profits from the trees. Over the short time period, *dt*, this value will change by *dF*. The change is uncertain. The random capital gains, *dF*, can be calculated using Ito's Lemma (Dixit & Pindyck, 1994)[7].

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

The total return per dollar invested in this option is given through equation (3), which is derived equivalently to equation (1):

$$\frac{F_t(V,t) + \alpha VF_V(V,t) + \frac{1}{2}\sigma^2V^2F_{VV}(V,t)}{F(V,t)}dt + \frac{\sigma VF_V(V,t)}{F(V,t)}dz\,. \qquad (3)$$

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[7] 3 Ito's Lemma states that the price of an asset is a function of the stochastic variables underlying the asset and time (Hull, 2003), which is in our case the value of the of the option *F*(*V*,*t*) and the output *V* respectively.

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 (3). 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 & Pindyck, 1994):

$$nV/(1+nV) = VF_V(V,t)/F(V,t) \tag{4}$$

and

$$\frac{F_t(V,t) + \alpha V F_V(V,t) + \frac{1}{2}\sigma^2 V^2 F_{VV}(V,t)}{F(V,t)} = \frac{r + n(\alpha+\delta)V}{1+nV}. \tag{5}$$

Equation (4) ensures that both assets are of equal risk (the *dz*-terms must equal each other) and as they are of the same risk they also must yield the same return, which leads to equation (5).

After some transformation the return for holding the option to invest can be expressed as a partial differential equation (6):

$$\frac{1}{2}\sigma^2 V^2 F_{VV}(V,t) + (r-\delta)VF_V(V,t) - rF(V,t) = 0. \tag{6}$$

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, 1996):

After solving equation (6) according to these conditions the function for the value of the option to invest is given by (7):

$$F(V) = \begin{cases} BV^{\beta} & \text{for } V \leq V^* \\ \\ V - I & \text{for } V \geq V^* \end{cases} \tag{7}$$

value of immediate investment.

with

$$B = (V^* - I)/(V^*)^{\beta} = (\beta - 1)^{\beta - 1}/(\beta^{\beta} I^{\beta - 1}), \tag{8}$$

and

$$\beta = \frac{1}{2} - (r - \delta)/\sigma^2 + \sqrt{\left[(r - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2r/\sigma^2}\ . \tag{9}$$

B is a shift parameter, and β is the positive solution to Equation (6) which is used to establish the hurdle rate V^*, which is the critical level of returns that will trigger off investment:

$$V^* = \frac{\beta}{\beta - 1} I\ . \tag{10}$$

Equation 10 states the value of immediate investment V should be at least as high as V^*. If the current level of V is less than V^* it is worthwhile to postpone the planting of domesticated indigenous fruit trees.