Optimizing renovation and rehabilitation programs in Cocoa and Coffee-based Agroforestry Systems

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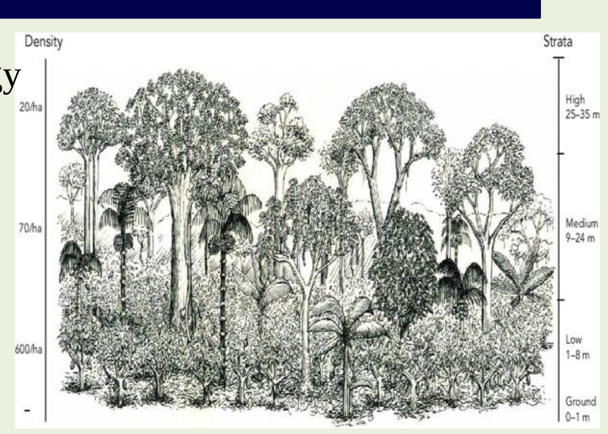
Introduction

Cocoa and coffee-based agroforestry systems are assets whose productivity declines with age, affecting the livelihood of millions of farmers worldwide and contributing to the astonishing levels of poverty of the backbone of a billionaire industry. Thus, the need for Renovation or Rehabilitation (R&R) is an important topic worldwide. Demand R&R tops the 14 million hectares (Dalberg, 2015). As well, low productivity orchards incentivize farmers to establish new tree crop stands in forest areas (Somarriba and López-Sampson 2018), contributing to deforestation, carbon emission and biodiversity loss. Furthermore, given the intensifying climate crisis, the renovation of cocoa and coffee with well-designed agroforestry systems can contribute to battle the coming climate crisis. The optimal time for R&R has always eluded agronomists and producers worldwide (Somarriba, et al., 2021). For a long time, agronomist and producers have used suboptimal protocols to decide when and in which proportion to do R&R. Most methods determine a course of action based on the assessment of whether three key variables have reached/passed critical threshold levels: age of the cacao/coffee plant, yields and planting density. Other parameters includes pest/disease status, the height of the cocoa tree, and shade levels. However, the critical levels for each criterion are site and context specific (Olaiya et al. 2006) and not necessarily lead to a maximization of the farmer's net income. Under this previous motivation, a theoretical framework was developed to determine the optimal time for a full or phase-out renovation/rehabilitation, which is intended to complement the extension programs for the cocoa and coffee sector in Latin America and the Caribbean. Then, the theoretical framework is tested with real data obtained from a cocoa farm in Costa Rica and 400 coffee farms in the Dominican Republic.

Theoretical Framework:

This study follows Perrin (1972)'s methodology to derive the theoretical framework. The method relies on the assumption that farmers want to maximize the net present value (NPV) of future cash flows of the standing crop (defender) and the improved agroforestry system (challenger). The objective function to maximize is as follows:



$$PVch = \int_0^a \frac{-[R_t^* + M_t^*]}{e^{tp}}dt + e^{-ap}\left[\int_a^b \frac{E_t^*}{e^{(t-a)p}}dt + \int_a^b \frac{C_t^* + F_t^*}{e^{(t-a)p}}dt + \int_b^m \frac{C_t^* + F_t^*}{e^{(t-a)p}}dt\right] + \frac{W_m^*}{e^{mp}}$$

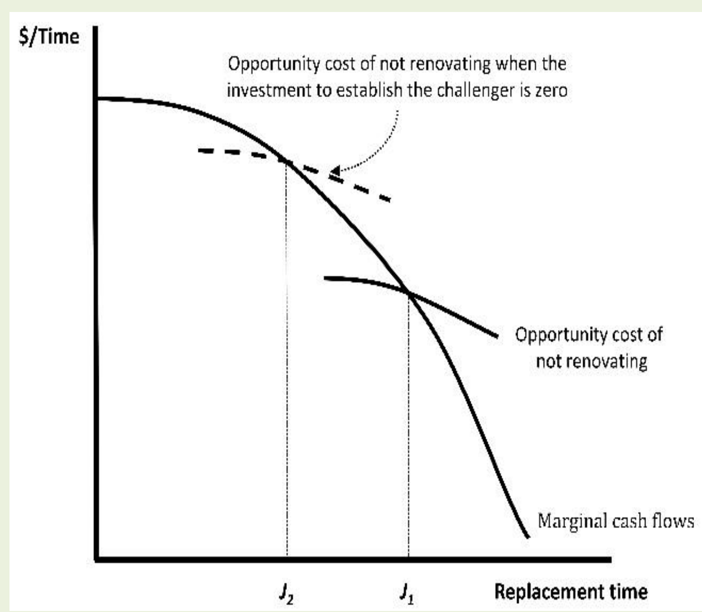
$$NPV = \overbrace{\int_c^j \frac{S_t}{e^{(t-c)p}}dt + \frac{W_j}{e^{(j-c)p}}}^{Defender\ =NPVdf} + \overbrace{\frac{-[R^* + M^*]}{e^{(j-c)p}}}^{Investment} + e^{-(j-c)p}\left[\overbrace{\int_0^m \frac{S_t^*}{e^{tp}}dt + \frac{W_m^*}{e^{mp}} + \frac{AL_m}{e^{mp}}}^{challenger\ =NPVch}\right]$$

The optimization rule derived

$$“C_j + F_j + W_j^{'} = p[W_j - (R^* + M^*) + NPVch + e^{-pm}L_m]”$$

Where *0-a* is the period for site restoration & preparation (*R*) and establishment (*M*); *a-b* is the period of early intercropping with cash crops (i.e., corn, beans, cassava, etc.) devised to generate income while the main crop grows. During the period *a-b,* the main cocoa or coffee (C) starts production with fruits (F) like bananas. For the period *b-j*, the main crop reaches maturity and other fruits start generating cash flows (i.e., avocados). In the final period, the farmers could sell some of the standing wood trees (*W*) or the appreciated land (*AL*). All letters represent cash flows. (*S*) is the total cash flow of any period t. And p is the continuous transformation of the discounting rate.

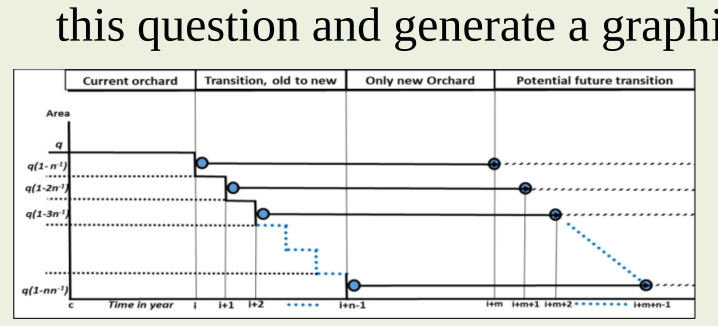
The optimization rule derived implies that a cocoa grove should be replaced in a period (J) when the sum of marginal cash flows is equal to the opportunity cost of not establishing the new orchard. The marginal cash flows are defined as the potential cash flows from cocoa/coffee, fruits, and the change in timber value that could be obtained from holding the grove one more year. Similarly, the opportunity cost is defined as the potential interest gained in the bank in period *j* from money equivalent to the timber harvested, the challenger NPV, and the land value appreciation in time *j* plus the expected land appreciation during *m* years above the discounting rate. The analytical framework allows for graphically comparing the challenger's marginal cash flows versus the opportunity cost of not renovating in a set of scenarios.

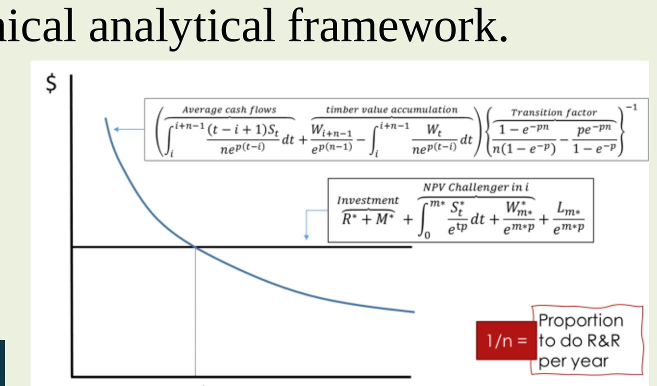


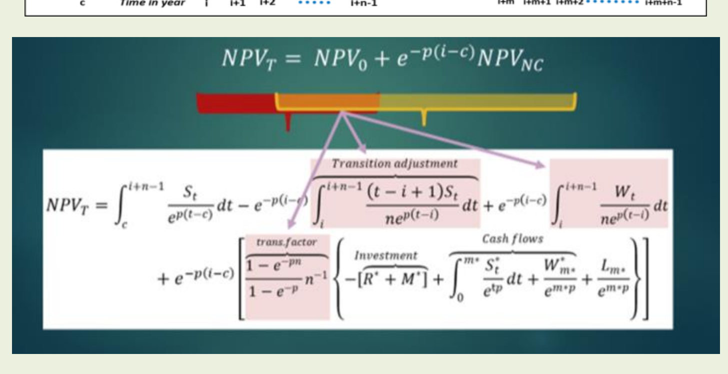
Thus, the user can evaluate what happens with the optimal time of renovation given investment incentives, price expectations, diversification (only cocoa/coffee production vs an agroforestry system with fruits and timber), different quality of a challenger, rate of land appreciation, among others.

The analytical tool is simple enough to complement extension programs regarding R&R in Latin America.

Farmers must make significant investments to remove the old orchard, restore the quality of the site, and establish a new grove. Additionally, they must face 3-5 years of zero income when the cocoa-coffee plants are young and unproductive. To cope with these financial demands, farmers focus on two pressing questions: When to start replacing the old orchard (i.e., at what age)? and What fraction of the old grove to renovate annually? Thus, a similar approach is used to answer this question and generate a graphical analytical framework.



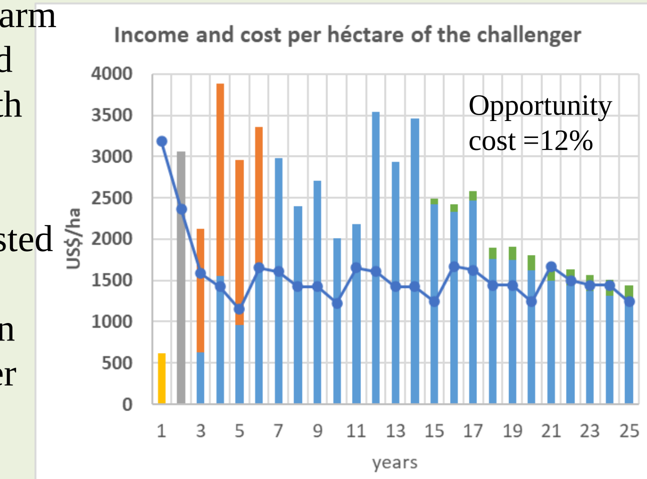




How much to R&R per year is determined by the NPV of the Challenger and the Defender cash flows during the R&R transition adjusted by a transition factor. The transition factor can be interpreted as an opportunity cost factor adjusted by the n periods of R&R.

Application to a Cocoa-based agroforestry system in Costa Rica, the renovation case

The model was applied to a real cocoa farm in Costa Rica. This farm is a 15-year-old cocoa orchard planted in association with fruits (Banana, Orange, Peach Palm, guava) and timber (Laurel, Cedar). The cash flows of the challenger was forecasted with the producer´s data and expert knowledge. The challenger consist of an improved variety cocoa planted at higher planting density. For early cash flows during year 1-3 (Corn, Cassava and Plantain). For timber production, Laurel was established at a density of optimal shading. During the 25 years forecasting, the agroforestry complement to cocoa Represented 28% of total income.

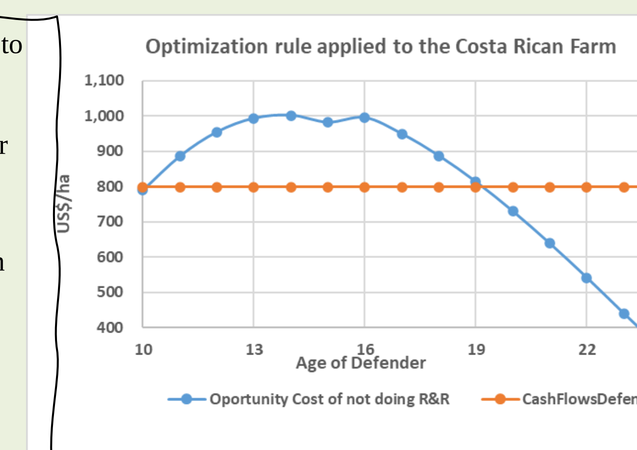


NPV US$/ha	6,659
IRR	46%
B/C	1.43

Years to do R&R from today	Age of defender	Total NPV NPV if R&R
6	15	8,103
7	16	8,943
8	17	9,246
9	18	9,266
10	19	9,377
11	20	9,274
12	21	9,187
13	22	9,137
14	23	8,936
15	24	8,786
16	25	8,652
17	26	8,519

The optimal time to do the R&R is 10 years from today, once the Defender becomes 19 years old.

Both optimization yield the same results; thus, the optimization rule provide a simple step for decision-makers.



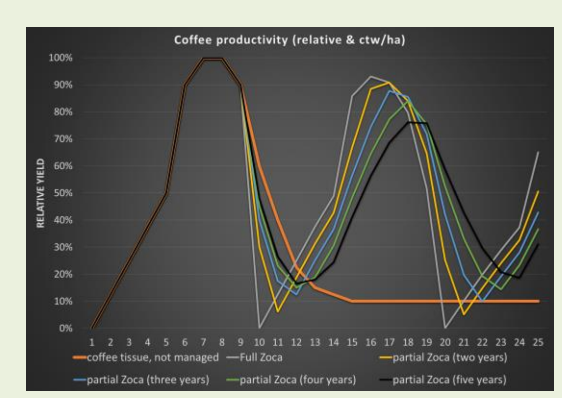
Application to a Coffee-based agroforestry system in the Dominican Republic, The rehabilitation case

The model was applied to a representative farm obtained from the 400 farms in the Dominican Republic. The optimization had the purpose of finding the optimal time to rehabilitate the productive tissue of the coffee plant through "Zoca". The coffee productivity decreases with time, and most farm in DR don´t recognize the value of renovating the tissue. Thus, this research is relevant.

Zoca: Activity to rehabilitate the productive tissue

Optimization was performed iterating the time of renovation and the proportion to renovate/year. Results from the optimization rule equal the optimization through iteration.

Results indicated that the optimal time to start rehabilitation of coffee is year 11 if the farmers decide for Full Zoca or Partial Zoca (2 year). If rehabilitation is done during years 3, 4, or 5, the optimal time for rehabilitation is year 10.



Year to start Zoca	NPV/ha, US$, Full Zoca	NPV/ha, US$, Partial Zoca (2 years)	NPV/ha, US$, Partial Zoca (3 years)	NPV/ha, US$, Partial Zoca (4 years)	NPV/ha, US$, Partial Zoca (5 years)
7	3,698	4,372	4,985	5,498	5,849
8	5,530	6,062	6,481	6,731	6,856
9	6,811	7,151	7,311	7,360	7,339
10	7,492	7,574	7,582	7,526	7,439
11	7,673	7,654	7,573	7,469	7,363
12	7,641	7,537	7,427	7,305	7,175
13	7,469	7,337	7,205	7,067	6,927
14	7,206	7,073	6,933	6,792	6,647
15	6,939	6,796	6,654	6,507	6,363

Further research about the coffee-based agroforestry system in Dom. Rep. showed that:

1) Farmers in DR are small, thus constant cash flows are more important than maximizing the NPV. Thus, Partial Zoca (period 3-5 years) offers more stable income than full Zoca.

2) One hectare with the current agroforestry system, still managed with optimal pruning, is not enough for a family of four to generate earnings above the poverty level (US $ 2 / day).

3) With a proposed and improved agroforestry system based on coffee-cashcrop-banana-avocado, 1.8 ha is required to cover the basic market basket for a family of 4. In contrast, with current systems, even with optimized pruning, 4.6 ha is required. This is important because 75% of the country's farmers have less than 5.62 hectares.