Assessing policies to mitigate abandonment of shade-grown coffee production in forest systems amid low and uncertain prices

Heidi J. Albers[1,*], Stephanie Brockmann[2] and Beatriz Ávalos-Sartorio[3]

[1]Department of Economics, University of Wyoming, Laramie, WY, USA,
[2]Department of Economics, University of New Hampshire, Durham, NH, USA and
[3]Rainforest Alliance, Cabo San Lucas, Baja California Sur, Mexico

*Corresponding Author. Email: jo.albers@uwyo.edu

ONLINE APPENDIX

This document contains additional information and results to supplement the material in the associated paper. Section I provides more information about our parameter set and calibration. Section II presents parameter and model amendments for policy analysis and relevant results. Section III contains more information about the analysis when farmers can choose to “opt out” of a price premium policy. Section IV contains a fuller description of the farmer decisions and abandonment over observed prices. Section V presents a decision tree illustrating path-dependence and irreversibility. Section VI describes the computational solution method for the stochastic dynamic optimal current period action choice. Section VII contains a description of the computational simulation method that defines time-paths of optimal decisions based on a series of actualized prices formed by sequential selection of a value for the error term in each year of the price path evolution. Section VIII presents parameter sensitivity analysis.

SECTION I: Interviews and parameterization of the model and price equation

We conducted interviews and semi-structured interviews with a range of stakeholders across the region, with particular variability in the degree of access to towns and paved roads. In addition to farmers and groups of farmers, the other key informants interviewed included: several “middle men” (including Adrián Luján-Audelo and Javier González from Candelaria Loxicha, Oaxaca); registered buyers (including C.P. Francisco García-Sánchez, Purchases Manager for CALVO EXPORT and Ing. Armando Villegas, General Manager of BECAFISA); the manager of a cooperative (Salomón García-Moreno, President of Productores de Café La Trinidad, S. De S.S.); officials from the local office of SAGARPA and from the CMCAFE (including Ing. Rolando Urías-García from the local SAGARPA office *DDR-Costa* and Ing. Rosalino Suárez-Colorado, Technical Secretary of CMCAFE in Mexico City); and lenders (including Ing. José García-

Santiago, Credit Official at FIRA, a government bank and Ing. David Morales-Viggiano, Fundación Mexicana para el Desarrollo Rural).

We used a set of parameters based in empirical values and defined other parameters to calibrate the model to represent the outcomes and decisions observed in this region (tables A1 and A2). As per stakeholder interviews, the typical famer in Oaxaca had a 5-hectare plantation on which he produced approximately six quintals of *pergamino* (green coffee with the papery membrane attached) per hectare (INEGI, 1997). We used the yield rate and the responses from the farmers and extension workers to define a relationship between the biomass and yield. The farmer relied mostly on family labor but required additional labor for help with harvesting. These additional labor costs, along with other observed non-labor related costs, are highlighted here and enter the main model through the total cost parameters shown in table A1.

Table A1. Model parameters for baseline run

Variable	Description	Value
p_0	Mean of coffee price	750
r	Discount rate	5%
T	Years forward-looking	10
m	Rate of yield decline a multiple of growth	5
γ	Yield/biomass growth factor	0.075
q_0	Initial total yield (quintals of pergamino)	30.5
$\bar{q}$	Maximum Yield	43.6
L	Total farmer labor (work-days)	190
l	Farmer labor for maintenance (work-days)	40
c_h	Total costs to harvest	1805
c_m	Total costs to maintain	8625
τ	Savings rate (percent of income over subsistence)	10%
W_0	Initial accumulated wealth (pesos)	500
w	Wage rate for off-farm labor (pesos/work-day)	53
S	Subsistence	9970

Notes: The average 2000 coffee price for Pochutla, Oaxaca from 1998 to 2003 was 726 pesos/quintal pergamino. We adjusted for inflation and converted to pesos using exchange rates from Banco de Mexico to get p_0.

Table A2. Additional model parameters used in calibration

Parameter Description	Value
Farm size (hectares)	5
Initial yield rate (quintals of pergamino/hectare)	6.1
Starting biomass as percent of maximum	70%
Initial biomass (Yield = 10% of biomass)	305
Maximum biomass	436
Intra-year credit monthly interest rate (harvest costs)	10%
Farmer labor for harvest (work-days)	150
Labor required to harvest (work-days/hectare)	35
Labor required to maintain (work-days/hectare)	34
Wage rate for hired on-farm labor (pesos/work-day)	60
Nonlabor costs for harvesting (pesos/hectare)	61
Nonlabor costs for maintenance (pesos/hectare)	165

Using actual coffee prices from 1998 to 2004 (NYBOT 1993 to 2002 and ICO 2004),[1] we estimated parameters to define our serially correlated price equation (section 3.2, equation (9)):

$$p_t = \begin{cases} p_{t-1}\big(1 + 0.0002(p_0 - p_{t-1})\big) + \frac{\varepsilon_t}{\left(10 - \frac{(p_0 - p_{t-1})}{100}\right)} & \text{if } p_t > 0.5\, p_{t-1} \\ 0.5\, p_{t-1} & \text{if } p_t \leq 0.5\, p_{t-1} \end{cases} \quad . \qquad \text{(A1)}$$

We then use estimated equation (A1) to develop the price paths, starting with the mean price in the initial time period (p_0, table A1) and drawing random error terms from a normal distribution for all future periods forming the 1,000 price paths.[2] Price paths are established for 10 years beyond our terminal time of 20 years to allow the farmer's decision in the final period to be forward-looking. Maintaining this forward-looking final decision minimizes the potential for terminal time effects.

[1] This timeframe corresponds to the period of data collection in Oaxaca.

[2] Prices are censored to be positive and to reflect the largest year over year price drop reported by the ICO over the crisis time horizon (1997–2001), which is 50% (ICO, 2019). Price drops larger than 50% are replaced by a 50% price drop, but our price path generation never generated more than a 50% drop.

SECTION II: Policy analysis

We include policies by changing prices and/or costs (table A3).

Table A3. Changes to prices and costs as a result of policy implementation

Policy	**Impact on Price**	**Impact on Costs**
Baseline	p_t	c_t
Payment for Ecosystem Service (PES)	-	$c_t^{pol} = c_t - c_{PES}$
Premium with:		
No Certification Costs	$p_t^{pol} = p_t + p_{Prem}$	-
Certification Costs	$p_t^{pol} = p_t + p_{Prem}$ for t > 3	$c_t^{pol} = c_t + c_{Cert}$ for t = 1-3
Certification Costs and Loan	$p_t^{pol} = p_t + p_{Prem}$ for t > 3	$c_t^{pol} = c_t + c_{Cert} - c_{loan}$ for t = 1-3 $c_t^{pol} = c_t + (i + c_{loan})$ for t = 4-9
Price Floor	If $p_t < p_{floor}$, then $p_t^{pol} = p_{floor}$	-

The table describes how the price of coffee or the costs of production differ from the baseline in the analytical model when a policy has been implemented. A dash indicates that there is no difference from the baseline.

When a policy is in place, p_t^{pol} and c_t^{pol} represent, respectively, the price the farmer receives and the costs the farmer incurs for that particular policy. Payment for ecosystem services (PES) policies do not alter the price the farmer receives because it is an annual cash payment based on the number of hectares that the farmer owns. Instead, the annual PES payment reduces the farmer's operating costs c_t by c_{PES} in all time periods that the policy is active. Price floor policies apply only to low prices. If the observed price is lower than the price floor, p_{floor}, the farmer will receive the price floor at no cost. The impact on prices is similar for the price premium policy with no certification costs: prices rise by p_{prem} at no cost to the farmer. When the price premium policy requires certification costs, the prices still increase by p_{prem} but with certification costs of c_{Cert} incurred. The farmer's operating costs increase for the first three years while he pays the certification fees, and then he receives the premium price. In the final policy scenario, the farmer receives the price premium and must pay certification costs yet receives a loan to help with expenses. The loan program helps reduce the costs of certification during the certification period by c_{loan}. Once the farmer receives certification, two things happen: (1) the farmer begins receiving the price premium, and (2) the farmer must pay back the loan plus interest i in subsequent years, which then increases the farmers costs.

The runs of the policy analysis are compared back to the baseline and relevant selected statistics as discussed in the main body of the text are presented below (table A4).

Table A4. Selected statistics and performance ranking from best (1) to worst (34)

Policy	Start Year	Cert. Cost	Ave. Years of HO before A	*Rank*	Total A	*Rank*	Ave. Bounce Length	*Rank*	Percent with Bounces	*Rank*	Percent of Bounces that A	*Rank*
Baseline	-	-	4.97	*26*	347	***30***	1.20	*7*	16.0	*28*	41.9	***32***
Prem., Low	1st	0	4.96	*27*	199	*10*	1.16	*18*	27.0	*18*	18.1	*19*
Prem., Low	5th	0	5.05	*24*	299	*25*	1.15	*20*	24.1	*22*	22.4	*22*
Prem., Ave	1st	0	5.19	*15*	54	***3***	1.10	***31***	32.2	*9*	5.0	***3***
Prem., Ave	5th	0	5.32	*11*	239	*16*	1.15	*22*	29.7	*14*	14.5	*13*
Prem., High	1st	0	5.28	*14*	18	***2***	1.10	***30***	44.6	***1***	1.8	***2***
Prem., High	5th	0	5.51	*7*	188	*9*	1.19	*9*	35.8	*6*	7.5	***5***
Prem., Low	5th	Low	5.07	*22*	355	***32***	1.21	*6*	20.3	*25*	30.0	*28*
Prem., Low	5th	High	5.06	*23*	418	***34***	1.24	***4***	21.2	*24*	28.8	*27*
Prem., Ave	5th	Low	5.31	*12*	285	*23*	1.21	***5***	30.6	*12*	14.7	*16*
Prem., Ave	5th	High	5.29	*13*	353	***31***	1.25	***3***	30.9	*10*	13.9	*11*
Prem., High	5th	Low	5.57	***5***	238	*15*	1.17	*15*	37.9	***4***	6.9	***4***
Prem., High	5th	High	5.53	*6*	308	*27*	1.25	***2***	40.9	***3***	9.0	*8*
Prem., Low; Loan, Low	1st	High	4.92	***29***	381	***33***	1.18	*12*	20.0	*26*	35.0	***31***
Prem., Low; Loan, Med	1st	High	4.77	***32***	342	*28*	1.15	*19*	18.9	*27*	27.0	*26*
Prem., Low; Loan, High	1st	High	4.62	***33***	346	*29*	1.14	*24*	24.9	*21*	33.3	***30***
Prem., Ave; Loan, Low	1st	High	5.14	*16*	303	*26*	1.18	*13*	28.7	*15*	14.6	*15*
Prem., Ave; Loan, Med	1st	High	4.96	*28*	265	*20*	1.15	*23*	26.7	*19*	14.6	*14*
Prem., Ave; Loan, High	1st	High	4.80	***30***	225	*13*	1.15	*21*	30.6	*13*	18.6	*20*
Prem., High; Loan, Low	1st	High	5.41	*9*	252	*18*	1.16	*17*	35.1	*7*	8.3	*6*
Prem., High; Loan, Med	1st	High	5.12	*17*	215	*11*	1.13	*25*	35.9	***5***	11.4	*10*
Prem., High; Loan, High	1st	High	4.78	***31***	163	*7*	1.10	*29*	34.9	*8*	10.3	*9*
PES, Low	1st	0	5.35	*10*	185	*8*	1.20	*8*	25.6	*20*	23.0	*24*
PES, Low	5th	0	5.44	*8*	286	*24*	1.18	*10*	22.7	*23*	22.0	*21*
PES, Med	1st	0	5.63	***3***	141	***5***	1.17	*16*	30.7	*11*	14.0	*12*
PES, Med	5th	0	5.59	***4***	273	*22*	1.18	*11*	28.3	*16*	17.7	*18*
PES, High	1st	0	5.90	***2***	90	***4***	1.10	***32***	42.8	***2***	8.4	*7*
PES, High	5th	0	5.91	***1***	247	*17*	1.17	*14*	27.9	*17*	16.1	*17*
Floor, Low	1st	0	5.12	*18*	233	*14*	1.13	*26*	8.7	***32***	33.3	*29*
Floor, Low	5th	0	5.04	*25*	268	*21*	1.10	*28*	10.5	***31***	45.7	***34***
Floor, Med	1st	0	5.08	*21*	156	*6*	1.12	*27*	6.1	***33***	26.2	*25*
Floor, Med	5th	0	5.09	*20*	261	*19*	1.10	***33***	11.2	***30***	44.6	***33***
Floor, High	1st	0	-	-	0	***1***	1.29	***1***	2.0	***34***	0.0	***1***
Floor, High	5th	0	5.10	*19*	225	*12*	1.06	***34***	12.7	*29*	22.8	*23*

Bolded rankings represent the five best and five worst policies. For example, the best policy providing the farmer with the largest average number of years that a farmer is able to *harvest only* before *abandoning* (Ave. Years of HO before A) is the High PES. A dash represents the inability to calculate a ranking for that policy (e.g., the high price floor has no abandonment, indicating there is no average amount of time that the farmer will *harvest only* (*HO*) before *abandoning* (*A*)).

SECTION III: Price premium option analysis

As discussed in the text, we consider an analysis that allows the farmer to optimally "opt out" of the price premium policy in the first period to forgo having to pay the certification costs for the cases where the "auto-enrollment" leads to higher abandonment percentages than in the baseline: the low premium, low certification cost case; the low premium, high certification cost case; and the average premium, high certification cost case. In each of these cases, the farmer chooses to opt out of the policy in the first period that the policy is offered if he assesses that the expected net present value of opting out is greater than the expected net present value of opting in. We find that the farmer optimally opts out in 237 (or 24%) of the price path iterations for the low premium, low cost case. As expected, when the certification costs increase, the representative farmer opts out more often. For the low premium, high costs case, 32% opt out, and for the average premium, high cost case, 28% opt out. With the ability to opt out, the abandonment percentages in each of the cases decreases relative to the auto-enrollment cases (table A5).

Table A5. Abandonment results for price premium policies with "opt out" option

BASELINE	Abandonment Percentage		
	By Year 10	By Year 15	By Year 20
	24	31	35

Policy: *Price Premium*	**Policy Value:** *Percent Increase in Price Per Unit*	**Policy Cost:** *Certification Cost (pesos)*	**Secondary Policy:** *Loan/Deferred Repayment (pesos)*	**Start Year:** *Immediate or Delayed*	**Abandonment Percentage with Policy Application** By Year 10 (% Change)	By Year 15 (% Change)	By Year 20 (% Change)
Low Premium, Low Certification Costs	5	500	-	5th	28 (17)	34 (10)	36 (3)
Low Premium, Low Certification Cost - Option to Opt Out					*26 (8)*	*32 (3)*	*34 (-3)*
Low Premium, High Certification Costs	5	1000	-	5th	36 (50)	40 (29)	42 (20)
Low Premium, High Certification Cost - Option to Opt Out					*30 (25)*	*34 (10)*	*36 (3)*
Average Premium, High Certification Costs	15	1000	-	5th	32 (33)	34 (10)	35 (0)
Average Premium, High Certification Cost - Option to Opt Out					*27 (13)*	*29 (-6)*	*30 (-14)*

Abandonment percentages for the baseline – no policy – model as compared to the abandonment percentages for permutations of price premium policies that increase abandonment percentages relative to the baseline. For the baseline, abandonment occurs in 24% of the 1,000 price path iterations by Year 10 and grows to 35% by Year 20. When implementing a low premium with low certification costs, the percent that abandon rises to 28% by the 10^{th} year. When compared to the baseline, this represents a 17% increase in abandonment by the 10^{th} year (value in parentheses). Presented in italics below the price premium polices are the results in which the farmer can opt out of the policy. For example, if the farmer can choose to opt out of the policy, abandonment occurs in 26% of the 1,000 price paths by Year 10, which is an 8% increase from the baseline. By Year 20, the abandonment percentage falls to 34%, which is a 3% decrease from the baseline.

The benefits to the farmer of the option to opt out become clear across time. By Year 15, abandonment percentages fall below the abandonment percentages in the baseline no-policy run for the average premium, high cost case. Similarly, by Year 20, both the low premium, low cost case and average premium, high cost case achieve lower abandonment percentages as compared to the baseline no-policy run. The only case in which the opt-out option does not decrease abandonment percentages relative to the baseline is the low premium, high cost case; the interaction between the certification costs and the need to meet the subsistence constraint is too large to be entirely offset by the combination of low prices, low premiums, and lower yields. Altogether, these results demonstrate that the option to refuse the policy limits the policy's adverse impact on abandonment due to that option allowing farmers to avoid certification costs.

SECTION IV: Observed price path

We used real price data from the crisis time period in our model to examine the decision path for a typical farmer in Oaxaca, Mexico. The International Coffee Organization (ICO) reported the "prices paid to growers in exporting countries" for 11 years of our time horizon (1998–2008), which we converted to pesos. We were only able to use the ICO's data explicitly for the first 10 years of farmer decisions (ICO, 2018), because the ICO did not report prices paid to growers in Mexico after 2008. Using simple trend analysis, we estimated prices for 2009–2028 given that our farmers are always 10-years forward looking. The model finds that the representative farmer neglects maintenance in the first year following the 1998 price drop and will continue to harvest only until 2001 and then abandon.[3] This abandonment decision is based on the actual observed price drop and corresponds to stakeholder observations and statements at that time.

[3] This outcome is not sensitive to the forecasted values of prices as the farmer abandons by 2002, at which point only 4 years of prices considered are from estimated prices.

SECTION V: Visualizing path dependence in actions from irreversibility and non-Markov processes

We construct a tree diagram to demonstrate how the farmer's decision in any period impacts his future period choices, creating path dependence in yield and abandonment (figure A1). Although yield is not stochastic, its growth over time depends on past farmer production decisions. Once the farmer forgoes maintenance (chooses *HO*), the yield growth trajectory differs from the growth with continual maintenance, and that non-Markov process leads to path dependence. Similarly, if the farmer abandons production in any time period, the irreversibility of the abandonment decision means that the farmer remains "abandoned" in every period thereafter, with that path dependence leading to a truncated decision tree.

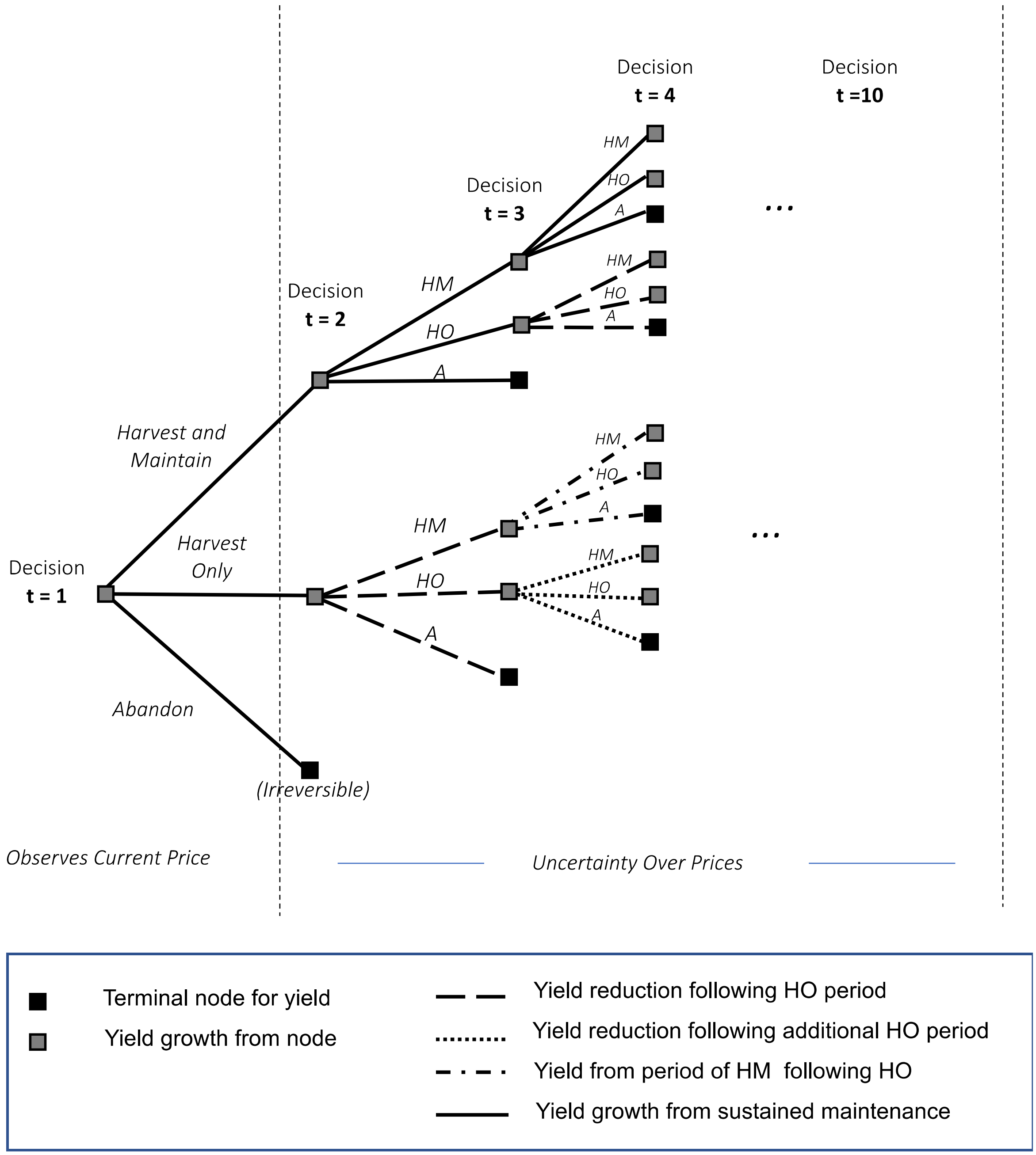


Figure A1. Tree diagram.

The yield growth paths for the representative farmer who is forward-looking 10 years (here, only four years are explicitly outlined to maintain image clarity), which depend on the farmer's past production decisions. In time period one, the farmer is making his current production decision based on current yield level, the current period's price, future path dependent yields, and expectations over uncertain future prices.

SECTION VI: Computational method – solution method

This section describes the computational method for solving the current period's stochastic dynamic programming problem based on the initial conditions[4] and forward looking by 10 years, as discussed in section 4.1 in the main text. In making each period's decision, the farmer must consider the impact of current decisions on all future decisions and consider the values of future decisions by forming price expectations. Due to the irreversibility of the abandonment decision, the non-Markov property of yield over time as a function of past maintenance decisions, and uncertainty about future prices that exhibit serial correlation, the farmer cannot examine simple average, or open-loop, values for future periods and instead uses a closed-loop method of incorporating all possible future paths – reflecting the path dependence fundamental to this problem – in assessing current period decisions (Arrow and Fisher, 1974; figure A1). The dynamic characteristics of the problem require a numerical solution method to determine the dynamically optimal current period decision that reflects all future values and decisions under uncertainty and irreversibility (Albers, 1996). We develop and employ a backward induction numerical solution method in MATLAB for the constrained dynamically optimal choices of current period production decisions that reflect serially correlated, stochastically variable, and uncertain future prices, accumulated wealth, and yield growth/decline as functions of prior decisions. The steps of the program:

Solution Method Steps

I. Compute current yield using the previous period's production decision
II. Draw an error term for current period to determine the current period's price, which the farmer observes
III. Form price probability distributions for each of T years of uncertain future prices, using current observed price, the distribution of random shocks to prices, and the stochastic price evolution equation
IV. Define the prices at which *HM*, *HO*, and *A* are optimal choices. (These are cutoff

[4] In the first time period, it is assumed that the farmer's previous decision was to harvest and maintain.

prices –the price above which *HM* is optimal and below which *HO* is optimal, and the price below which *A* is optimal)

V. Compute the expected price for each production choice conditional on that production choice being optimal and feasible[5]

VI. Compute expected net present value from each possible production decision using backward induction

VII. Save future net present value computations for all possible future paths

VIII. Calculate the present value of each decision available to the farmer based on current yield and price, production costs, and wealth

IX. Use the current period's present value of each decision to determine if the farmer can meet his subsistence constraint

X. Add the present value (step VIII) to the future value (step VII) to find the ENPV for each production decision

XI. Select the production decision that yields the highest ENPV

XII. Use the production decision (step IX) to determine accumulated wealth in the current period

The MATLAB program first defines the current period's yield (as a result of the previous period's decision) and draws an error term to determine the current period's price. The program then calculates the farmer's expected prices for the future 10 years, based on the current price and price evolution (section 3.2, equation (9)). Next, the program defines the 10-year "tree" of possible decision pathways incorporating irreversibility and path-dependence from the current period state. The path-dependence and irreversibility lead to a truncated tree of possible decision pathways; for example, if the farmer abandons in any time period, the possible future decisions devolve to all abandonment and the future value includes the (discounted) sum of wage income in every period

[5] We use a recursive method across all possible trajectories of path-dependent yields, as the result of all possible paths of production decisions from the current node until time T, to compute the expected value of future profits. At time T, cutoff prices at which the farmer will shift from one production decision to another are defined. Using the price probability distribution from step III and the cutoff prices from step IV, step V then calculates the expected price conditional on *HM* (*HO*, *A*) being optimal and uses that price to form the expected value of choosing *HM* (*HO*, *A*, respectively). Thus, the method uses a cumulative distribution function to calculate the probability that the optimal choice in time T, given the expected (but uncertain) price and path-dependent yield, will be to abandon production or to choose one of the harvest options. The expected value of profit in time T is then the probability weighted present value of the production decisions, which becomes the future value in time T-1. The model then recurses back to the (T – 1) period, computes the expected value of profit, and then adds it to the expected value from time (T); this recursive process continues until reaching the current time period, treating the sum of all expected profits as the future expected value of profits.

thereafter. For each of the possible current year choices, the program employs backward induction from all possible endpoints in time T (T=10 here), through all possible nodes of the tree, using the expected prices to establish the current expected value of the future T years of choices. The numerical solution method then calculates the farmer's present value of every production choice – *HM*, *HO*, or *A* – in his current time period and checks if each of production choices will satisfy his constraints. Conditional on meeting the constraints, the program then computes his expected net present of each current production decision based on the path-dependent expected value of every possible future production decision. The MATLAB program's last step is to select the highest valued current period option – including the current value and the expected value of the future 10 years. That choice is the solution to the stochastic dynamic optimization decision based on the current coffee price and current state variables under future price uncertainty and path dependence of land use choices, wealth accumulation, and per-period constraints.

SECTION VII: Computational method – simulation analysis

We complete two sets of simulation analyses:

(1) To create one pathway of decisions and outcomes, we use the single period solution method in (section VI) for a first period decision, find the outcomes from that decision and use those as the initial condition for the second period problem[6] and continue the loop of decisions creating the next year's initial conditions over 20 years. This price simulation analysis creates 1 series of dynamically optimal farmer decisions for one randomly drawn series of prices and reflects path dependence.

(2) We repeat the full simulation analysis 1,000 (i=1,000) times; we start with a new error draw to find the price for the initial single period solution and then draw errors to compute prices for the subsequent years, which consequently generates 1,000 different price paths.

Simulation Analysis Steps

[6] For clarity, the farmer sees only the current period realized price and forms price expectations for T future years; they make decision under future price uncertainty in each period of the simulation using the previous decisions as their "initial condition" for yield for the current period.

Loop until i = 1,000

0. Use outcomes from initial single period solution's decision as initial conditions for next year's decisions (section VI).

Loop until t = 20

I. Compute current yield using the previous period's production decision[6]

II. Draw an error term for current period to determine the current period's price, which the farmer observes

III. Form price probability distributions for each of *T* years of uncertain future prices, using current observed price, the distribution of random shocks to prices, and the stochastic price evolution equation

IV. Define the prices at which *HM*, *HO*, and *A* are optimal choices. (These are cutoff prices –the price above which *HM* is optimal and below which *HO* is optimal, and the price below which *A* is optimal)

V. Compute the expected price for each production choice conditional on that production choice being optimal and feasible

VI. Compute expected net present value from each possible production decision[7] using backward induction

VII. Save future net present value computations for all possible future paths

VIII. Calculate the present value of each decision available to the farmer based on current yield and price, production costs, and accumulated wealth

IX. Use the current period's present value of each decision to determine if the farmer can meet his subsistence constraint

X. Add the present value (step VIII) to the future value (step VII) to find the ENPV for each production decision

XI. Select the production decision that yields the highest ENPV

XII. Use the production decision (step XI) to determine accumulated wealth in the current period

XIII. Save outcomes to use as conditions in Step I for next time period.

XIV. Resolve (section VI) drawing a new error term to determine the price in section VI, Step II.

Section VIII: Sensitivity analysis

We performed sensitivity analysis on eight key parameters in the baseline model. To assess sensitivity to the yield parameters, we considered changes in the maintenance reduction factor and the starting point on the yield curve. For cost assessments, we looked at fluctuations in both the wages a farmer receives for foregoing maintenance and the wages the farmer pays to on-farm

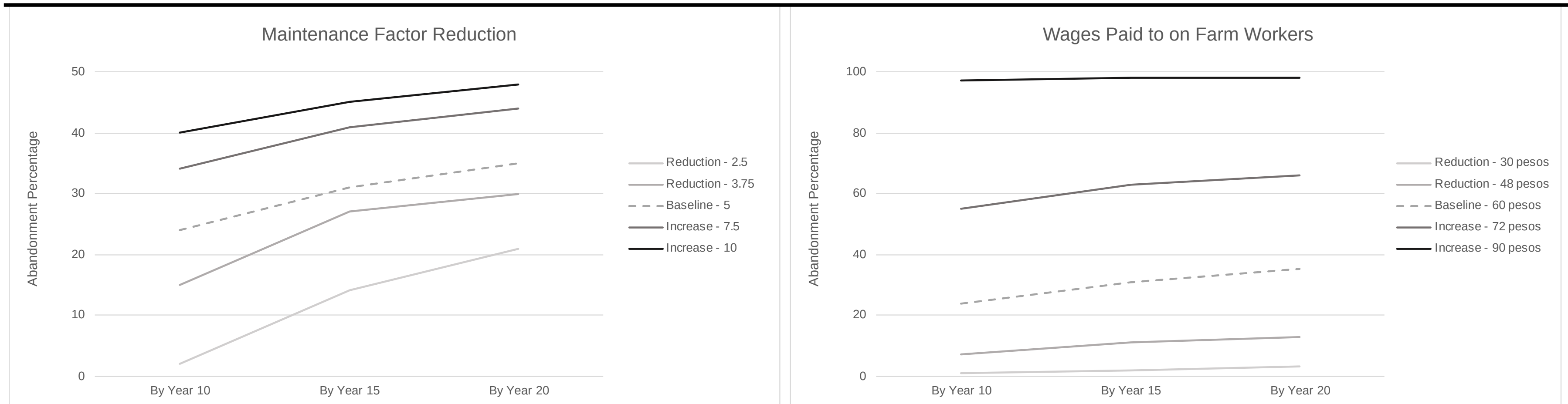
[6] If the farmer abandoned in the previous period, the program computes the current yield as zero.

[7] If the farmer abandoned in the previous period, the expected future value is simply the (discounted) sum of wage income in every period thereafter.

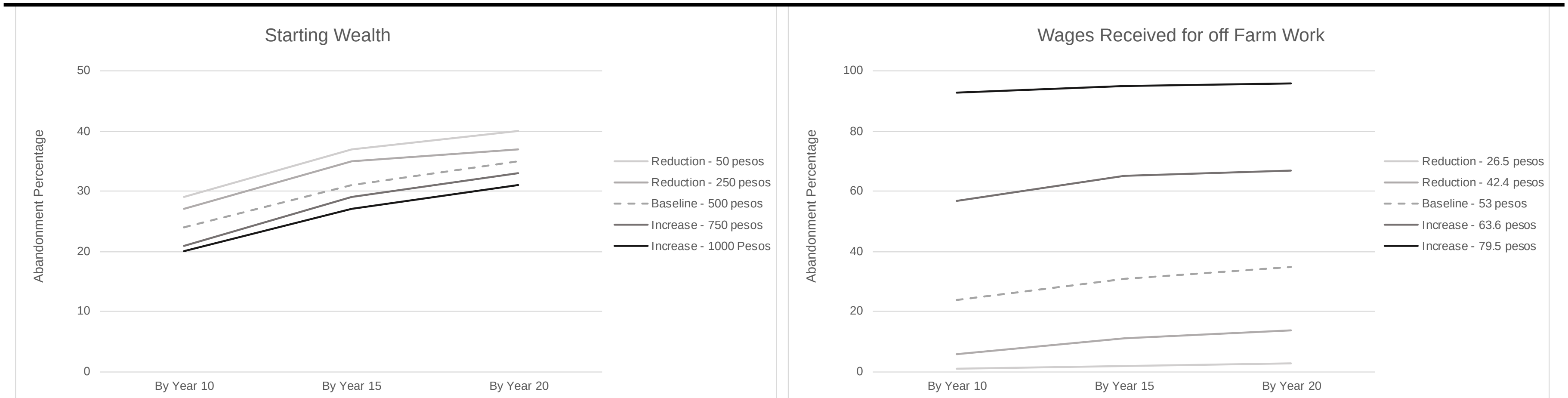
workers. Finally, we varied the starting values of wealth, the savings rate, the discount rate and the subsistence constraint. For most parameters, we considered two values above the baseline value and two values below the baseline. Because the subsistence constraint and starting yield curve value were already near their upper bounds, we ran a single higher value and two lower values. Similarly, with the discount rate near its lower bound we ran a single lower value and two higher values. Additionally, we considered how having a higher level of baseline wealth affects abandonment percentages in the costly price premium policy scenarios.

All parameter variation sensitivity analysis produced expected results (figure A2). For example, when the maintenance yield reduction factor is higher (lower), there is more (less) abandonment (figure A2, panel A). Intuitively, if foregoing maintenance has a greater negative impact on yields, farmers are more likely to abandon. Similarly, greater (lesser) subsistence constraints lead to more (less) abandonment (figure A2, panel D), as did higher wages (figure A2, panels A and B). When the farmer had to pay higher wages to his workers, this increased his costs in each period leading to more abandonment (figure A2, panel A). Also, at higher off-farm wages, the farmer forgoes maintenance and abandons production sooner because the off-farm wages offered more income and certain income (figure A2, panel B). A higher (lower) discount rate leads to more (less) abandonment (figure A2, panel D). Higher (lower) values for the starting wealth (figure A2, panel B) and savings rate decreased (increased) abandonment by helping the farmer protect himself against bad price years (figure A2, panel C).

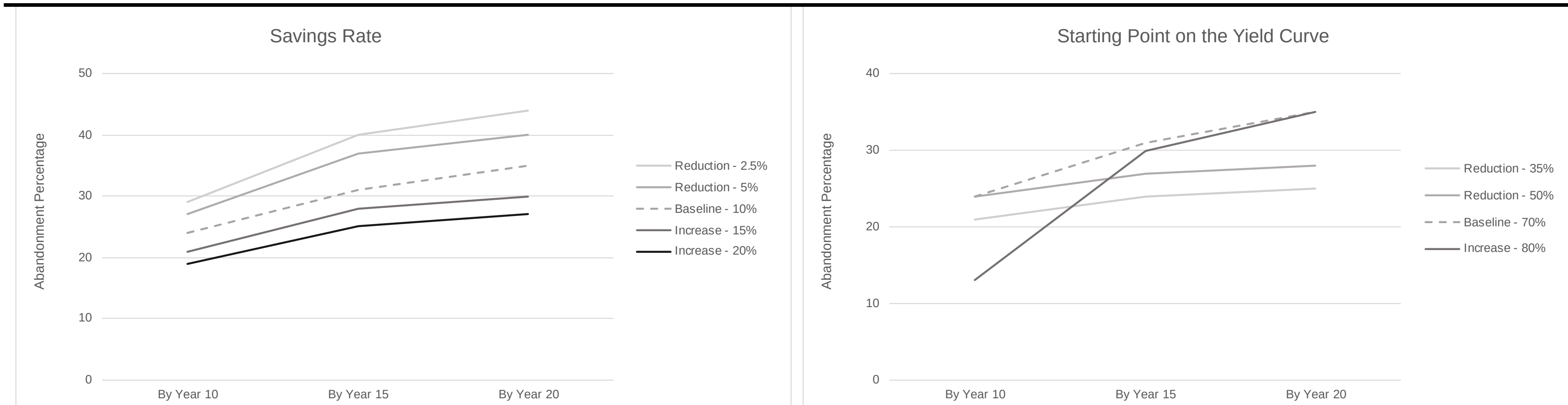
Panel A



Panel B



Panel C



Panel D

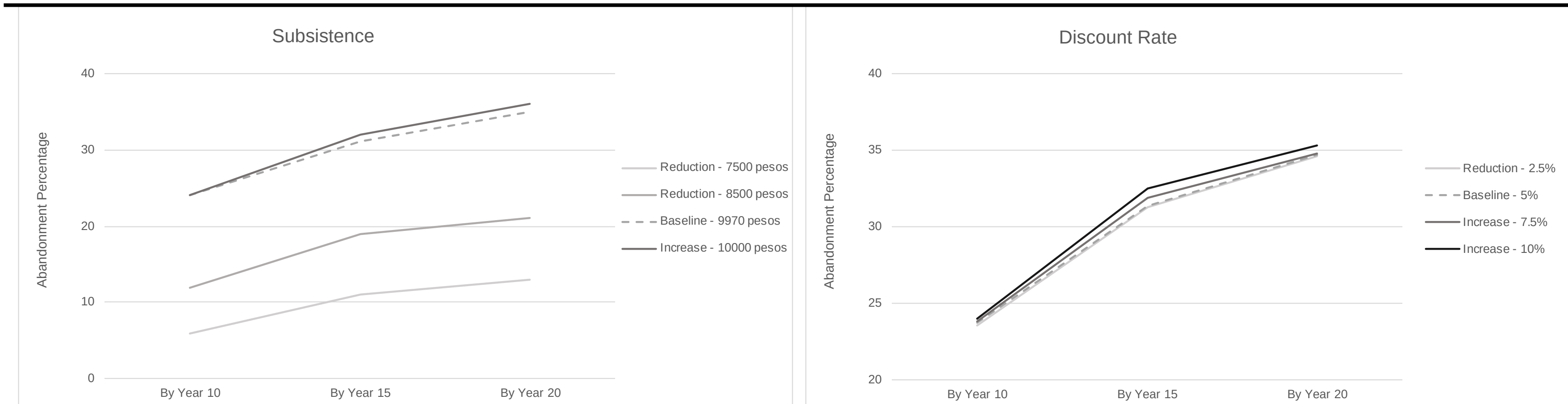


Figure A2. Sensitivity analysis for key baseline parameters.
Key selected baseline parameters (e.g., off farm wages, wealth, or subsistence) were scaled up or down to complete sensitivity analysis for the simulation analysis. Darker lines represent abandonment percentages for runs with a higher baseline value for the select parameter, and lighter lines represent abandonment percentages for runs with a lower baseline value for the select parameter. The dotted line portrays the abandonment percentage for the baseline parameter values. For example, with double (darkest line) the starting wealth (panel B) the abandonment percentages fall over the course of the 20-year simulation horizon as compared to the baseline (dotted line).

The yield parameter describing where the farmer starts on the logistic yield curve requires more discussion (figure A2, panel C). There are two competing effects with this variable: the starting income and the marginal changes in yield. Lowering the starting point on the yield curve implies that the farmer receives less income in the initial periods when compared to the baseline because all other parameters, including the benchmark price, remain the same as in the baseline. Even though the farmer starts with marginally less income, in the following years he experiences increasing marginal yields, which makes the farmer better protected against low price years; he has more yield to sell at the lower prices. At the higher starting point, there is less abandonment early on – the farmer starts with higher absolute yield and thus his higher initial income staves off abandonment. However, because the farmer experiences diminishing marginal yields in combination with lower prices, the abandonment outcomes mimic the baseline case after several periods. Starting higher on the yield curve results in higher rates of abandonment later on. By Year 20, abandonment occurs in 347 price paths in the baseline and in 352 price paths for the yield starting point sensitivity run.

Increasing the farmer's starting wealth from 500 pesos to 1,000 pesos results in lower abandonment percentages in nearly all of the price premium policies (figure A3). The extra wealth helps the farmer cover the cost of certification, which reduces the probability of abandonment. Only in the low premium, high certification cost case do we see that the farmer still struggles to maintain coffee production because the premium does not generate enough income later to offset the combination of costs and constraints.

Considering the same difference in starting wealth (500 pesos – baseline vs 1,000 pesos – sensitivity), we assess the abandonment percentages for a policy pathway (figure A4). In all cases, having the extra wealth decreased the abandonment percentage. For example, in the low premium, low certification cost policy, the abandonment percentages with the extra wealth were 23 (by Year 10), 29 (by Year 15) and 31 (by Year 20) as compared to abandonment percentages for the same policy with the baseline amount of wealth of 28, 34 and 36 respectively.

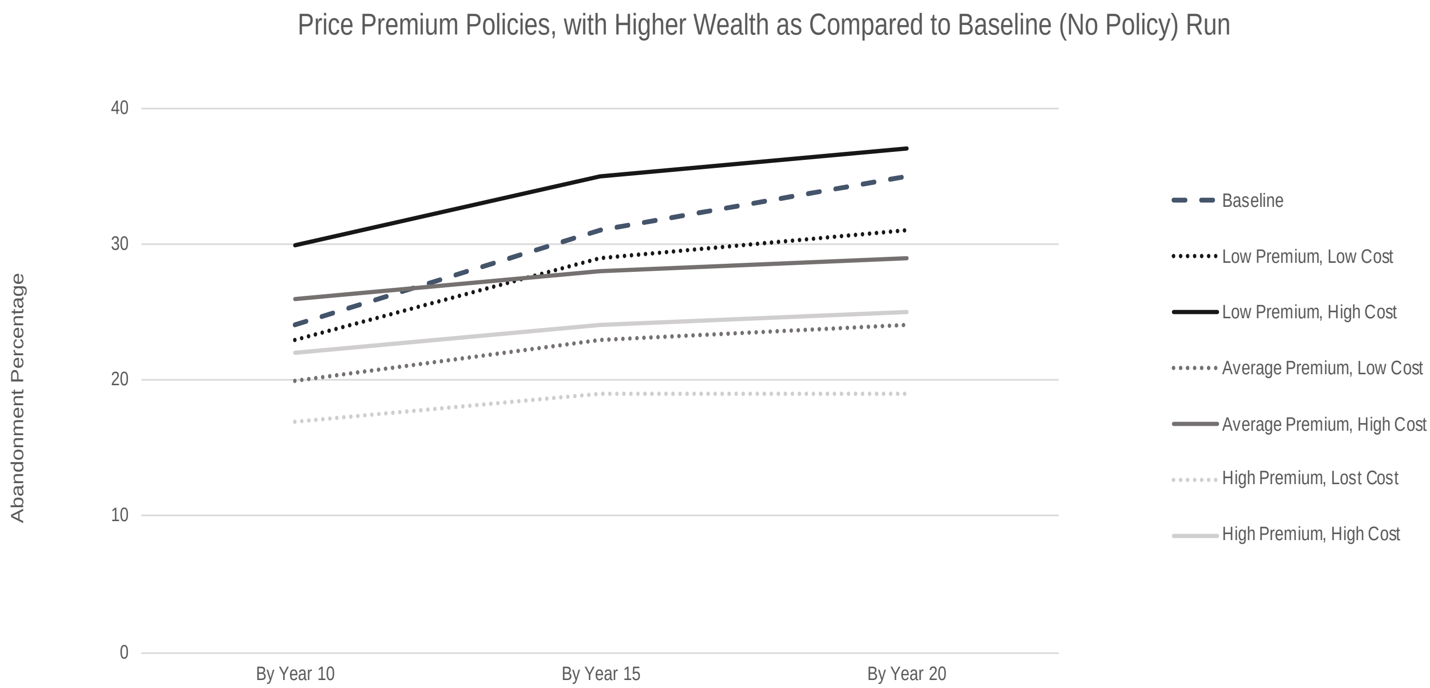


Figure A3. Policy Sensitivity Analysis I.
Abandonment percentages for the price premium policy simulation analysis using a higher starting wealth (1,000 pesos, as opposed to 500 pesos). The dotted line represents the baseline run, whereas the finer dotted lines represent policy runs with low certification costs and the solid lines represent the policy runs with high certification costs. For example, the higher level of starting wealth lead to lower abandonment percentages in the simulation analysis, except for the low premium, high certification cost run (solid dark line above the baseline line).

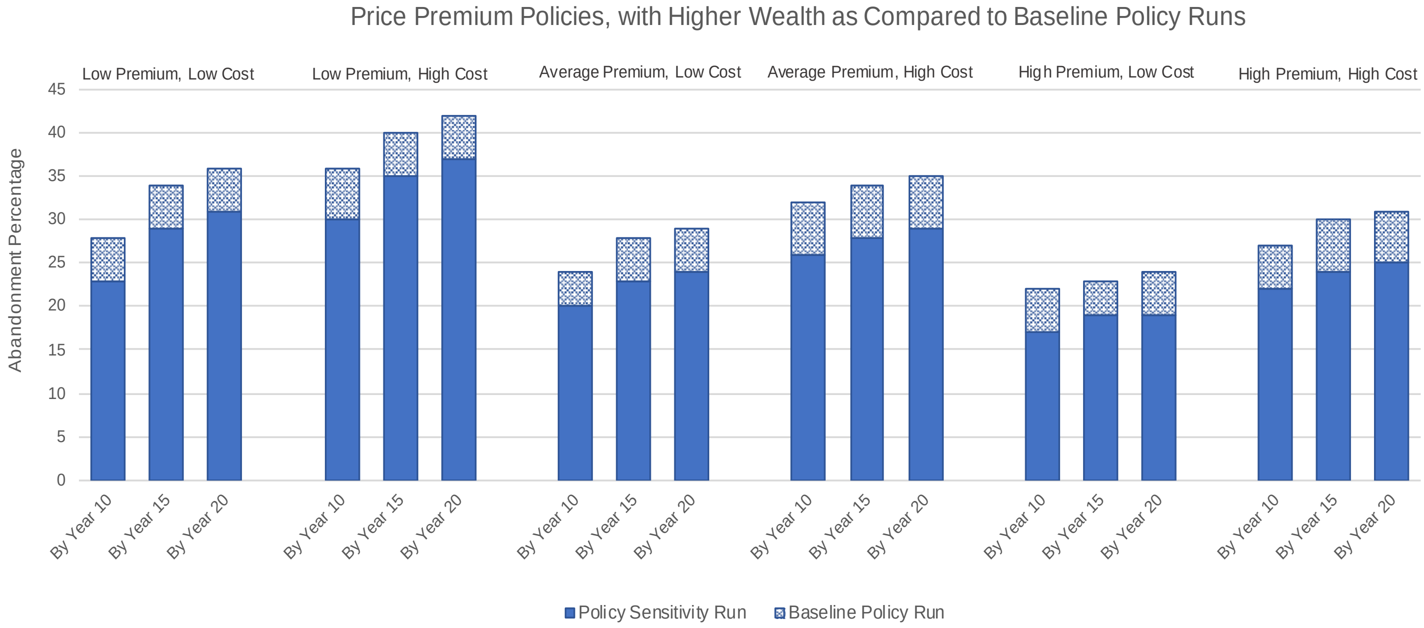


Figure A4. Policy Sensitivity Analysis II.

Baseline policy simulation analysis for price premium policies uses a starting wealth of 500 pesos versus the policy sensitivity analysis runs – over same price premium policies – with a higher starting wealth of 1,000 pesos. For example, in the baseline low premium, low certification cost scenario the representative farmer abandoned by Year 10 in 28% of the price paths. With a higher starting wealth, in the same low premium, lost certification cost scenario the representative farmer abandoned fewer times by Year 10 – a 23% abandonment percentage.

References for Econometric Land Use Models in Discussed in Main Text

Baerenklau KA, Ellis EA and Marcos-Martínez R (2012) Economics of land use dynamics in two Mexican coffee agroforests: implications for the environment and inequality. *Investigación Económica* 93–124.

Blackman A, Albers HJ, Ávalos-Sartorio B and Murphy LC (2008) Land cover in a managed forest ecosystem: Mexican shade coffee. *American Journal of Agricultural Economics* **90**(1), 216–231.

Blackman A, Ávalos-Sartorio B and Chow J (2012) Land cover change in agroforestry: shade coffee in El Salvador. *Land Economics* **88**(1), 75–101.

Bosselmann AS (2012) Mediating factors of land use change among coffee farmers in a biological corridor. *Ecological Economics* **80,** 79–88.

Wale E (2010) How do farmers allocate land for coffee trees? Implications for on-farm conservation and seed technology adoption in Ethiopia. *Journal of Sustainable Agriculture* **34**(3), 270–291.

Wale E, Holm-Muller K, Mburu J and Zeller M (2005) Economic analysis of farmers' preferences for coffee variety attributes: lessons for on-farm conservation and variety adoption in Ethiopia. *Quarterly Journal of International Agriculture* **44**(2), 121–140.

References for Online Appendix

Albers HJ (1996) Modeling ecological constraints on tropical forest management: spatial interdependence, irreversibility, and uncertainty. *Journal of Environmental Economics and Management* **30**, 73–94.

Arrow KJ and Fisher AC (1974) Environmental preservation, uncertainty, and irreversibility. *The Quarterly Journal of Economics* **88**(2), 312–319.

ICO (2004) ICO Indicator Prices. Available at http://www.ico.org/historical.asp.

ICO (2018) ICO composite and group indicator prices (annual and monthly averages). Available at http://www.ico.org/historical.asp.

ICO (2019) ICO composite and group indicator prices (annual and monthly averages). Available at http://www.ico.org/historical.asp.

INEGI (1997) El café en el estado de Oaxaca. INEGI: Aguascalientes, Mexico.

NYBOT (1998-2003) Daily quotes. Nearest futures coffee "C". Available at http://www.nybotlive.com/.