AARES 53rd ANNUAL CONFERENCE 2009

Optimal replanting and cutting rule for coffee farmers in Vietnam

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Content of paper

Abstract

This paper identifies the optimal cutting and replanting rule for coffee farmers in Vietnam. Some previous studies examined the optimal price at which to cut trees for coffee farmers in Vietnam but they have not investigated the relationship between the age of tree and the cutting point. Fixed-form optimization is applied to analyze a rule that links market coffee prices and age of tree with the cutting decision.

Keywords: Coffee in Vietnam, fixed-form optimization, optimal cutting and replanting, price fluctuation, crop replacement.

1. Introduction

Coffee is a vitally important part of the Vietnam's economy – even though the price collapsed recently it is still the second largest export earner after rice, and employs over 600,000 workers, rising to nearly 800,000 workers at the peak of the season or 2.93% of the agricultural labor force (Worldbank 2002).

Since the early 1990s, coffee production in Vietnam has increased sharply. The area of coffee increased from around 100,000 ha in early 90s to nearly 600,000 ha in 2000, with an average annual growth rate of 16% over the same period (see Figure 1).

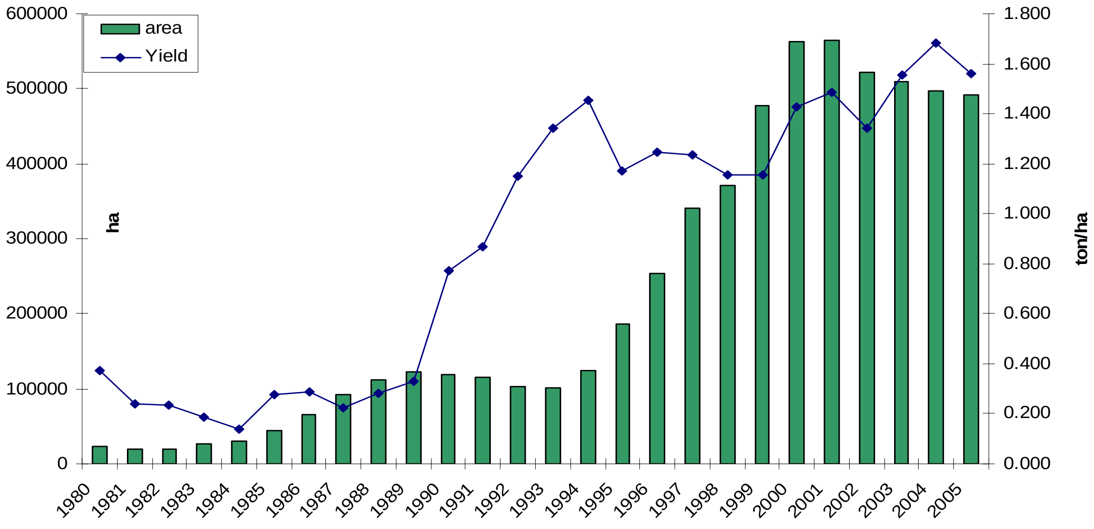

Figure 1. Increase in coffee area in Vietnam, 1980-2005

Source: GSO

The coffee price crisis in the early 2000s affected dramatically the coffee producers as well as other involved sectors in Vietnam, as well as other exporting countries. The coffee price received by farmers in Vietnam reduced to only 0.336 USD per kg in 2001 comparing to 2 USD/kg in the mid of 90s[2].

Coffee farmers in Daklak an important coffee production province in Vietnam) were suffering severe losses from the depressed price. A large number of households had to cut trees and switch to other crops. Figure 2 shows the % of the surveyed farmers who entered coffee production in each year (Thang, 2008)[3]. This shows that about 30% of household in the sample started to grow coffee in 1995, 1996. Before 1986, Vietnam was centrally planned economy so only a small area of coffee was grown for domestic consumption. That is why there was no coffee grown in early 80's despite the price being high. When the economy was opened, demand for export coffee motivated farmers to expand coffee area. However, in the years 2002-2003, the total area of coffee cut in Daklak province was approximately 30,000 ha[4] (or 16.6 % of the total).

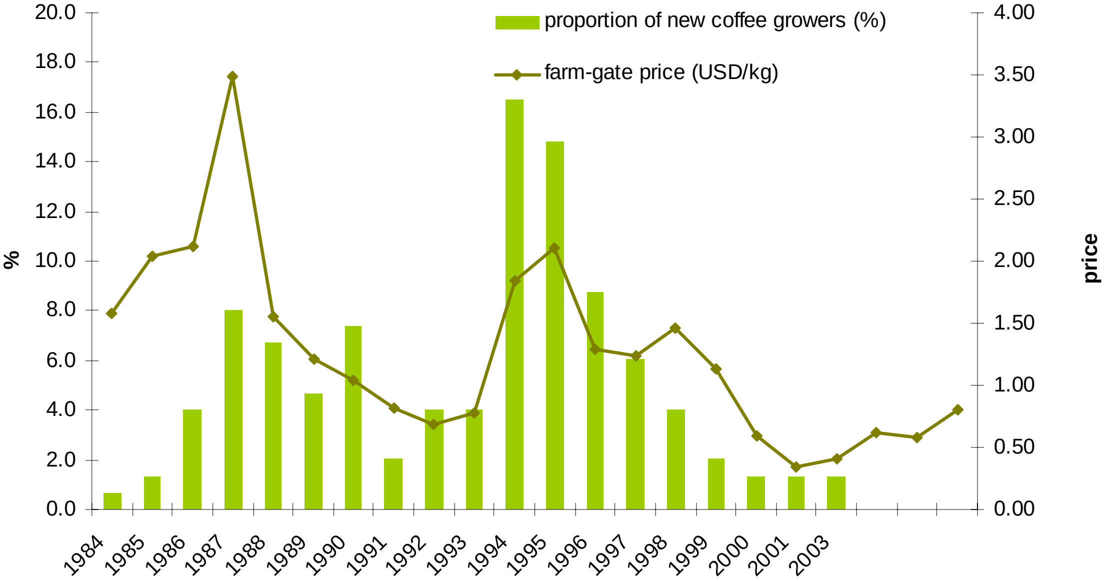

Figure 2. Coffee price and new planting trend[5] in Daklak province

Source: Thang (2008) and GSO

Managing a farm is complex and the choice of farm strategy may be influenced by the farmer's knowledge of scientific issues (biological and/or physical), machinery availability, economic/commercial factors, political events, legal constraints, historical

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[2] www.ico.org

[3] Coffee farm survey was implemented by the author in 2007 in Daklak province, Vietnam. A sample of 150 coffee farmers was interviewed by face to face method using a questionnaire. The survey collected data on household size, coffee production (farm size, yield, production cost, price, sale), farmer's decision and response to price falls, credit access and support services (see Thang (2008) Daklak coffee farm survey 2007 (mimeo))

[4] Department of Agriculture and Rural Development, Daklak province.

[5] This number is measured by percentage of households who firstly entered in the coffee production

trends, climate/weather, environmental issues, personal circumstances and any number of practical considerations (Pannell 1996). In recent years the decision to remove trees, and specially new planting of coffee Vietnam were seemingly out of government's control and strategy

In addition, coffee is a perennial crop thus, deciding the point to plant or quit from coffee is much more complicated than annual crops. The investment decision including new planting and replanting, or cutting decision of coffee farmers are determined by factors such as (i) land and other resources availability (capital, labor), (ii) age of orchards (with lower yields and increased maintenance and harvest costs push farmers to try replanting), and (iii) relative prices or profit (farmer can decide to switch to other crop if price of coffee is too low)[6].

The major objective of this paper is to identify the optimal cutting and replanting rule for coffee farmers in Daklak province, Vietnam using fixed-form optimization when price varies stochastically.

2. Literature review

The analysis of crop rotation and optimal decisions has been extensively studied. Various methods have been applied to identify the optimal farmer behavior.

In all methods, Linear programming (LP) is the most popularly applied to analyze farm's optimization, including the identification of optimal cutting and harvesting rules. Some examples of LP are Heady (1954), Hildreth and Reiter (1951), El-Nazer and McCarl (1986), Peterson (1955) and Swanson (1956). Even with much improvement, applying linear programming can sometimes not reflect correctly the behavior of farmers and the relationship between constraints. This occurs because the true objective function and constraints are not linear.

To overcome the assumption of LP that choice variables in fact are perfectly divisible, integer programming is developed. This is a good method to solve different optimization problems when decision variables must be integer such as number of animals, number of machinery equipment or number of plants. This method was applied in Danok and McCarl (1978), Moseley and Speen (1986), Upcraft and Noble (1989) applied the mixed integer programming to find an optimal decision of farmers. However, generally, integer programming has not applied popularly in agricultural analysis due to its integer constraints of variables.

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[6] See more potential criteria intervene in investment of farmers in Ruf, F. and K. Burger (2001). Planting and Replanting Tree Crops – Smallholders' Investment Decision. paper presented at the international conference on The Future of Perennial Crops, Yamoussoukro.

Generally, the relation and constraints in the model are not linear. Hence, quadratic programming is thought as a more comprehensive technique for reflecting farm behaviors. Hall, Heady *et al.* (1968) used the quadratic programming to analyze competitive equilibrium in US[7]. Hossain (2002) applied quadratic programming to analyze farm planning in Bangladesh under uncertainty[8].

Initially, applications of LP tried to find the optimal control for a single period time horizon, normally one year. Later, multi-period LP was developed to identify the decision of farmers over a longer time horizon. Jayasuriya, Barlow and Shand (1981) used the **inter-temporal profit maximization model** for analyzing the long-term investment decision of Sri Lankan rubber smallholders. Similarly Kearnev (1994) applied the **inter-temporal LP** to analyze the planting and replacement decision of farmers for pip fruit in New Zealand. Those improvements help to build models which can reflect closely farm system and decisions.

The decisions of farmers over time are generally not independent. The decision in the current year will have consequences in the futures. Thus, the Dynamic programming (DP) method was developed to analyse and find the optimal rule for sequential decision problems. DP is based upon the principle of optimality which states that at any point in a sequence of decision, one decision should be chosen to maximize the sum of yields received from this decision plus total future yield which can be attainable from the system (Bellman 1957)[9]. The main difference between LP and DP is that while LP is computationally much more efficient than DP for solving deterministic problems with a linear objective function and constraints, DP maybe more suitable for solving more intractable problems (Kennedy 1986)[10]. Furthermore, Kennedy (1986) also points out that DP is a technique particularly suited for obtaining numerical solution to problems that involve functions which are non-linear, stochastic and have state and decision variables which are constrained to a finite range of values.

Dynamic programming has found wide use in pest management, water resources, fisheries, and in the management of other animal populations. However, DP also has been used for analyzing crop rotation, and popularly applied to find the optimal cutting time for forest trees. Examples of DP are Burt and Allison (1963), Matheson (2007), Jia (2006), Dixon and Howitt (1980), Penttinen (2006) ,Chladna'(2007), Alvarez and Koskela (2004).

Another method has also been extensively used to analyze optimal decision rules farmers, especially for forester is the real option approach. Options add value as they provide

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[7] see more in M. Gould (2001)
[8] see more in M. Gould (2001)
[9] pp 340-341.
[10] p.6

opportunities to take advantage of an uncertain situation as the uncertainty resolves itself over time. The combination of two things need to be in place for a real option to exist: there must be uncertainty in terms of future project cash flows *and* management must have the flexibility to respond to this uncertainty as it evolves.

Several previous studies applied the real option method to analyze the cutting and replanting of multi-year crops including timber trees. Luong and Loren (2004) used real option model to examine Vietnamese coffee growers' investment decisions. The objective of this study is similar to the current study but with a different approach.

This method was also applied by Abadi Ghadim and Pannel (1999), Insley and Rollins (2005) and Chladná (2007) for analyzing the optimal harvesting decision of forestry crops.

In analyzing or finding the optimal decision on tree cutting, some author applied another method called **Bayesian Approach.** Paulo and Otten (2007) used Bayesian approach to find the optimal decision on tree cutting in a Portuguese eucalyptus production forest.

In all applications to analyze the optimal farmer's decision, especially in the context of the cutting and replanting rule, little research has applied the fixed form optimization approach. This paper applies this method to find the optimal cutting and replanting rule for coffee farmers in Vietnam. Fixed form or policy space optimization is a technique which has been used to obtain near optimal feedback policies for complex ecosystem problems. It can be most easily thought of as a multidimensional extension of the control-space optimization. According to Walters and Hilborn (1978), there are two basic steps in the development of fixed form optimization. The first is to find the algebraic form of control function. Commonly, the form can intuitively be guessed at a reasonable form, and in systems with a few state variables and controls, one can simply make the control a polynomial function of the state variables.

The second step in fixed-form optimization is to find the optimal values of the control parameters (Walters and Hilborn 1978). There are two alternative approaches to this problem. The most elaborate is to use one of the many general gradient search algorithms that have been developed for nonlinear optimization. However, each evaluation of a set of parameters involves a numerical simulation of a fairly long time horizon, and the number of simulations required is usually much more than the number of parameters. A second and much simpler approach is by testing a large set of randomly chosen values for the control parameters. Such random searching methods can work as well as gradient search methods for problems that involve discontinuous response surfaces, or ones with several peaks.

Peterman (1977) applied the fixed form method for hazard index function (H) of budworm. He tried to find out the optimal threshold value of H at which spraying should happen. Generally, spraying and tree harvesting are the two primary management options present for the budworm-forest system in Eastern Canada. The paper tried to investigate the "rules" for two options: the age above which trees are harvested and the "threat state" above which insecticide is applied. "Threat state" is measured by the hazard index which is dependent upon egg density and amount of defoliation of both old and new foliage. A simple fixed-form optimization for spraying was defined as follows (see more in Peterman 1977; Walters and Hilborn 1978):

$$H = \alpha_1 (defoliation) + \alpha_2 (eggs) \text{ Spray if H>1}$$

Then the values for α_1 and α_2 are searched over in-order to maximize the objective function. This form can also be extended by including the product of defoliation and eggs to account for potential interaction between these variables.

When trying to find the algebraic form of the control function, in a system with few state variables, authors can make the control as a polynomial function of state variables. Walters (1975) explored the optimal harvest strategies for salmon in relation to environmental variability and uncertainty about production parameters. To get the objective, Walters applied the fixed-form for exploitation rate as a function of total population (N) as follows:

$$Exploitation - rate = \alpha_1 + \alpha_2 N + \alpha_3 N^2 + \alpha_4 N^3$$

After the different steps, Walter can find α_i to give the best overall return and the curve between harvest rate and population is called the optimal control law.

In the style of the budworm management study, Sonntag and Hilborn (1978)[11] used fixed form optimization for spruce budworm to decide whether farmers should spray or cut the trees. The fixed form is given by:

$$\text{Spray if } \begin{cases} \text{Age} > P_1 \text{ and} \\ \text{Foliage} > P_2 \text{ and} \\ \text{Budworm density} > P_3 + P_4 * (\text{Foligae-}P_3) \end{cases}$$

$$\text{Cut if } \begin{cases} \text{Age} > P_1 \\ \text{or} \\ \text{Age} > P_5 \text{ and Foliage} < P_6 \end{cases}$$

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[11] Quoted in Walters, J.C. and Hilborn, R. (1978)

They then applied a random searching algorithm to optimize several alternative objective functions.

In conclusion, there have been many studies looking at optimal rules for dynamic optimization of crops (especially for forestry) and for fishery. Depending on the specific purposes, condition and aspects, authors applied different techniques to achieve their objective functions. In this paper, the fixed-form optimization approach is applied to identify the optimal cutting and replanting rules for coffee farmers in Daklak province, Vietnam under price uncertainty. The next sections will describe the region and model specification in detail.

3. The coffee farm system in Daklak

Daklak is located in the Central Highlands of Vietnam. With favorable climate and land, Daklak (including Daknong[12]) is the principal coffee producer in Vietnam, accounting for nearly 50% of national output. In the 1990s, the area for coffee cultivation in the province dramatically increased (14.1% per year in average). In 2000, the coffee area in Daklak reached the peak level of 260,000 ha, accounting for nearly 60% of cultivated land and 86% of the area of long-term industrial crops in the province.

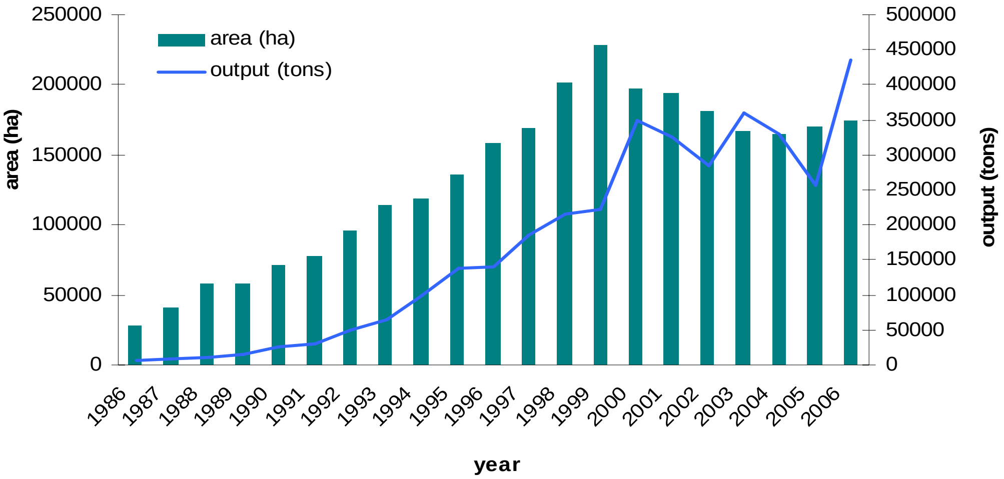

Figure 3. Development of coffee production in Daklak, 1986-2006

Source: MARD

After 2000, due to the price cuts, the coffee area in Daklak had reduced relatively. However, since 2003 when the price started recovering, most farmers replant again.

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[12] Daklak has just been divided into two provinces : Daklak and Daknong

Box: A glance at Daklak province

Daklak is located in the Centre Highlands of Vietnam. The province borders to Gia Lai Province to the North, Lam Dong and Binh Phuoc Provinces to the South, Khanh Hoa and Phu Yen Provinces to the East and Cambodia to the West with 240km of common frontier. Daklak Province consists of 18 districts and the Buon Ma Thuot City; 27 administrative units at communal level (13 wards, 18 townships and 177 communes) and 2,308 hamlets, highland villages, street bocks.

There are about 1,882,221 people inhabiting Daklak including 44 ethnic groups. Among those groups in Daklak, groups with large number of inhabitants are:

- Kinh:70.65% total population
- E de: 13.69 %,
- Nung: 3.9%,
- Mnong: 3.51%,
- Tay: 3.03%
- Thai: 1.04%
- Dao: 0.86%

Agro-forestry (62.9%) is main driver of the Daklak economy. This has an average annual growth rate of 15.2% for the period 1995-2000 with production value increasing 9.8% annually. In 2000, total cultivated area was 395,000 hectares of which perennial industrial crops such as coffee, rubber occupied 54%.

Coffee households in Daklak are highly specialized, with the major land use being for coffee cultivation. Besides coffee, however, several households try to utilize flat land to grow annual crops such as rice for both home consumption and cash. Table 1 below presents the cropping system of coffee farm in Daklak. As shown in Table 1, rice, maize, rubber, cashew or even sugarcane is cultivated by coffee farms.

Table 1. Average crop area by district (m2)

	Cu Mgar	Krong Pak	Eakar
Rice	104	2529.0	2118
Maize	60	279.6	0
Cassava	0	20.4	20
Sugarcane	0	0.0	1600
Coffee	19376	9038.8	7354
Rubber	200	0.0	0
Pepper	101	0.0	234
Cashew	0	0.0	3270
Durian	0	20.4	0

Source: Thang (2008).

The farm size varies highly among households and districts. According to the 2007 survey in three districts in Daklak province, coffee farms in Cu Mgar have the largest area with an average level of over 1.9 ha while households in Krong pak and Eakar have a smaller scale with 0.9 ha and 0.73 ha, respectively.

Table 2. Percentage of household with other activities (%)

District	Cu Mgar	Krong Pak	Eakar
Chicken	20	8.2	8
Pig	20	49.0	4
Cattle/buffalo	14	16.3	0
Other animal	0	2.0	0
Aquaculture	0	4.1	58
Wage	10	26.5	50
Other activities	2	30.6	4

Source: Thang (2008).

When the price of coffee was depressed, most farmers had to reduce their inputs and labor cost to save money. Some farmers had to cut coffee trees and change to other crops, with maize as the main substitute crop for farmers in Daklak. According to the survey 2007, over 6% of coffee farmers in Daklak have ever had to cut trees before the normal time, mainly due to the price reduction (see Table 3). The majority of cut coffee trees were in unproductive areas with low yield and most of cutters are relatively poor, the largest proportion cut coffee to grow maize (29.2%) and paddy (25%) (see Table 4).

Table 3. Percentage of households reducing coffee in the past

District	Yes	No
Cu Mgar	0	100
Krong Pak	4.0	95.9
Eakar	14	86
Total	6.0	93.9

Source: Thang (2008).

Table 4. Percentage of farmer switched to other crops

	Percent	Cumulative
Paddy	25.0	25
Maize	29.2	54.2
Durian	2.1	56.3
Sugarcane	6.3	62.5
Cassava	2.1	64.6
Pepper	14.6	79.2
Bean	2.1	81.3
Cashew	18.8	100.0

Source: Thang (2008).

Because the main proportion of farmers switched to maize due to the price fall, in the model, we assume that when the farmers switch out of coffee, they will grow maize.

4. Model structure and solution

This section will describe the model structure for identifying the optimal cutting and replanting rule for coffee farmers. The model was built based on a system of equations including an objective function. The objective function is the maximum of the average NPV of farm profit over 50 years. The system of equations includes a profit function, coffee yield function, production cost function, revenue function. Those equations are linked together and specified through the cutting and replanting rule scheme. The following sections will describe in more detail the functions in the model. More importantly, the last part of this section will present the cutting and replanting rule identification.

Objective function

The model tries to find the optimal decision to maximize the expected NPV over the entire planning horizon. At given point in time, the expected NPV of a coffee farm depends on current age of the trees, price of coffee and input use. The expected NPV in the model is given by:

$$ExpectedNPV = \sum_{t=1}^{n} \frac{\prod^{e}{}_{t}}{(1+i)^{t}} + \mathrm{TV}$$

$\prod^{e}{}_{t}$ is profit of coffee and maize in year t and TV denotes for the terminal value of coffee garden, i is interest rate. In this model, n = 50 years, so at the end of the period terminal value will be insignificant and is ignored. It is assumed that the farmer controls a unit area (1 ha) and the planning decision applies to the whole area i.e. they cannot make decisions on a fraction of the land area, and as a result any individual farmer has trees of only one age. However, the model is solved for all possible (22) ages of trees

Profit function

The expected profit of the farm is attained from coffee production and maize. Profit is simply measured by the difference between revenue and cost.

$$\Pi^{e}{}_{t} = CP^{e}{}_{t} + MP^{e}{}_{t}$$

In which $CP^{e}{}_{t} = P_t{}^{c} * Y_{ti} - TC_{ti}$

where P_t is expected price of coffee in year t

Y_{ti} is the yield of coffee in year t at age i. In this version of model, coffee yield is defined as a function of coffee age, and is assumed to be known with certainty.

TC_{ti} is total cost of coffee in year t with age i. Similar to yield, total cost of coffee is a function of age.

$$MP^e_t = P_t^m * Y_t - TC_t$$

In the model, the price of maize, and profit of maize is assumed to be constant over the time horizon. However, a sensitivity analysis is implemented to investigate the impact of efficiency of maize on the farmer's decision by changing maize profit and see how the optimal cutting and replanting rule respond.

Coffee area

The coffee area in the model is defined based on previous area and price. Farmers will cut coffee to grow other crops if price is lower than a certain level of price (defined as Cutting Price-CP) and they will replant coffee if price hits a profitable price (called as replanting price-RP).

With such response, the coffee area in the current year can be expressed as follows.

$S^c_t = S^c_{t-1}$ if $P^c_t > CP_c$ where CP_c is the cutting price

$= 0$ if $P^c_t < CP^c_c$

In the case when $S^c_{t-1} = 0$ farmers can replant coffee if $P^c_t > RP$ where RP denotes for replanting price.

When the age of tree does not exceed 22 year olds and coffee price is smaller than CP, so farmers will cut coffee and switch to maize. The decision of the farmer is dependent on the price of coffee and more importantly the rule for keeping or cutting existing trees. The farmer's behavior is described more detailed in the "decision rule" section below.

Yield function

The yield of a crop depends on various factors such as natural conditions (land quality, weather, and water supply), variety, level of intensive farming, farmer characteristics (such as experience, farm size, education) and so on. With perennial crops as coffee, rubber, cashew or forestry, yield is affected strongly by the age of trees.

In the current model, yield is only assumed to be a function of coffee age. The first two years of coffee life cycle is an unproductive period. Farmers can start to harvest coffee in the 3rd year, even though the yield is still very low (only about 500 kg of coffee bean per ha). After that, the coffee yield increases as age of tree increase and it gets the peak level at age 8. Once hitting the mature yield, generally coffee yield becomes stable and only start reducing at around age 15-16. During the mature period, on average farmers can attain 2500 coffee bean per ha. In general, the coffee cycle is about 20 to 25 years. In the model, we assume that the maximum coffee life cycle is 22 years. After that, farmers will cut the tree and if the price is profitable they will start replanting new trees.

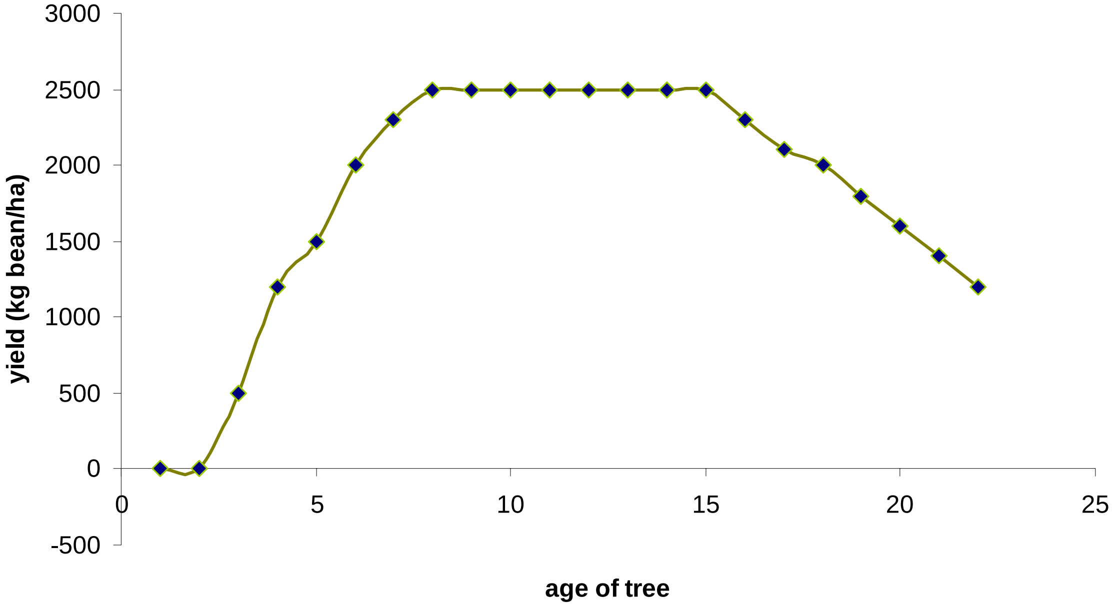

Figure 4. Coffee yield by age of tree

Source: Thang (2008).

The yield cycle by age is sketched in Figure 4 was generalized based on the data survey from Thang (2008) and experience of coffee experts. However, the yield of coffee was affected heavily on the level of insensitivity of production as some farmers with over 17 year old coffees reported their coffee yield was approximately 2200 kg per ha in 2006.

Production cost

All production costs are estimated from the author survey.

Table 5 summaries the production cost by age of tree. There is a very high level for Year 1 (replanting cost) due to the investment for small trees, fixed assets and land preparation and planting. In the model, it is assumed that the annual production cost in the 5-20 age range are the same, about $930 per ha. In the last two years of the coffee cycle, the cost reduces to just over $600 per ha because of the reduction in labor cost for harvesting, and lower level of input application.

Table 5. Coffee production cost by age of tree (US$/ha)

Items	Year 1	Year 2	Year 3	Year 4	Year 5-20	Year 21-22
Seedlings	179.7	18.8	9.4	0.0	0.0	0.0
Labor cost	517.5	480.1	420.0	515.0	602.5	301.3
Chemical fertilizer	106.9	118.4	134.7	168.8	181.3	90.6
Manure/organic	312.5	0.0	312.5	0.0	0.0	0.0
Pesticide	2.5	6.5	7.5	10.0	15.0	7.5
Lime	34.4	0.0	0.0	0.0	0.0	0.0
Fixed asset	156.3	0.0	0.0	0.0	0.0	0.0
Fuel/electricity	114.3	149.3	114.3	114.3	114.3	114.3
Others	16.3	21.2	16.3	16.3	16.3	16.3
Total cost	1440.2	794.3	1014.6	824.3	929.3	613.0

Source: Thang (2008).

Decision rule

The perennial crops such as coffee, rubber and cashew typically have long gestation periods and it takes several years to produce cherries for coffee. Thus, plantings and replanting of coffee confront farmers with long term investment problems and they always face some related decisions. The first decision is the point when they should cut the tree. The second problem relates to the decision after cutting, whether they should replant, switch to a new crop or leave the land idle. When deciding to switch to other crops, farmers have to pay the cost for cutting existing trees and invest capital for developing new crops. The cutting or replanting decision of farmers are usually based on future or expected prices.

Besides, with perennial crops such as coffee, rubber, cashew, yield or investment cost relate closely to the age of tree. Generally, after reaching the peak level, perennial crop yield will start decreasing. With coffee, as mentioned above, yield will get the maximum yield after 8 years and the mature period generally lasts about 7- years. After that, the coffee yield will decline by age of trees. Thus, the cutting decision not only depends on the price of coffee but also based on the current age of the tree.

The identification of optimal cutting and replanting rule based on the age of tree with stochastic prices are the expected outcome from this model. The model deals with both the stochastic and dynamic elements of the farmer's problem. To deal with those problems, a sensitive fixed- form is also used for describing the decision of farmers. This approach is similar to the method applied by Sonntag and Hilborn (1978)

when coffee age
<=22 & age >0

If coffee price > min (CPage, RPage)
➔ continue to grow coffee

but

If coffee price <= CPage➔ cut
coffee and switch to maize

when coffee age
=22 or age =0
(land is
currently used

If coffee price > = RPage ➔ replant
coffee

but

If coffee price < RPage➔ keep
growing maize.

where CPage and RPage are the cutting/replanting rules for trees of age a.

In its simplest formulation, the model will identify at what prevailing price should coffee producers cut and when they should replant.

The fixed-form law for cutting price in the model will be defined by one of two alternative rules, as follows:

$$CP^{I} age = \alpha_o + \alpha_1 * age + \alpha_2 * age^2 \qquad \textbf{(1)}$$

and

$$CP^{II}{}_{age\,t} = \alpha_o + \alpha_1 * age + \alpha_2 * age^2 + \gamma * (P_t - P_{t-1}) \qquad \textbf{(2)}$$

where age denotes for the age of coffee tree, P_t is price of coffee at year t. Equation (2) expresses the Cutting Price at year t as depending not only on the age of tree but also the change in coffee price between year t and t-1. This is to allow for information on direction of change in prices to influence decisions, on the assumption that previous price movements may carry information about future prices.

The replanting decision does not depend on the age of tree so the RP function can be defined more simply as follows:

$$\textbf{RP} = \alpha_3 \qquad \textbf{(3)}$$

and if land are used for maize (or bare) or the coffee tree are in the last year of cycle, farmer will replanting if price of coffee > α_3

A searching procedure is implemented to identify α_i and γ which generate maximized expected NPV of net income from the farm over a 50 year time horizon. The next section will describe clearly all steps for estimation procedure.

The profitability of substitute or competitive crop can change the decision of farmers. In the function of CP or RP, we do not include this factor, however a sensitivity analysis is reported to show how the profit of maize impacts on farm decision.

5. Procedure for estimation

To identify the optimal CP and RP that maximizes the expected net profit, the model applies a search procedure for retrieving α_i and γ in Equation (1) and Equation (2). Procedures for estimation includes the steps as follows

Step 1: In this step, data on coffee production cost, yield for 22 groups of coffee by tree ages, maize profit were calculated from survey data and other sources.

Step 2: As mentioned earlier, the model time horizon is 50 years. In order to get revenue and profit of coffee production, a series of coffee prices for 50 years are predicted. To allow for generality, 22 alternative sub-sets of data are constructed, one for each of the possible ages of the tree in year 1. This is to ensure that the estimated decision rules are not biased by considering only specific starting ages (i.e. if all simulations started with trees of age 1, then there would be little return from accurately identifying the rule for trees of latter age, as they would always be considerably discounted). To attain the significant representatives for all coffee groups, the model generates 100 price trajectories over 50 years, for each age group, giving a total of 2200. The simulation of these price trajectories was based on the historical price data and an estimated price prediction model. The functional form of the price model may generate different results which in turn give the certain optimal cutting and replanting rule. In this model, two price models are estimated using the annual international coffee price series from 1964 to 2006. The first model estimates the current price as a function of lagged prices. The second model is a trigonometric cycle price model, with a time trend as a dependent variable. The best estimated price function in each model is used for predicting the price trajectories, assuming random initial value(s). Those price trajectories are used as exogenous variable in the model. The following part of this step will provide the function form and results of two price models.

Lagged price model

As mentioned earlier, the dependent variable in this model is current price and the explanatory variables are prices in previous years. By testing with various model with different number of lags, the selected model is one in which logarithm of price in year t is a function of lagged one year price and lagged two year price. The regression equation is specified as:

$$\mathbf{lnP_t = 0.093 + 1.15{*}lnP_{t-1} - 0.334{*}lnP_{t-2}} \qquad \mathbf{(4)}$$

p- value	(0.08)	(0.000)	(0.000)
Se	(0.05)	(0.15)	(0.15)
R^2	78.1%		

The model looks good with quite high R^2 (78%), and all coefficients are statistically significant (p values are closely to 0). The fitted value of logarithm of price and observed price since 1964 are shown in Figure 5.

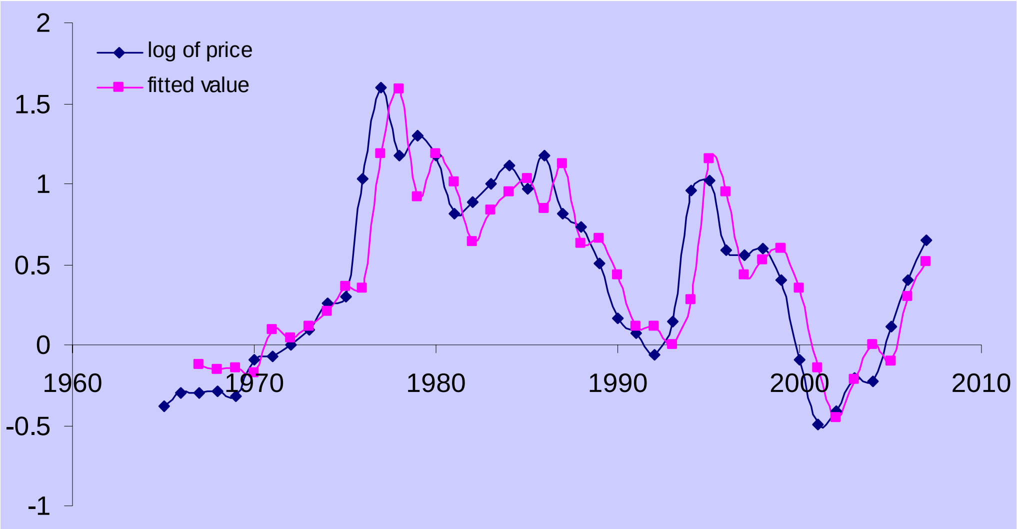

Figure 5: Fitted and actual value of logarithm of price

Based on the estimated price equation (4), we generate 2200 series of price in 50 years.

The price in year t is specified as :

$$\mathbf{P^e_t = exponentiation\ of\ (0.093 + 1.15{*}lnP^e_{t-1} - 0.334{*}lnP^e_{t-2} + error\ term)} \qquad \mathbf{(5)}$$

The error term is drawn randomly from a normal distribution with a mean of zero, and the estimated regression variance. Figure 6 gives some example of price trajectories generated from the lagged model. A presented in Figure 6, some price trajectories are changing with very high variation which generate very high price at some points in time horizon. However, it is necessary to note that the simulated prices are the international price. In the model, the farm-gate prices are calculated as a fixed multiplicative factor of international price[13].

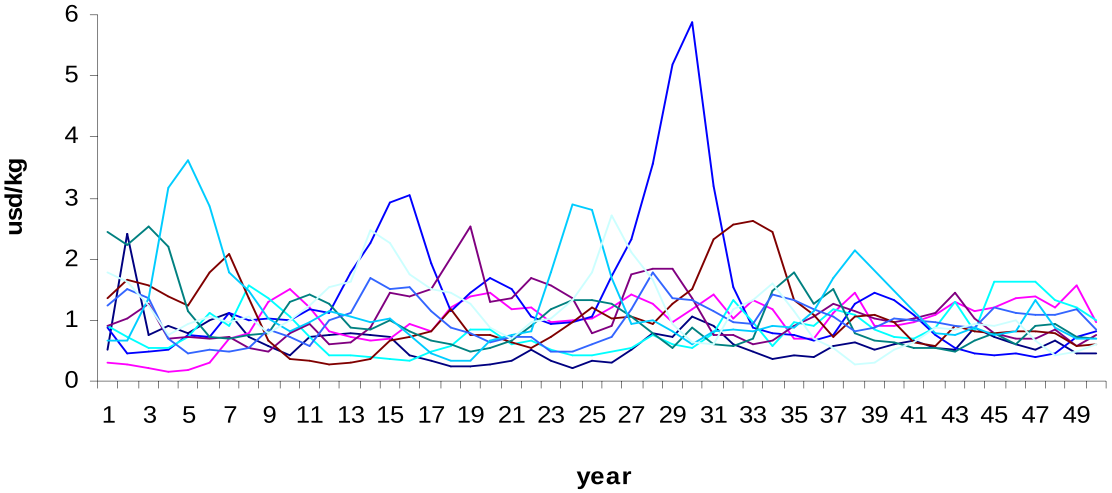

Figure 6. Examples of price trajectories predicted from lagged price model

Cycle price model

A cyclical price model is suggested from observing the historical trend of coffee price. By analyzing coffee price in last 30 years, results show that coffee price seemingly follows a 9 year cycle.

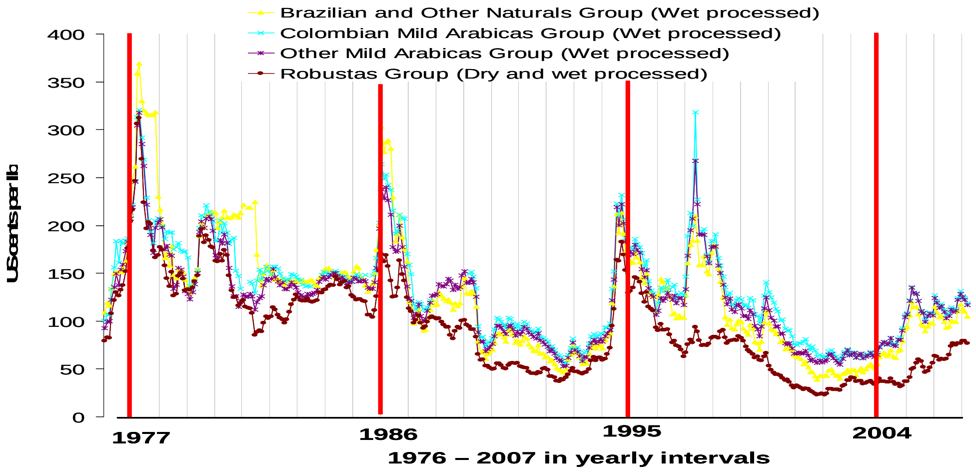

Figure 7: Price cycle of coffee in the world market

Source: ICO

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[13] The available farm gate coffee price in Vietnam is not sparse in all provinces; the series is quite short which is not representative thus, we have to use the international prices for estimating the price function.

Thus, an alternative model, that simulates a 9 year price cycle is estimated:

$$\mathbf{Pt= a_0+a_1*sin(2\text{Л}*year/9) +a_2*cos(2\text{Л}*year/9) +a_3*year +error\ term} \tag{6}$$

Equation (6), imposes a nine year cycle, but the amplitude of the cycles and the trend effect are estimated.

Using data price series from 1964 to 2006 and applying egression method, the estimated price cycle model was given by:

$$\mathbf{P_t \ = \ 171.5 - 0.33*cos(2\text{Л}*year/9) - 0.43*sin(2\text{Л}*year/9) - 0.085*year} \tag{7}$$

p-value (0.00) (0.02) (0.00) (0.00)

se (21.7) (0.13) (0.14) (0.01)

Prob > F = 0.0000

R-squared = 74.1%

The results also look good with relatively high R^2 (74%), all coefficients are statistically significance. Based on Equation (5), we can generate new series of price data for model. There are two important things when generating the predicted price from the cycle model. The first thing is the selection of the "reference year" in the model. The year is chosen at which the price is closest with the mean of coffee price in the past. This occurs when year=1990. The second is the selection of the year (and hence price) at the beginning of the time horizon. To produce random price trajectories, the starting year is changing between price series. Figure 8 gives an example of price trajectories predicted from cycle price model. The predicted prices of the cycle model look less fluctuated than those generated from lagged price model.

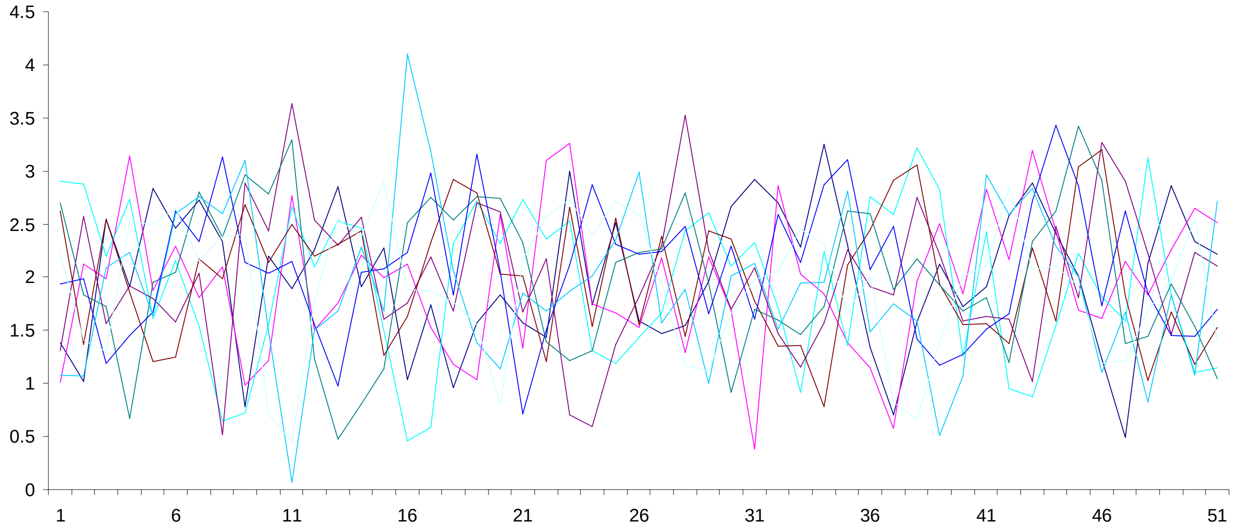


Figure 8. Example of price trajectories predicted from cycle price model

Step 3: Apply the fixed-form for cutting rule and replanting decision of coffee farmers which was presented in "decision rule" section earlier into the model (either equation (2) or (3) combined with (4)).

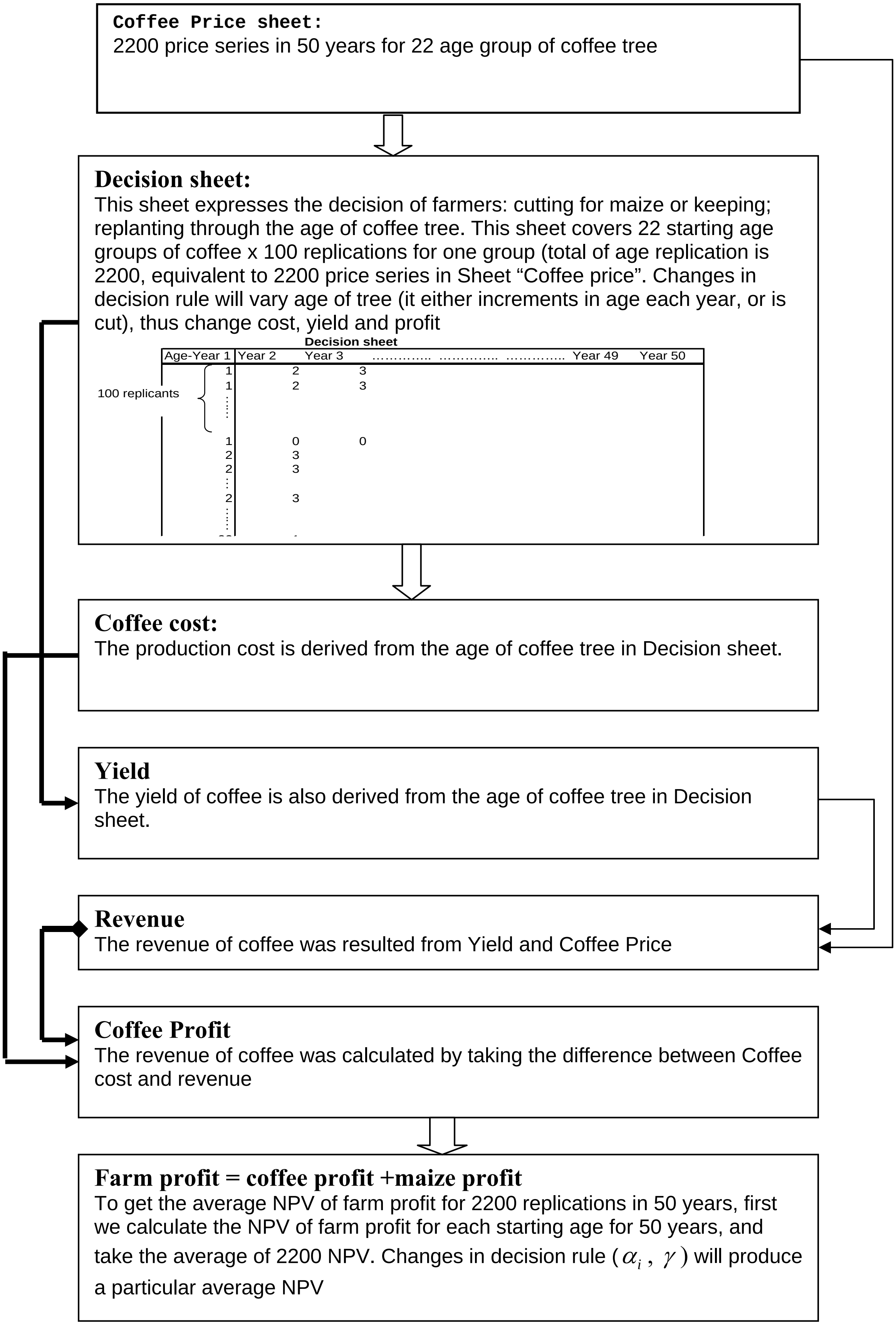
Step 4: This step uses the searching method to find the cutting price rule (CP) and replanting price (RP) to get the maximum NPV. As described above, the CP was expressed as a fixed form of coffee age, and change in price. Thus, the final objective of searching method is to find the α_i and γ to identify the optimal CP, and later RP to maximize the average (over the 2200 simulations) NPV.

To get the optimal parameter value for the two variables CP and RP, we can apply the one-at-a time method. This is one of the simplest optimum seeking technique which may be applied to any number of decision variables (Taylor, Schmidt et al. 1973). To apply the one-at-a time method, we first fix RP by assigning an initial value for RP and find the optimal CP. When having optimal CP rule in Step 1, the CP rule is now fixed and γ is varied until its optimal value is determined. The entire procedure is repeated over and over until the CP and RP converges and the NPV gets the maximum value.

The searching procedure takes time because of the number of parameters, and the need for a fine grid across potential values. The strategy used is to start with a relatively course grid of g values, giving a total search space of g^n (where n is the number of parameters) and then progressively refine the search with a smaller grid size around the maximal values.

We use Excel as software for running the model. The spreadsheet model structure map in Excel is presented in Figure 9. The model consists of different sheets: coffee price, land decision sheet, coffee yield, production cost, revenue and profit. When cutting and replanting rule change, the decision of farmer will change which in turn bring about the new cost, yield, profit and finally NPV

Figure 9. Model Structure Map



Coffee Price sheet:
2200 price series in 50 years for 22 age group of coffee tree

Decision sheet:
This sheet expresses the decision of farmers: cutting for maize or keeping; replanting through the age of coffee tree. This sheet covers 22 starting age groups of coffee x 100 replications for one group (total of age replication is 2200, equivalent to 2200 price series in Sheet "Coffee price". Changes in decision rule will vary age of tree (it either increments in age each year, or is cut), thus change cost, yield and profit

Decision sheet

100 replicants

Age-Year 1	Year 2	Year 3	…………..	…………..	…………..	Year 49	Year 50
1	2	3					
1	2	3					
⋮							
1	0	0					
2	3						
2	3						
⋮							
2	3						
⋮							

Coffee cost:
The production cost is derived from the age of coffee tree in Decision sheet.

Yield
The yield of coffee is also derived from the age of coffee tree in Decision sheet.

Revenue
The revenue of coffee was resulted from Yield and Coffee Price

Coffee Profit
The revenue of coffee was calculated by taking the difference between Coffee cost and revenue

Farm profit = coffee profit +maize profit
To get the average NPV of farm profit for 2200 replications in 50 years, first we calculate the NPV of farm profit for each starting age for 50 years, and take the average of 2200 NPV. Changes in decision rule (α_i , γ) will produce a particular average NPV

6. Model results

This section will present the optimal rule for cutting and replanting coffee. As mentioned above, the optimal rule may be dependent heavily on the way in which price of coffee will be predicted. Thus, the results of model will be divided into two parts. Section 6.1 will present the results with lagged price prediction model. The results from cycle price prediction will be discussed in Section 6.2.

6.1 Optimal rule with lagged price prediction model

With price trajectories predicted from the lagged model and applying the searching procedure, the model finds the optimal cutting and replanting rule for coffee as follows:

$CP_t = 0.4 - 0.05*age + 0.0036*age\^2$ **(8)**

RP =0.74 ($/kg of coffee bean)

Optimal NPV = $9224.8 (per ha)

Figure 10 depicts the optimal rule for all age group of coffee. The results shows that the optimal CP for trees of age 1 is 0.34 $/kg. In initial years of the life cycle, the CP decreases slightly when tree age increase and CP is smallest for 7 year old tree, at only 0.23 $/kg. The higher CP for one year than the two year old trees (or three year old tree) is definitely rational because farmers with one year old tree have to wait several years to harvest while they still pay annual cost.

The replanting price of $0.74 per kg indicates that if farmers have bare land or land is using for maize, they should grow or switch to coffee if the coffee farm gate price is greater than or equal to $0.74 per kg

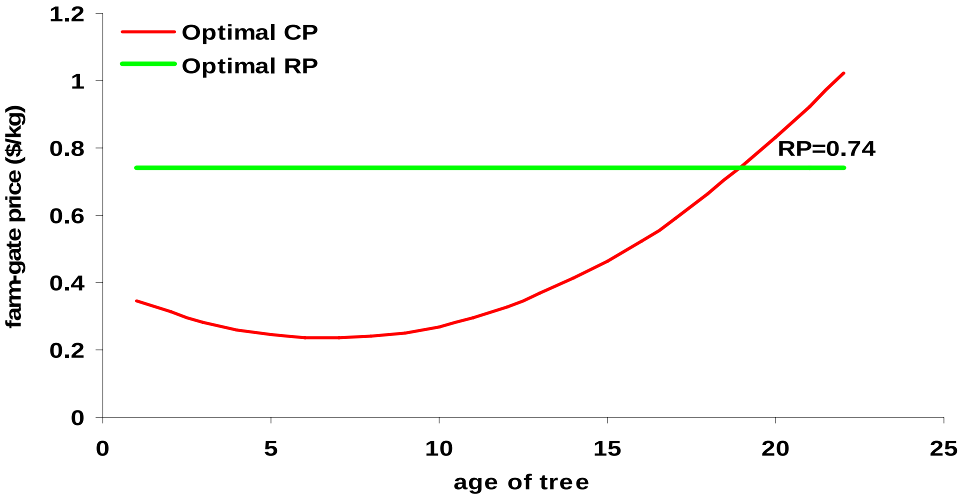


Figure 10. Optimal cutting and replanting rule by age of coffee tree

These results have been found when CP is a quadratic function of age (Equation (1) above). The model was also tested with a cubic function of coffee age. However, the expected NPV results were almost the same but the cubic form model takes much longer time for searching for the optimal rule because grid size increases exponentially with parameters. So, to save time for running model with different scenarios, the model only uses the quadratic function form of CP.

It is informative to see how many times the cutting rule is invoked at each age within the simulation. The Figure 11 presents the proportion of times at which the cutting rule is invoked by age of tree. As shown in this graph, within the simulation farmers very rarely cut if the age of coffee is less than 11 years old. The cutting percentage of tree is increasing for age from 11 to 20.

Figure 11. Proportion of cases in which cutting rule is invoked, by age of tree

The model also identified the cutting rule as a function of age and the difference between current and previous price, but the results from model show that difference of price in year t and previous one does not impact on cutting rule (γ value is very small, γ=0.002). Similarly, the optimal NPV and RP are unchanged.

$$\mathbf{CP_t = 0.4 - 0.05*age + 0.0036*age^{\wedge}2 + 0.002\ (P_t - P_{t-1})} \qquad \mathbf{(9)}$$

RP=0.74

The model was also solved to find the maximum NPV per ha with a constant CP function. This means CP does not depend on the age of tree and cutting price CP=α_0. With such an assumption, the results show that coffee farmer will get the maximum income if they cut trees when the farm gate price is $0.36 per one kg of coffee bean. The optimal RP of constant CP was found as same as the RP when CP is a function of age (see Figure 12).

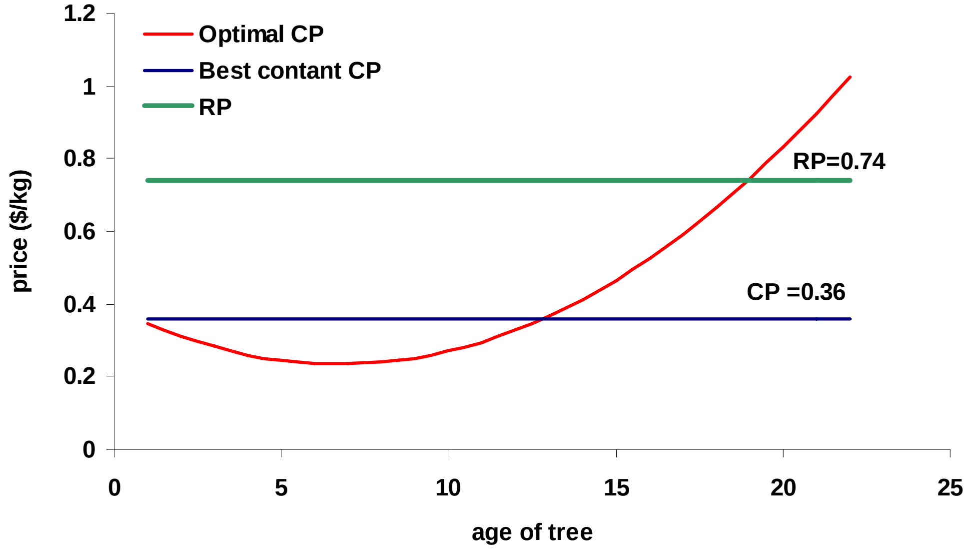


Figure 12. Optimal cutting rule and the best constant cutting rule

Figure 13 presents the expected NPV per ha by the different cutting rules. The data shows that income per ha using the optimal CP rule (as in Equation 8) is about 3% higher than income with constant CP (the best constant CP =0.36), and nearly 5% higher than the value if farmers never cut, but maintain trees for the full 22 years.

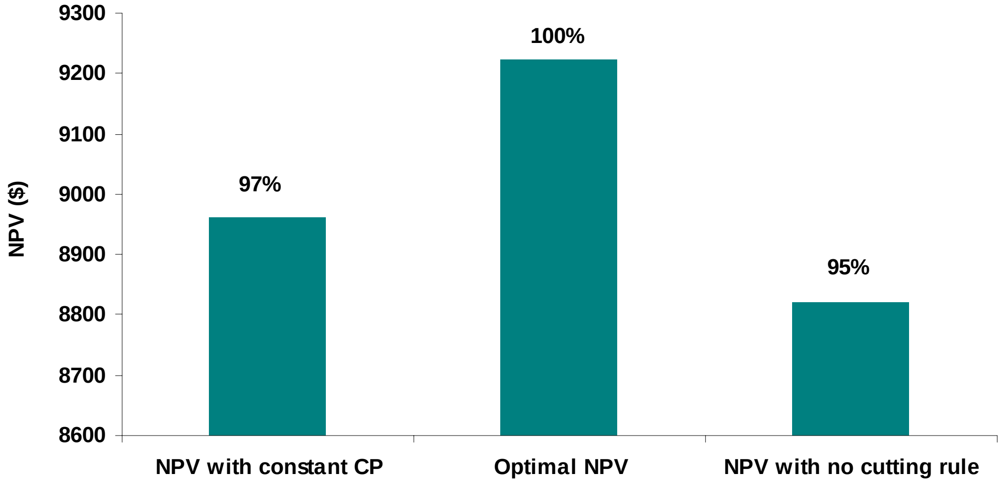


Figure 13. A comparison of income per ha among different CP rules

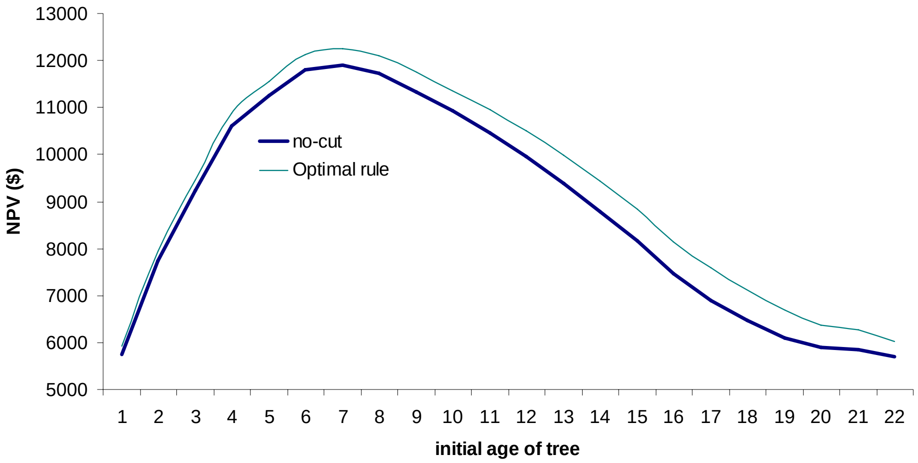


Figure 14. NPV per ha obtained by optimal cutting and no cutting rule by ages

The difference of income among rules will change if the profit of the substitute crop varies. In the model, it is assumed that the maize profit is constant, but to see how income of the substitute crop impacts on the farmer's decision, the model is resolved with a variation of maize profit.

First we increase maize profit by 20%. With young coffee trees, the CP is seemingly unchanged when maize profit rises by 20%. However, farmers are more likely to cut with older trees. With 20% increase in maize profit, total income per ha is $ 9405.54, approximately 2% higher than the previous NPV. The RP in case of higher maize profit increases as well. This means farmers will keep growing maize and decide to replant coffee at more expected profitable price.

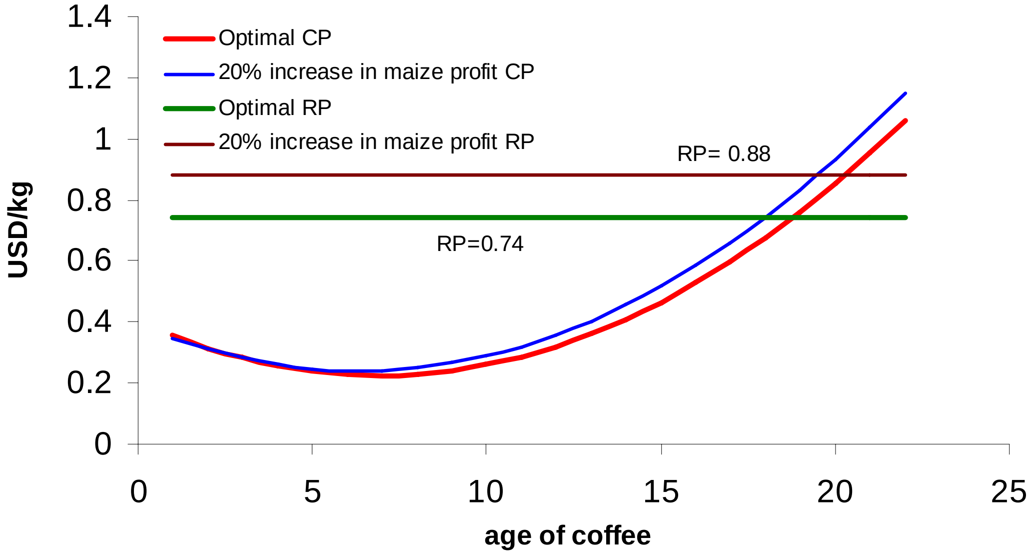


Figure 15: Change in Cutting and RP rule when maize profit increases by 20%.

4.2. Optimal rule with price cycle prediction model

In the previous section, the model identifies the optimal rule for coffee farmers based on prices simulated using an autoregressive model. The estimated equation implies some structure in the simulated price, but no structural cycles. If a coffee cycle exists, then it may make prices more predictable, and in particular, it may be the case that the decision to cut and trees may depend not only on the level of the price, but where in the price cycle one is. This section reports the results from running the model with the same procedures but with price cycle prediction model.

With the price cycle model, the optimal cutting and replanting rule without accounting for price changes is identified as follows:

$$\mathbf{CP = -0.07 -0.0087*age +0.0065*age^{2}} \qquad \mathbf{(10)}$$

RP = 0.61

NPV= 9659

The rules are depicted in below. The results show that if the price follows the historical price cycles, at mean levels, farmers should never cut if trees are younger than 14 years old. The optimal RP is only $0.61 per kg of coffee bean. The optimal NPV of income per ha in cycle model is the similar to maximum NPV from lagged price model simulation.

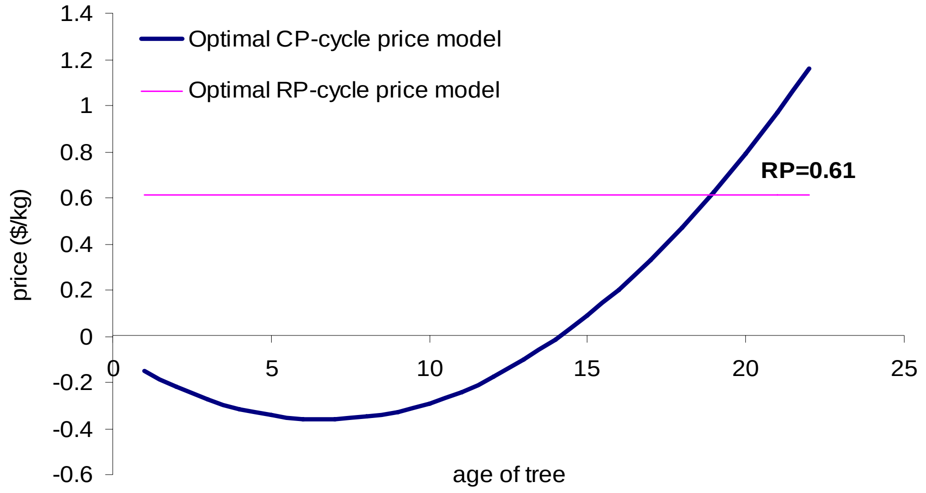


Figure 16: Optimal cutting and replanting rules with cycle price model

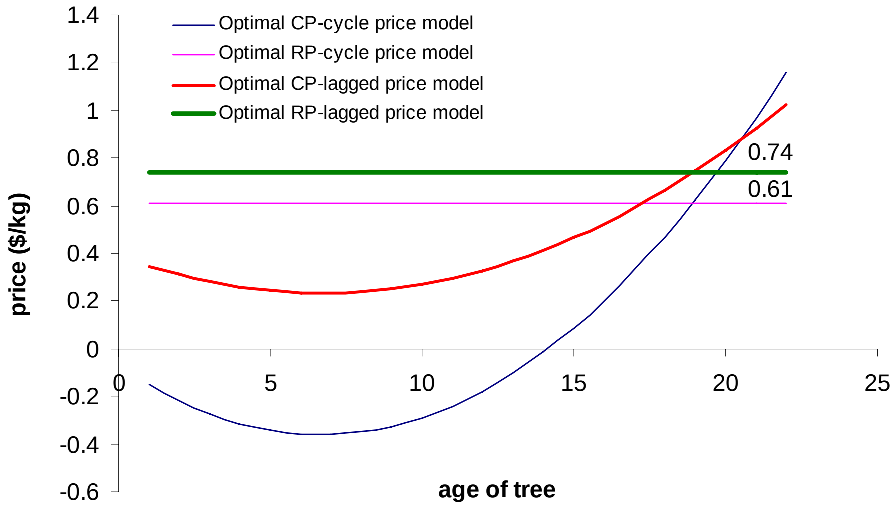


Figure 17. A comparison between optimal rules for cycle and lagged price model

The difference between optimal rules in two simulations is made by the distribution of price trajectories predicted from the two models. Figure 18 depicts the distribution of prices simulated by the lagged model and cycle model. The mean of the two data sets is similar but the distribution is quite different. Price data set predicted from lagged model is log normal, with a higher standard deviation while the cycle price data is symmetric with a similar mean of 1.04 but a smaller standard deviation (0.34).

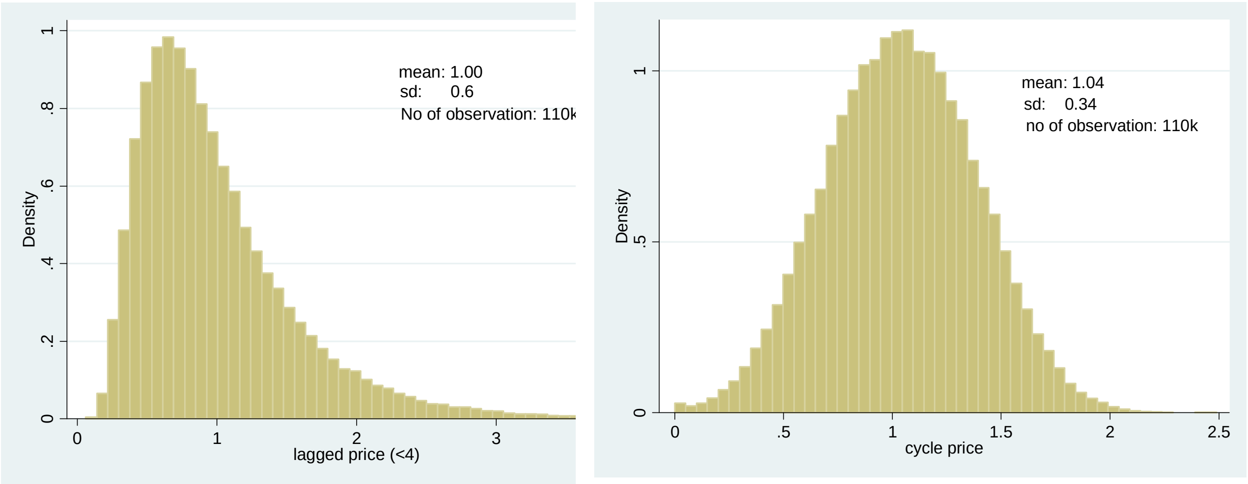


Figure 18. Distribution of price data set predicted from lagged and cycle model

From the optimal cutting rule, we can identify the actual percentage of tree at each age are cut in this case. Figure 19 shows the cutting percentage at each age for both price cycle simulations. As shown in the line graph, with the lagged price model simulation farmers are more likely to cut earlier. With the cycle result, the cutting percentage of tree increase quickly at ages from 16 to 19.

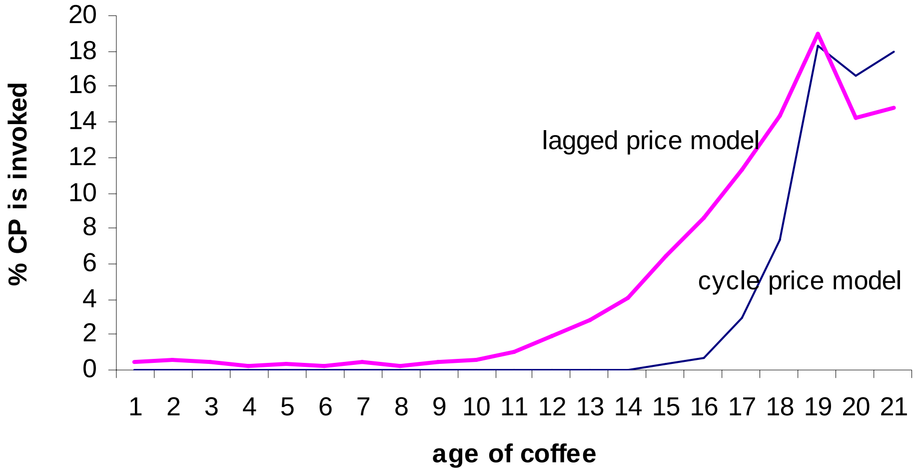


Figure 19. Percentage of cutting tree from two data set by age

When the price tends to vary cyclically, one might expect that the decision to cut depends not only on the level of the price, but also its position in the cycle (i.e. increasing or falling). Thus, as in lagged price model, we also want to modify the fixed form of cutting rule and now cutting rule becomes a function of age of tree and difference of price in year t and previous year. In this case, the form of cutting rule can be repeated as follows:

$$CP_t = \alpha_o + \alpha_1 * age + \alpha_2 * age^2 + \gamma * (P_t - P_{t-1})$$

With above cutting function, the model was processed again and the new CP is given by:

$$\mathbf{CPt = -0.16 - 0.0083*age + 0.0063*age^2 - 0.24*(P_t - P_{t-1})} \qquad \mathbf{(11)}$$

RP = 0.61

NPV = 9660

The negative signal of price difference coefficient (-0.24) is rational and it shows that if current price in downward trend, farmer should cut earlier and vice versa. The coefficient (-0.24) also proves the more significant impact of price difference in cycle model simulation rather than in lagged model. However, the new rule generates almost exactly the same optimal NPV, suggesting that there is little economic value in including the additional information.

Conclusion

There are many approaches to analyze farmer's decision and identify the optimal cutting and replanting rule. By using fixed form optimization, this paper pointed out the optimal cutting rule and replanting rule for coffee farmers in Vietnam in which CP is function of coffee age and price. However, the optimal rule for cutting and replanting by age of tree are changed when expected coffee price in the future, profit of substitute crops alter.

This model which identified the optimal cutting and replanting rule for coffee farmers in Vietnam does not account for production constraints such as capital, labor or land. Thus the model would be more valuable if it covers all constraint of households when specifying the cutting and replanting price. Thus, model will be improved to analyze the optimal rule for the poor farmers who are generally in shortage of capital for replanting coffee.

References

Abadi Ghadim, A. K. and D. J. Pannell (1999). "A conceptual framework of adoption of an agricultural innovation." Agricultural Economics **21**(2): 145-154.

Alvarez, L. H. R. and E. Koskela (2004). "On Forest Rotation under Interest Rate Variability " International Tax and Public Finance **10**(489-503).

Bellman, R. (1957). Dynamic Programming. Princeton, Princeton University Press.

Burt, O. R. and J. R. Allison (1963). "Farm Management Decisions with Dynamic Programming." Journal of Farm Economics **45**(1): 121-136.

Chladná, Z. (2007). "Determination of optimal rotation period under stochastic wood and carbon prices." Forest Policy and Economics **9**(8): 1031-1045.

Dixon, B. L. and R. E. Howitt (1980). "Resource Production under Uncertainty: A Stochastic Control Approach to Timber Harvest Scheduling." American Journal of Agricultural Economics **62**(3): 499-507.

El-Nazer, T. and B. A. McCarl (1986). "The Choice of Crop Rotation: A Modeling Approach and Case Study." American Journal of Agricultural Economics **68**(1): 127-136.

Heady, E. O. (1954). "Simplified Presentation and Logical Aspects of Linear Programming Technique." Journal of Farm Economics **36**(5): 1035-1048.

Hildreth, C. and S. Reiter (1951). On the choice of a crop rotation plan in Analysis of Production and Allocation Koopmans(ed.)(1951). New York, John Wiley & Sons**:** pp. 177–188. .

Insley, M. and K. Rollins (2005). "On Solving The Multirotational Timber Harvesting Problem With Stochastic Prices: A Linear Complementarity Formulation " American Journal of Agricultural Economics **87**(3): 735 - 755.

Jayasuriya, S., C. Barlow, et al. (1981). "Farmers' long-term investment decisions: A study of Sri Lankan rubber smallholders " Journal of Development Studies **18**(1): 47-67.

Jia, H. (2006). The optimal single forest rotation under climatic fluctuation effect. Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meetings Orlando, Florida, February 5-8, 2006.

Kearnev, M. (1994). An intertemporal linear programming model for pip fruit orchard replacement decisions. Technical paper No 94/6, Ministry of Agriculture and Fishers, Wellington, New Zealand.

Kennedy, J. O. S. (1986). Dynamic programming: applications to agriculture and natural resources. London, Elsevier Applied Science.

Luong, Q. and T. Loren (2004). "A Real Options Analysis of Coffee Planting in Vietnam." Working Paper.

Matheson, V. A. (2007). Alternative Methods of Calculating Optimal Timber Rotations: A Critique of the Stokey/Lucas/Prescott Tree-Cutting Problem. D. O. E. College Of The Holy Cross, Faculty Research Series, Paper No. 07-01.

Pannell, D. J. (1996). "Lessons from a decade of whole-farm modelling in Western Australia." Review of Agricultural Economics **18**: 373-383.

Paulo, M. J. and A. Otten (2007). "A Bayesian approach for exact optimal measurement and cutting times for a Eucalyptus production forest." Statistica Neerlandica **61**(3): 345-357.

Penttinen, M. J. (2006). "Impact of stochastic price and growth processes on optimal rotation age " European Journal of Forest Research **125**(4): 335-343.

Peterman, R. M. (1977). "Graphical Evaluation Of Environmental Management Options: Examples From A Forest--Insect Pest System." Ecological Modelling, **3**: 133--148.

Peterson, G. A. (1955). "Selection of Maximum Profit Combinations of Livestock Enterprises and Crop Rotations." Journal of Farm Economics **37**(3): 546-554.

Ruf, F. and K. Burger (2001). Planting and Replanting Tree Crops – Smallholders' Investment Decision. paper presented at the international conference on The Future of Perennial Crops, Yamoussoukro.

Sonntag, N. and R. Hilborn (1978). "Beyond dynamic programming: determining improved management policies for budworm-forest interaction." Uni.British Columbia **In press**.

Swanson, E. R. (1956). "Application of Programming Analysis to Corn Belt Farms." Journal of Farm Economics **38**(2): 408-419.

Taylor, R. E., J. W. Schmidt, et al. (1973). Optimization of simulation experiments. The 6th conference on Winter simulation San Francisco, CA ACM New York, NY, USA

Thang, T. C. (2008). Daklak coffee farm survey 2007. *(mimeo)*.

Walters, C. J. and R. Hilborn (1978). "Ecological Optimization And Adaptive Management." Ann. Rev. Ecol.Syst. **9**: 157-188.

Worldbank (2002). Vietnam: Agricultural Price Risk Management.