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Shade-Grown Coffee

Simulation and Policy Analysis for Coastal Oaxaca, Mexico

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RESOURCES FOR THE FUTURE

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Abstract

Shade-grown coffee provides a livelihood to many farmers, protects biodiversity, and creates environmental services. Many shade-coffee farmers have abandoned production in recent years, however, in response to declines in international coffee prices. This paper builds a farmer decision model under price uncertainty and uses simulation analysis of that model to examine the likely impact of various policies on abandonment of shade-coffee plantations. Using information from coastal Oaxaca, Mexico, this paper examines the role of various constraints in abandonment decisions, reveals the importance of the timing of policies, and characterizes the current situation in the study region.

Key Words: coffee farming, decision analysis, numerical modeling, Monte Carlo, price variability

JEL Classification Numbers: O13, Q17, Q12, Q23, Q24

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Introduction

Premium coffee sellers market shade-grown coffee as a green or environmentally friendly product because its production maintains environmental services and biodiversity, particularly when it is grown below a largely natural forest stand (Perfecto et al. 1996). In Mexico, two-thirds of all coffee production involves "traditional" management, which requires few inputs or mechanization; under traditional management coffee is grown in the forest understory or in the shade of trees (Moguel and Toledo 1999). Promoting shade-grown coffee in Mexico could prove important in protecting biodiversity because the 14 main coffee-growing regions in Mexico have all been designated biodiversity "hotspots" (Moguel and Toldeo 1999). Because such a small fraction of these coffee farms are officially certified as "shade grown," "bird friendly," or "organic," however, shade-grown coffee farmers provide public goods without incentives or compensation beyond the lower sale price of standard non-shade-grown coffee.

In the last 15 years, coffee prices have fallen significantly; many shade-grown coffee farmers have therefore abandoned coffee production. Anecdotal information from our study region, Sierra Sur y Costa in Oaxaca, Mexico, describes a marked upturn in the number of farmers who "abandon" their shade-grown coffee plantations for some portion of the year, traveling to the cities to find employment; and in the number of farmers who have abandoned their shade-grown coffee plantations altogether. When farmers abandon their plantations, the forested land comes under threat of conversion to a nonforest land cover through logging or cropping. Such conversion dramatically alters the ability of the land to provide habitat for birds and other animals, or to provide environmental services, such as erosion control.[1]

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[1] This abandonment also creates social disruption in rural communities when male farmers, and sometimes whole families, leave the area in search of wage labor jobs.

Despite the increasing popularity of shade-grown coffee with U.S. customers and the push by many international organizations to promote this production process, we know remarkably little about how shade-grown coffee farmers make decisions about maintenance, harvest, and abandonment, and thus how they will react to policies to promote shade-grown coffee. This paper develops a stylized model of farmers' year-by-year decisions under uncertainty about future prices, a model based on interviews conducted in this region of Oaxaca. A key feature of the coffee production function is that neglect of maintenance activities in a given year leads to lower yields in subsequent years. Parameterizing the model with data from the area allows us to run simulations that depict the farmer's behavior in response to price paths and various policies. These simulations provide evidence about the likely impact of policy on the probability that farmers will abandon their shade-grown coffee plantations over the coming 20 years. With rural welfare and biodiversity conservation under threat from shade-grown coffee plantation abandonment, policies to slow the rate of abandonment would have both social and environmental benefits. This paper considers the effectiveness of various policies, and the timing of these policies, in enabling farmers to remain on their coffee plantations. The paper also examines some implementation issues using data from coastal Oaxaca, and presents a case study using recent historical price data for the region.

Shade-Grown Coffee Production in Oaxaca's Sierra Sur y Costa

The forests of Oaxaca's Sierra Sur y Costa contain many shade-grown coffee plantations and high levels of biodiversity; because of this, we have used this region to form the empirical basis for this analysis. The Smithsonian Migratory Bird Center has designated this region an Important Bird Area—shade-grown coffee plantations offer important habitat to many birds (Rice and Ward 1996). In addition, the forests provide many environmental services, such as erosion control and flood protection, on which coastal farms and fisheries rely (Ávalos-Sartorio 2002).

The Sierra Sur y Costa region of Oaxaca produces approximately one-fifth of Mexico's coffee, with three-quarters of the coffee acreage in the region managed by poor, small-scale farmers (Nestel 1995). Most of these farmers grow coffee bushes in the understory of natural forest in a shaded system. Although lower yielding, this traditional production system has advantages for poor farmers over sun-grown coffee because it obviates the need for expensive clearing activities, reduces weeding, and requires far fewer inputs such as fertilizers and pesticides (Moguel and Toledo 1999, Donald 2004). This production system relies primarily on labor input for both harvest and plantation maintenance activities.

In extensive interviews with farmers from varied backgrounds and locations in the region, they describe a similar path toward abandoning coffee production. The story begins with declines in coffee prices, which drop too low for farmers to cover the basic subsistence needs of their families. As a result, farmers migrate temporarily to towns to generate cash income, forgoing important farm maintenance activities such as pruning. Unfortunately, the future yield from coffee plants declines when the plants are not maintained; lower yields require higher prices to cover fixed costs, so declines in yield result in even greater difficulty meeting subsistence needs in future years, even if prices recover. That prospect, in turn, implies that, in subsequent years, farmers may again need to forgo maintenance activities for wage employment, which means that future yields will decline even further. Through this mechanism in which low prices result in forgone maintenance and forgone maintenance results in lower yields, even a single bad-price year can set farmers on a downward slide of declining yields and income. Eventually, due to lack of maintenance activities, yields drop so low that farmers cannot even cover harvesting costs and are forced to abandon their plantations entirely.

Complicating the situation further, if coffee cherries are not harvested from a plant in any given year the yield from that plant drops off precipitously thereafter. Harvest costs are large, and in years when prices are particularly bad, some farmers may forgo harvesting. That decision is tantamount to abandoning the plantation, because only very significant investment can reinvigorate a coffee plantation once the cherries have been left unharvested for a year.

In our interviews, poorer farmers began this downward slide at higher “bad” prices than the prices at which wealthy farmers began to slide, in part because poorer farmers had little recourse in terms of credit or wealth to allow them to perform maintenance activities in bad-price years. In the last two seasons, however, even relatively wealthy farmers have decided to forgo maintenance and even harvesting on some or all of their plantations. Policies could focus on enabling farmers to withstand bad-price years without reducing maintenance activities, to stem such abandonment and to prevent the potential losses in rural welfare and biodiversity.

Methodology

To determine whether policies will be effective in reducing abandonment of coffee plantations, we predict farmer behavior over time using a stylized decision model. In each period represented in the model, the farmer, parameterized to represent a typical farmer in our study region, maximizes the net present value of a future stream of income by allocating labor between coffee production and wage employment. The farmer faces constraints on total labor time, costs of subsistence, and available credit. We drew coffee prices randomly in each period from a predefined probability distribution; the farmer faces uncertainty about future coffee prices, but knows the distribution from which prices are drawn. In each period, the farmer makes one of three possible decisions:

The farmer can “harvest and maintain” (HM), harvesting and selling coffee and performing maintenance on the plantation to increase future yields; HM has costs for hired labor, as well as non-labor costs, such as transportation, fertilizers, and pesticides.

The farmer can “harvest only” (HO), harvesting and selling coffee and working in town using remaining labor time. HO has costs for hired labor, as well as non-labor costs, though only for the harvesting activities and not for maintenance activities.

The farmer can permanently “abandon” (A) the plantation, working in town with all available labor time. Agronomic constraints imply that forgoing harvesting in a given year decreases yields so dramatically that doing so is equivalent to permanent abandonment.

In a given period, the farmer makes his or her decision by calculating the expected net present value of HM, HO, and A, based on that period’s realized coffee price and expectations about prices in future periods. The farmer then chooses the option that provides the stream of income with the greatest expected net present value. The farmer recognizes that uncertainty about prices is dispelled in each period and uses a closed-loop decision rule to capture the value of that forthcoming price information in the face of largely irreversible declines in yield after HO or A.

Performing maintenance activities is much more costly than harvesting alone because of additional hired-labor requirements and because the farmer earns no income through off-farm wage employment. This situation is offset, however, by comparatively greater yields in future periods. The farmer who opts to maintain (HM) in a given period expects the higher costs in that period to be more than recouped by higher yields in subsequent periods, as compared with harvesting without maintenance (HO). In this region, forgoing maintenance in one year can depress yields enough to the point that it will take several years of maintenance to recover.

In our model, yield is a direct result of biomass, which follows an *S*-shaped growth function, and both yield and biomass are higher if farmers completed maintenance activities in prior periods (see Equation 1.4b).[2] In each period, the farmer must meet a subsistence income constraint *S*. If the farmer faces a particularly low price in a given year and has not accumulated enough wealth to meet subsistence needs, the farmer may not be able to undertake maintenance activities or perhaps even to harvest. In the benchmark, the farmer has access to intraperiod credit that the farmer must repay at harvest, modeled as an additional constraint. In some scenarios, farmers also face an interperiod credit constraint.

In sum, the farmer solves a constrained dynamic optimization problem (Equation 1) under price uncertainty (with price revealed in each period) by choosing an action, k_t, for the current period in $t=1$ to T from a set of actions $K_t=\{HM_t, HO_t, A_t\}$, and while meeting subsistence and credit constraints and considering the impact of current choices on future values. The choice of *A* is irreversible, and the choice of HO versus HM implies a difference between future yields because these land uses alter biomass differently. The following equations characterize the optimization problem and constraints:

$$\max_{k_t \forall t} V = v_1(k_1) + E[\max\{v_2(k_2) + \max\{v_3(k_3) + ... + \max\{v_T(k_T)\}...\}] \quad (1)$$

s.t.

Value Equation: $$v_t(k_t) = p_t q(k_t) + wl(k_t) - c(k_t) \quad (1.1)$$

where $q(k_t)$ is the output associated with k_t, $l(k_t)$ is the labor time spent in off-farm employment associated with choice k_t, p is the price of the coffee output, w is the off-farm wage, and $c(k_t)$ is the cost associated with each choice as defined by

$$c(k_t) = \begin{cases} c_h + c_c + c_m & \text{if } k_t = HM_t \\ c_h + c_c & \text{if } k_t = HO_t \\ 0 & \text{if } k_t = A_t \end{cases}, \quad (1.2)$$

where c_h is harvest costs, c_c is intraperiod credit costs, and c_m is maintenance costs.

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[2] In our model and simulations, farmers do not face yield uncertainty; all of the uncertainty is contained in price fluctuations. This assumption simplifies the model and places the emphasis of the discussion on policies and actions that stem from reactions to price uncertainty.

Labor Time Constraint: $l(k_t) = \begin{cases} 0 & \text{if } k_t = HM_t \\ l & \text{if } k_t = HO_t \\ L & \text{if } k_t = A_t \end{cases}$ (1.3)

and $L - l$ = harvest labor. (1.4)

Dynamic relationships and irreversibility constraints

if $k_t{=}A$ then $k_{t+i}{=}A \; \forall I$ (1.4a)

Logistic growth with slower growth for no maintenance:

$$q(k_t) = \begin{cases} q(k_{t-1})\left[1+\gamma\left(1-\dfrac{q(k_{t-1})}{\bar{q}}\right)\right] & \text{if } k_{t-1} = HM_{t-1} \\ q(k_{t-1})\left[1+\gamma m\left(1-\dfrac{q(k_{t-1})}{\bar{q}}\right)\right] & \text{if } k_{t-1} = HO_{t-1} \\ 0 & \text{if } k_{t-1} = A_{t-1} \end{cases}, \quad (1.4b)$$

where q is yield growing according to a sigmoid equation, $\bar{q}$ represents yield carrying capacity, and γ is the intrinsic growth rate that is reduced by a factor m when no maintenance occurs.

Wealth accumulation: $W_t = \begin{cases} W_{t-1} + v_{t-1}(k_{t-1})s & \text{if } v_{t-1}(k_{t-1}) > 0 \\ W_{t-1} + v_{t-1}(k_{t-1}) & \text{if } v_{t-1}(k_{t-1}) \le 0 \end{cases}$, (1.4c)

where s is the savings rate on annual profits.

Price distribution: $p{\sim}N(X,X)$ (1.5)

Subsistence constraint: $v_i(k_i)+W_i \geq S$ (1.6)

The first-order conditions simply show that the farmer will perform maintenance (HM) when the discounted expected value of future years offsets the current costs; that the farmer will harvest only (HO) when subsistence constraints prevent HM or when the maintenance costs are not balanced by future yield improvements; and that the farmer will abandon (A) when constrained by subsistence requirements or when the expected future stream of income from farming is lower than that of working for off-farm wages.

In order to look at pathways toward abandonment of coffee plantations, however, we need to explore behavior in response to price draws rather than focus on first-order conditions. To do this, we use a numerical solution and simulation approach, working within the MATLAB programming framework (see Appendix B). The simulation model projects a farmer forward for some number of years based on a set of initial conditions. In each year, the model generates a decision rule, which is conditional on starting values and prior history of actions (with biomass and accumulated wealth as state variables). In the benchmark case, the decision rule considers expectations of the next 10 years. The marginal difference in behavior between farmers who look forward 10 years as opposed to eleven or twelve years is trivial, but the computational costs of extending the planning horizon are decidedly nontrivial (see Appendix A). As the simulation model is "run forward," we apply the decision rule in each year; we draw the coffee price in each year randomly from a known price distribution, and the results of the decision rule affect yield and wealth in the subsequent period. Over 20 years, the program maps out the farmer's decisions and the state variables for each year of that random price sequence. Using a Monte Carlo approach, we run the simulation model through 150 iterations using 150 random sequences of price draws (see Appendix A). We compute various statistics over all 150 iterations, with the percentage of farmers—that is, the percentage of iterations—who have abandoned by each simulation year being of particular importance for this discussion.[3]

Data and Benchmark Results

To place our results and discussion in a relevant setting, we conducted interviews with farmers in coastal Oaxaca. We asked them about their decisions, costs, constraints, and yields. We combined those data with information about agronomic characteristics of the costs of production, farm size, credit availability, wages, and prices to determine the parameters and functional forms used in the benchmark and subsequent analysis. The benchmark parameter values shown in Table 1 represent the yield, price levels, and price variability seen in the 1990s. We draw prices from a normal distribution, with the mean and standard deviation defined to be

[3] Increasing the number of iterations beyond 150 resulted in no statistically significant effect to variables of interest and therefore did not merit the additional computing time (see Appendix A).

equivalent to real coffee prices witnessed in the region from 1998 through 2003.[4] In the benchmark, as in the region, farmers do not have access to interperiod credit. Interviews revealed, however, that most farmers rely on high-interest short-term loans from coffee buyers to cover expenses during the growing season. We include the cost of these loans in the model as an additional cost of harvesting. The benchmark reflects the situation of a typical coffee farmer, in that farmers begin with minor wealth but accumulate wealth by saving 10 percent of their profits above subsistence in each period.

In the benchmark simulation, the farmer abandons coffee production by Year 5 in 15 percent of random price path iterations. Henceforth, we define the probability of abandonment by year *X* as the percent of price path iterations during which the representative farmer abandons by year *X*. After 10 years, that percentage rises to 51 percent, and after 20 years, that percentage is 70 percent (Table 2). (Because abandonment is a trapping state, the probability of the farmer having abandoned is strictly nondeclining over time.) For a typical farmer, therefore, a combination of price variability, uncertainty, and constraints leads the farmer to abandon coffee within 20 years in 70 percent of randomly drawn price paths; in other words, there is a probability of abandonment of 0.70 by Year 20.

To discern what leads to the decision to abandon, we can analyze farmer decisions to harvest and perform maintenance (HM) over time. In 22 percent of iterations resulting in abandonment, the farmer moves from HM directly to A, and in the remaining 78 percent of abandonment decisions the farmer chooses HO, forgoing maintenance, for an average of 4.38 years before moving to A. If low prices force the farmer to forgo maintenance in a given period, the farmer either “bounces back” to HM in the subsequent period, or begins a downward slide of consecutive years of HO, eventually resulting in abandonment. Of all transitions from HM to HO over all iterations, 41 percent eventually result in abandonment and 59 percent are followed by HM in subsequent periods. On average, the farmer bounces back approximately 1 time per 20-year projection. In fewer than 3 percent of iterations was the farmer able to choose HO two periods in a row and still revert to HM, and the farmer was never able to do so after three periods of HO. The farmer was able to choose HO for no more than 7 consecutive periods before

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[4] The average real 2000 coffee price for Pochutla, Oaxaca, for 1998 through 2003 was 726 pesos/quintal pergamino, with a standard deviation of 285, based on data from the New York Board of Trade (NYBOT) and the International Coffee Organization (ICO), adjusted for inflation and converted to pesos using exchange rates from the Banco de México. In our study area, one quintal weighs 46 kilograms. Most farmers in Oaxaca sell pergamino, the green coffee whose paper-like membrane has not been removed.

declining yields forced the farmer to choose A. The simulations show that subsistence constraints and low prices lead farmers to forgo maintenance, and that this decision often leads to A due to a downward cycle of declining yields.

Policy and Sensitivity Analysis

A variety of policies could alter farmers' decisions enough to encourage them to remain in coffee production. This analysis focuses on extending credit, paying a price premium for shade-grown coffee, providing a price floor for coffee, creating conservation payments for environmental services, and performing agricultural extension to boost the productivity of existing plantations. Although we have carefully parameterized the model to represent the coastal Oaxacan setting, we perform some sensitivity analysis on those parameters to understand the model more fully before we delve into policy analysis. Except for analysis scenarios affecting realized coffee prices, policy and sensitivity analysis scenarios use the same randomly drawn price paths as in the benchmark case. That is, we assume that the price drawn in year *X* of iteration *A* of the benchmark case is the price drawn in year *X* in iteration *A* of the comparable sensitivity and policy case.

Sensitivity Analysis

We performed a number of sensitivity analyses to explore model functionality under alternative scenarios pertaining to price, farm, and farmer characteristics. Namely, we adjusted coffee price variability, farmer expectations of future prices, the discount rate of future expectations, the yield curve describing coffee growth and decline, farmer credit and subsistence constraints, and farmer treatment of uncertainty in decisions.

Price Variability. We based our benchmark variability for random prices drawn from a normal distribution on the variability seen in prices during the late 1990s. We adjusted the variance of this normal distribution in sensitivity analyses, and show the results in Table 3. Reducing the standard deviation of the price distribution from the benchmark's 250 to 150 (around a mean of 750) reduces the probability of abandonment by Year 10 from 51 to 28 percent, and by Year 20 from 70 to 37 percent, a 45- and 47-percent reduction, respectively. Increasing the standard deviation to 350 doubles the probability of abandonment for the first 6 years, but by Year 20 the difference is smaller, with approximately 27 percent more abandonment than in the benchmark case. This decreasing impact of price variation comes from the fact that, as farmers accumulate wealth (as is the case in later years of the projection, after many years of HM), they are less sensitive to bad-price years. These changes in abandonment in response to price variability appear reasonable and demonstrate the importance of modeling farmer decisions under uncertainty as opposed to assuming that the average price is enough to depict farmer decisions.

Price Expectations. In the benchmark analysis, farmers base their price expectations on the known distribution of prices. In reality, farmers probably base their price expectations on experience and other information, although farmers in this region have access to NYBOT prices on a daily basis and are savvy about prices.[5] Some of the farmers we interviewed stated that they use some sort of historical average to determine price expectations. Using the benchmark parameters, but assuming future price expectations to be the three-year running average of prices in the current and two previous years, farmers in the simulation had an increased probability of abandonment over the benchmark. After 20 years, the probability of abandonment is about 13 percent higher than that of the benchmark (Table 4). We performed additional sensitivity and policy simulations beyond those discussed here on these farmers, but we found the results to be qualitatively very similar to those from farmers with known distribution of prices. For this reason, and because farmers expressed various ways of forming price expectations, we discuss subsequent analyses only with regard to price expectations based on a known distribution.

Discount Rate. We chose a rather low discount rate of 5 percent in the benchmark case as a conservative assumption to ensure that farmers adequately consider the long-term future.[6] We varied the discount rate in sensitivity analyses and found that the probability of abandonment per year is remarkably insensitive to the discount rate between 0 and 10 percent. By the twentieth year, a discount rate of 0 results in only 3 percent fewer iterations of abandonment than in the benchmark case, whereas a discount rate of 10percent results in no change in the probability of abandonment (Table 5). A discount rate of 20 percent, however, causes all farmers to abandon by the ninth year. These simulations demonstrate that, when the future carries weight in current decisions, farmers are more likely to perform costly maintenance activities in exchange for higher yields in subsequent periods and thereby forestall the slide toward abandonment.

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[5] Universidad del Mar (UMAR), in Oaxaca, has broadcast daily coffee prices over the radio since the late 1990s.

[6] The discount rate and the number of years forward considered by the farmer in the decision rule are closely related; a farmer with a higher discount rate is similar to one who is less forward-looking, and vice versa. However, although computing time increases exponentially with increased number of years forward-looking, it is unaffected by changes to discount rate. Thus, we decided to limit the years forward-looking to 10, but lower the discount rate such that years closer to the horizon are still considered in the decision rule.

Yield Curve. The *S*-shaped logistic curves for the growth and decline of biomass (and thus of yield) are defined by three key parameters. First, they are defined by the maximum achievable yield, or the asymptotic maximum of both curves. As we parameterize initial farmer yield (that is, yield in the first period) to typical regional conditions, changing the maximum achievable yield is equivalent to changing where on the curves the farmer begins; a lower maximum (relative to initial yield) implies that the farmer starts off closer to the asymptotic part of the curves. The probability of abandonment is relatively insensitive to changing this parameter; a 20-percent higher maximum yield results in a 4-percent greater probability of abandonment by the twentieth year, and a 20-percent decrease in maximum yield results in a 10-percent lower probability of abandonment by the twentieth year (Table 6). This result demonstrates that, as farmer yield approaches the asymptotic maximum, farmers are better able to bear bad-price years, because the impact on yield of forgoing maintenance in a single period is small in that part of the curve.

Second and third, the curves are defined by their steepness; the growth curve is determined by a rate-of-growth parameter, and the decline curve is determined by a rate-of-decline parameter that is defined as a multiple of the rate-of-growth parameter. For sensitivity analysis, we vary the rate-of-growth parameter as well as the rate-of-decline multiplier, thus varying both the absolute steepness of the curves and the relative difference in steepness. Changing the rate-of-growth parameter by a third in either direction (and holding constant the rate-of-decline multiplier) resulted in less than a 7-percent change in probability of abandonment (Table 6). Changing the relative difference in steepness of the curves, however, resulted in significant changes to probability of abandonment. Decreasing the multiplier by 33 percent (and thus decreasing the rate of decline relative to rate of growth) results in a 26-percent lower probability of abandonment, whereas increasing the multiplier by 33 percent results in a 16-percent higher probability of abandonment.

These three sensitivity analyses suggest that the relative difference in yield following either maintaining or not maintaining is an important driver of farmer decisions. This result is not surprising, but does suggest that making smart policy decisions may be dependent on being able to predict with some precision the yield penalty of forgone maintenance.

Credit and Subsistence Constraints. The benchmark farmer faces subsistence and credit constraints. If, in a given year, the coffee price is too low to meet subsistence and the farmer does not have enough accrued wealth to make up the difference, the farmer will have no choice but to forgo maintenance. If the farmer faces no subsistence constraint, the farmer has a very low probability of abandonment; in the case in which subsistence costs are zero, there is only an 11-percent probability that the farmer will abandon by Year 20 (Table 7). Farmers that abandon in this case do so due to prices that are so low that the farmers cannot even cover the costs of coffee production. In the case in which there is no credit constraint, which is equivalent to the farmer having an infinite credit limit, the probability of abandonment drops to zero. This suggests that, absent a credit constraint, HM is the preferable long-term strategy given the benchmark price distribution. In general, farmers who do not face cost or credit constraints are highly likely to stay on the path of regular maintenance.

Open-Loop Farmer. The benchmark farmer uses a closed-loop formulation in which the farmer makes decisions that incorporate the fact that forthcoming price information in subsequent periods will dispel uncertainty about expectations of future earnings that result from these decisions. The closed-loop decision leads the farmer to choose an option that is more flexible (not irreversible) in order to be able to take advantage of the forthcoming information. This decision is contrasted with the open-loop formulation, in which the farmer ignores the forthcoming information, uses simply the expected value of each option in each future period, and makes less flexible choices. The quasi-option value is the value of the forthcoming information, or the value of dispelling uncertainty, conditional on remaining flexible enough to use that information, and is defined as the difference between the benefits of the closed-loop and open-loop farmers (Arrow and Fisher 1974, Albers 1996). In sensitivity analysis, the open-loop farmer makes nearly all of the same decisions as in the benchmark case. Although there are small differences in decisions year to year, there is essentially no difference in the probability of abandonment by Year 20 (Table 7). Thus, the quasi-option value is very small for the full duration, given the price distribution used in the benchmark. Indeed, further analysis suggests that, given our benchmark parameters, farmer expectations of the net present value of HM are nearly always greater than expectations for HO, and that farmer decisions to forgo maintenance are therefore due almost entirely to subsistence and credit constraints rather than to decisions made without regard for forthcoming information.

Policy Analysis

We tested a variety of policies designed to encourage farmers to remain in coffee production. These policies are aimed at shielding farmers from low prices that otherwise would force abandonment. Extending credit to farmers allows them to weather bad price years, while providing a price floor similarly protects against bad years. Likewise, certification for shade-grown coffee opens farmers to premium markets with higher prices, while agricultural extension services boost the productivities of existing plantations. Another policy involves creating conservation payments for the environmental services provided by shade-grown coffee over alternate land uses.

Intraperiod Credit. Most farmers on average-size coffee farms (5 to 10 hectares) in this region depend on short-term loans during the growing period to cover costs of production and harvesting such as those for hired labor and transportation. Farmers often receive the credit from an intermediary who charges a high monthly interest rate and who stipulates that the farmers must sell the coffee back at a set price after harvest. In the benchmark case, the monthly interest rate is set to 10 percent, a rate typical of the region, and we assume the duration of the loan to be four months. Doubling the monthly interest rate to 20 percent increases the probability of abandonment by Year 20 by 14 percent (Table 8). Halving the interest rate to 5 percent reduces this probability by 5 percent, and an interest rate of 0 percent reduces the probability by 13 percent. These simulations signal that high interest costs on these short-term loans can cause farmers to abandon, and that lower interest rates, such as those found in farmer cooperatives, may markedly decrease the likelihood of abandonment.

Interperiod Credit. In the benchmark case, the farmer does not have access to credit other than the short-term intraperiod loans described above. Providing access to year-to-year credit could prevent the downward cycle toward abandonment by enabling farmers to perform maintenance in low price years when declining prices otherwise would force them to forgo such activities to seek wage employment. After the collapse of the Mexican Coffee Institute (INMECAFE) in 1989, little of this type of interperiod credit is available in our study region. We estimated three levels of credit availability: low, equal to about 25 percent of annual subsistence needs; mid, equal to about 50 percent of subsistence needs, and high, equal (approximately) to subsistence. In the low-credit scenario, the probability of abandonment is reduced by the tenth year by 30 percent and by the twentieth year by 21 percent (Table 9). Doubling available credit reduces the probability of abandonment in Year 20 by 46 percent, and doubling the credit limit again reduces abandonment by 74 percent. Clearly, access to credit enables farmers to overcome subsistence constraints and thus prevent themselves from sliding toward abandonment.

In the above simulations, however, we made credit available starting in the first period. In practice, such policies are usually implemented only once a problem begins to reveal itself. If the credit is not made available until the fifth or tenth year, the efficacy of all three credit scenarios decreases dramatically. In the low-credit case, making the credit available in the tenth period results in only a 5-percent reduction from the baseline in probability of abandonment, compared with a 21-reduction if credit is made available in the first period. The efficacy of the middle-credit case is reduced from a 42-percent reduction in probability of abandonment to 6 percent, and the effect of the high-credit case drops from an 80-percent reduction to just 11 percent.

The timing of the credit policy is important for determining its effectiveness. If policy makers wait until farmers begin to abandon before implementing a credit program, yield levels may be too far depressed to enable farmers to remain in coffee production. The credit program has a much larger impact when implemented at a time when it enables farmers to avoid the beginning of the downward cycle of low maintenance and depressed yields rather than when implemented at the outward crisis point of abandonment.

Price Premium. In some areas, although rarely in our study region, certification of green coffee practices enables farmers to receive a price premium for their shade-grown, organic, or bird-friendly coffee of 5 percent to 15 percent above noncertified coffee. In our simulations, price premiums of 5 percent and 15 percent of the mean price reduce the probability of abandonment by Year 20 by 24 percent and 74 percent, respectively (Table 10, top). These policies essentially shift upwards the entire path of price draws, which has two significant effects. First, low prices that otherwise would have resulted in forgone maintenance are increased enough that farmers can afford to perform maintenance and still meet subsistence. Second, the price increase also provides enough additional profit to make it easier for farmers to return to HM after time in HO, thereby preventing the slide toward abandonment. Probability of eventual abandonment increases with delays in policy implementation, however. If premiums are implemented in the fifth year, the probability of eventual abandonment is 65 percent and 48 percent for 5-percent and 15-percent price premiums, respectively, while immediate implementation results in abandonment probabilities of 53 percent and 18 percent, respectively. Once yields are low due to years of forgone maintenance, the price premium policy is much less effective in stemming abandonment.

This analysis assumes that the price premium is available at no cost, but in reality, the certification process has significant associated costs. In addition to fees for certification, labeling, and other services charged by certifying bodies, such as the Organic Crop Improvement Association (OCIA), farmers must pay the Certificadora Mexicana de Productos y Procesos Ecológicos (CERTIMEX), the main certifying agent in our study area, for annual or biannual inspections. These certification fees include costs for travel, report writing, and translation. Farmers might also have to change on-farm processes if certification inspections indicate that they are out of compliance. In our analysis, we introduce three years of certification costs prior to the price premium at the conservative estimate of 1,000 pesos per hectare per year, based on Universidad del Mar (UMAR) researchers' analysis of data from OCIA and CERTIMEX. These costs put additional price pressure on farmers in those three years and thus reduce the efficacy of the price premium policy by as much as 9 percent (Table 10, bottom). Without certification costs, a 15-percent price premium initiated in Year 5 (to allow for the three-year certification period) results in a 31-percent reduction in probability of abandonment by Year 20; with certification costs, there is only a 22-percent reduction.

Price Floor. A policy that creates a coffee price floor limits the farmer's exposure to bad-price years. Mexico has such a policy in place, although farmers must file paperwork and work with registered buyers to qualify. This price floor is about 675 pesos per quintal of pergamino, which is well within the benchmark price distribution. In our analysis, a price floor at this level (10 percent below the mean price) reduces abandonment completely if initiated in the first period (Table 11). A lower price floor of 625 (17 percent below mean price) reduces the probability of abandonment by 47 percent by Year 20 and prevents any abandonment in the first six years. Again, a price floor established in Year 5 or Year 10 has a much more limited impact on abandonment (Table 11), with a particularly striking difference in the efficacy of the higher price floor. In scenarios in which price floors are implemented in later years, farmers drive yields down through lack of maintenance in the years prior to the policy, and the policies cannot help them recover; yields are already driven too low to prevent abandonment over time.

Agricultural Extension. Agricultural extension activities operate on the productivity of the plantations. In our analysis, a policy that increases the underlying productivity of the plantation by approximately 11 percent dramatically reduces the probability of abandonment by 63 percent over 20 years, from a 70- to a 26-percent probability of abandonment (Table 12). This policy increases yields, and thus income, and alters the probability of abandonment in two ways. First, higher yields and income mean farmers do not need to forgo maintenance as often. Second, when farmers do forgo maintenance, their yields are not depressed to as low a level as without the policy's yield boost. As with the price and credit policies, however, waiting until the fifth year to implement the policy halves its effectiveness in reducing abandonment because, for some farmers, yields are already low.[7]

Conservation Payments. Mexico has recently announced a conservation program for forested land in which the government will give landowners annual payments of about 400 pesos

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[7] There is generally a two- to five-year lag from the time when agricultural extension staff initiate activities before farmers realize substantial increases to yield

per hectare to maintain forest cover. In our simulations, farmers receive these payments so long as they choose to harvest. Under such a policy initiated in Year 1, the probability of abandonment by Year 20 is reduced markedly, by nearly 50 percent (Table 13). Waiting until Year 5 to enact the policy reduces the efficacy of the policy by more than half, resulting in only 19-percent fewer iterations resulting in abandonment. Conservation payment policies are generally time limited, however. If conservation payments are provided for only five years starting in Year 1, the probability of abandonment by Year 20 is reduced only by 21 percent compared with the benchmark.

Discussion of Policy Analysis

The results that we present here derive from a stylized decision model of a farmer that is parameterized to a typical farmer in the region, though heterogeneity in farm characteristics (size, yield, wealth, labor, access to transportation and credit) and site-specific situations will likely affect the efficacy of any chosen policy. Nonetheless, the results of analyses do provide some general guidance to policy for promoting shade-grown coffee where traditional farmers already use this production process. Any policy that enables shade-grown coffee farmers to meet subsistence more easily will slow abandonment.

The first lesson of this policy analysis is that timing is everything. In shade-coffee plantations, the decision to abandon is rarely the result of a single year of low yield or prices. The downward cycle of low income, forgone maintenance, and declining yields usually lasts numerous years before abandonment is necessary, but the longer a farmer stays in this cycle, the less likely it becomes that the farmer will ever recover. This strong pressure implies that policies enacted near the end of the downward cycle will have little impact on rates of abandonment, whereas policies enacted as farmers begin to forgo maintenance will have greater impact.

Timing issues aside, the choice between policies may largely be one of cost effectiveness. The analysis here provides only limited information about the costs of simulated policies, but some comparisons are possible. First, price floor policies are more cost effective than price premium policies because price floors only kick in during bad-price years. A price floor of 10 percent below mean price that is initiated in Year 1 reduces abandonment by 100 percent and costs approximately 15,000 pesos (real 2,000 pesos, discounted at 5 percent) per farmer over the twenty-year period, whereas a price premium of 15 percent over mean price initiated in Year 1 reduces abandonment by 74 percent at a cost of around 40,000 pesos per farmer. These two policies, however, differ substantially in who bears the costs: A price floor policy imposes costs on the government, whereas the price premium policy passes costs on to the consumers of certified coffee. It is more difficult to compare costs of price and credit policies, but credit policies may be more cost effective because farmers must pay back the loans, with interest. In our analysis, credit policies have no interest rates and no time constraints on payback, so it is not surprising that they cost much less than price polices per percent reduction in rate of abandonment. Credit policies, however, cannot achieve the same sized reductions as price policies except at very high, and unreasonable, credit limits. The cost effectiveness of conservation payments ranges between that of price floor and price premium policies, and puts the cost burden on the nongovernmental organization (NGO) or government agency that values those public goods. We do not have reliable data on the costs of agricultural extension policies—which may include a wide variety of activities, such as planting additional crops, introducing pesticides or fertilizer, initiating education or information dissemination programs, or training managers—so we cannot reasonably estimate their cost effectiveness.

Beyond cost effectiveness, the success of a policy may lie in which subgroups of farmers benefit. Our surveys of farmers in coastal Oaxaca provide some information about which farmers have access to particular policies. For example, our discussions revealed that coffee farmers who belong to cooperative organizations—approximately 55 percent of the coffee farmers in this region belong to cooperatives—have better access to intra- and interperiod credit and to agricultural extension activities than do other farmers. The effectiveness of introducing these types of policies, then, relies on ensuring that farmers outside cooperatives have access to these programs or are encouraged to participate in a cooperative organization. Similarly, Mexico's current price floor policy requires that farmers fill out various forms and agree to sell to registered buyers in order to receive the minimum price. Farmers who do not belong to cooperatives, do not speak or read Spanish (estimated to be 7 percent of the region's farmers), or who live in areas far from coffee marketing towns have reduced access to these papers and buyers, and therefore often do not benefit from the price floor. Likewise, there are language, access, and credit barriers to farmers benefiting from agricultural extension policies. Although the region has few examples of green certification for the price premium and the conservation payments have not yet begun, the effectiveness of these policies could also be limited by similar issues of access, particularly for farmers who are poorer, less well educated, indigenous, or who are located in more remote regions.

Further Policy Analysis: Joint Implementation

These issues of which farmers will have access to the benefits of particular policies or programs mean that the policies can only be effective to the extent that farmers can participate.

For example, despite its appeal, a price premium policy can only offer benefits to farmers, and therefore can only slow abandonment, if farmers can overcome the large costs associated with certifying their coffee plantation as shade grown, organic, or bird friendly. Farmers who participate in cooperative organizations may face lower certification costs due to access to markets and credit. To reach other farmers, the region could implement a price premium policy at the same time as a price floor to enable farmers to incur a few years of certification costs and weather bad-price years prior to being able to capture the price premium. We ran simulations for joint policies in which we implemented combinations of programs to overcome multiple barriers and aid a greater number of farmers.

As discussed previously, 44 percent of the farmers who face three years of certification costs prior to a price premium of 15 percent starting in Year 5 abandon by Year 10, and 55 percent of these farmers abandon by Year 20. The case in which certification costs are zero is equivalent to a policy in which the government pays for certification; even in this case, discussed previously, 42 percent of the farmers abandon by Year 10 and 48 percent of them abandon by Year 20. In contrast, only 17 percent of the farmers with access to a joint policy involving a price floor in the certification years prior to the price premium abandons by Year 10 and 25 percent of these farmers abandon by Year 20 (Table 14, top left). If in addition to the price floor the farmer also has access to some interperiod credit and a lower interest rate for short-term intraperiod loans, only 2 percent of the farmers abandon by Year 10 and 3 percent of them abandon by Year 20 (Table 14, top right). As with individual policies, if the government waits to implement joint policies for five years results in much lower reductions in abandonment (Table 14, bottom).

In practice, implementing a policy alone can decrease its effectiveness, because some farmers face constraints that make the policy inaccessible to them. In addition, there may be a lag between costs and benefits; costs of green certification occur before farmers realize higher prices, and it may take several years before agricultural extension or maintenance activities result in higher productivity. Eliminating or reducing barriers to accessibility, as well as providing credit or price supports during the lag years between investment and pay off, will increase effectiveness of policies. Indeed, policies may flounder without these additional supports.

Case Study: Price Declines in Coastal Oaxaca

Anecdotal and Landsat image analyses demonstrate that some forest cover in Mexico's shade-grown coffee region has declined in the last fifteen years, and that high levels of coffee abandonment leave many forests vulnerable (Blackman et al. 2004). Farmers report that much of the conversion or the abandonment of coffee production is due to the precipitous decline in international coffee prices during the 1990s. In addition, Mexico's coffee marketing board, INMECAFE, closed in 1989 after years of providing price floors and low-cost credit to many coffee farmers. The model developed here can be used to examine how a typical farmer might have responded to these changes in the coffee market and to investigate what issues confront implementation of policies intended to stem abandonment.

We examine a typical shade-grown coffee farmer's decisions over the last 15 years (1989 through 2003) based on actual prices (Figure 1), and then project the farmer forward an additional 5 years using the average price of 2000–2003. Based on interviews, farmers appear to fall loosely into several groups in terms of how they formed price expectations during this period (1989 through 2003). First, although no farmers reported that they failed eventually to recognize that the international and Mexican coffee markets had fundamentally changed, we consider a "price regime–unaware" farmer who expects prices in the 1990s to be drawn from a distribution similar to that seen previous to 1989 (Table 15, column 1). With actual prices somewhat lower than expected, the farmer performs maintenance activities in 12 of the first 13 years, then stops performing maintenance in 2002, embarking on a 6 year slide toward abandonment.

The second type of farmer is the "price regime–aware" farmer—who recognizes that a price regime change has occurred, and bases expectations of prices on a distribution with a consequently lower mean. This farmer forgoes maintenance in 1992 due to the low price, but otherwise performs maintenance through 2001 (Table 15, column 2). The farmer forgoes maintenance in 2002, starting the downward cycle and abandoning in 2007, one year earlier than the "price regime–unaware" farmer. In some cases, farmers may take several years to recognize a price regime change, but even a lag of 10 years does not create a difference in farmer decisions compared with the price regime–aware farmer who recognizes the regime change immediately. For farmers at this level of yield, wealth, and available credit, the expectations of future prices do not drive many decisions at the margin.

A third type of farmer uses a three-year running average of the current and 2 prior years of prices to forecast prices over time, as in the sensitivity analyses described previously. The "Bayesian average price" farmer performs maintenance in 10 of the first 12 years, forgoes maintenance in 2001, and abandons in 2002 (Table 15, column 5). Both the price regime–unaware farmer and the Bayesian average farmer bounce back from one year of HO following the low price in 1992, but neither is able to bounce back from the low prices in the early 2000s.

A fourth type of farmer reported that they viewed prices to be dropping, on average, over the period. These "price trend–aware" farmers performed maintenance activities for 11 of the first 12 years, but did not perform maintenance activities in or after 2001, resulting in a projected abandonment date of 2005 (Table 15, column 6). Again, a lag in recognizing that prices are declining—even a lag of 10 years—does not lead to differences in farming activities. The duration of the downward cycle is only four years for these farmers (contrasted to five years for price regime–aware farmers), as their expectations of prices beyond 2003 continue to drop below tenable levels.

In addition to differences in how farmers form price expectations, farms in this region vary in levels of productivity. Regardless of how a farmer forms price expectations, if the starting yield in 1989 is lower than in the benchmark, the farmer will abandon earlier. In these cases (Table 15, columns 9–16), having a long lag before recognizing the price regime change encourages farmers to perform maintenance in more periods, but all farmers abandon by 2004. Conversely, farmers with better yielding farms can weather bad-price years more easily and do not enter a slide toward abandonment in late periods. In addition, farmers with access to wealth or credit are more likely to continue to perform maintenance activities at the prices seen during the last 15 years.

The fact that so many farmers at relevant yield levels have begun to forgo maintenance activities in recent years in these simulations signals that the cumulative impact of low prices has led these farmers into a downward cycle moving toward abandonment. To the extent that our interviews and data collection have enabled us to characterize a typical farmer in the region, and given the earlier policy analysis discussion regarding the importance of the timing of policies, these stylized results using actual prices suggest that there may be very few years left to implement policies to stem abandonment—at least within an important subgroup of farmers—of shade-grown coffee production in Oaxaca’s Sierra Sur y Costa.

Conclusion

Many groups seek to support the production of shade-grown coffee both to improve the welfare of impoverished traditional shade-grown coffee farmers and to ensure that this land use continues, because it protects species and provides environmental services. Despite the intuitive appeal of, and large push by NGOs for, developing policies that allow shade-grown coffee farmers to capture some value for the public goods this land use provides, very little is known about how traditional shade-grown coffee farmers make decisions and, therefore, how they will respond to any type of policy. Because many such farmers appear to have responded to recent falls in coffee prices by abandoning this production system, understanding that abandonment decision and its response to various policies has become a timely issue.

This paper develops a model of farmer decisions, based on observations and interviews with farmers in coastal Oaxaca; the model elucidates the farmer's decisions about when to abandon shade-coffee production. The typical farmer faces subsistence and credit constraints that force him to work in towns and forgo important maintenance activities on the coffee plantation during low price years. Because forgoing maintenance drives future yields down, this farmer faces increased price pressure in future years and therefore finds it even more difficult to perform maintenance. The farmer may be forced to forgo maintenance year after year, until yields are driven so low that the farmer decides to abandon shade-coffee production altogether.

The policy analysis presented here suggests that policies that enable farmers to perform maintenance activities during bad-price years can effectively stem abandonment. The analysis stresses, however, that such policies are much more effective when implemented before farmers forgo maintenance than when they are implemented when abandonment is imminent. Timing is critical. Anecdotal information and simulations of decisions under recent historical prices suggest that many farmers have already begun the slide toward abandonment; rapid policy intervention is required to stop and reverse this slide. Furthermore, observations of the Oaxaca setting and our simulations indicate that implementing policies jointly improves the effectiveness of policies by reaching more farmers and by enabling farmers to incur the costs of investment that may be required to take advantage of some policies. Poor farmers, indigenous farmers, and farmers who are not members of cooperatives have limited abilities to respond to policy incentives unless multiple policies combine to address their joint issues of credit, subsistence, logistal concerns, and language barriers.

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Figures and Tables

Table 1. Key Model Parameters for Benchmark Farmer

Variable	*Description*	*Value*
YEARSOUT	Years forward looking	10
PSTART	Mean of coffee price distribution (pesos)	750
PVAR	Standard deviation of coffee price dist (pesos)	250
PSLOPE	Declining slope of coffee price dist (pesos/year)	0
PRICEDIST	Type of price distribution	Normal
DISCRATE	Discount rate	5%
FSIZE	Farm size (hectares)	5
BIORATE	Biomass growth factor	0.075
BIOMULT	Rate of biomass decline as multiple of growth	5
STARTPCTBIO	Starting biomass as percent of maximum	70%
YIELDRATE	Initial yield rate (quintals of pergamino/hectare)	6.1
STARTYIELD	Initial total yield (quintals of pergamino)	30.5
STARTMASS	Initial biomass (Yield = 10% of biomass)	305
BIOMAX	Maximum biomass	436
CREDIT_ANN	Annual available interperiod credit (pesos)	0
CREDIT_TOT	Total available interperiod credit (pesos)	0
MIDINTEREST	Intraperiod credit monthly interest rate (harvest costs)	10%
PCTSAVINGS	Savings rate (percent of income over subsistence)	10%
STARTWEALTH	Initial accumulated wealth (pesos)	500
TLABOR_F	Total annual available farmer labor (work days)	190
HLABOR_F	Farmer labor used for harvest (work days)	150
MLABOR_F	Farmer labor used for maintenance (work days)	40
HLAB_PH	Labor required to harvest (work days/hectare)	35
MLAB_PH	Labor required to maintain (work days/hectare)	34
WAGE_ON	Wage rate for hired on-farm labor (pesos/work day)	60
WAGE_OFF	Wage rate for off-farm labor (adjusted) (pesos/work day)	53
NONLABOR_H	Nonlabor costs for harvesting (pesos/hectare)	61
NONLABOR_M	Nonlabor costs for maintenance (pesos/hectare)	165
SUBSISTENCE	Subsistence	9970

Table 2. Cumulative Probability of Coffee Abandonment by Benchmark Farmer, by Year

Year	*Probability of abandonment*	*Year*	*Probability of abandonment*
1	0%	11	55%
2	5%	12	57%
3	10%	13	58%
4	12%	14	59%
5	15%	15	64%
6	21%	16	65%
7	29%	17	66%
8	39%	18	66%
9	45%	19	67%
10	51%	20	70%

Table 3. Sensitivity Analysis Results: Price Variability

	Benchmark	*High variability*	*Mid-high variability*	*Mid-low variability*	*Low variability*
Price mean	750	750	750	750	750
Price standard deviation	250	450	350	150	50
Probability of abandonment					
... by Year 10	51%	78% (54%)	67% (32%)	28% (–45%)	3% (–95%)
... by Year 15	64%	89% (39%)	79% (23%)	36% (–44%)	3% (–96%)
... by Year 20	70%	95% (35%)	83% (19%)	37% (–47%)	3% (–96%)

Note: In Tables 3 to 9 the percent difference in the probability of abandonment between each run and the benchmark run is reported in parentheses, as a percentage of the benchmark probability.

Table 4. Sensitivity Analysis Results: Price Expectations

	Benchmark	*Bayesian price expectations*	
Probability of abandonment			
... by Year 10	51%	56%	(11%)
... by Year 15	64%	73%	(14%)
... by Year 20	70%	79%	(13%)

Table 5. Sensitivity Analysis Results: Discount Rate

	Benchmark	*No discount rate*		*High discount rate*		*Very high discount rate*	
Discount rate	5%	0%		10%		20%	
Probability of abandonment							
... by Year 10	51%	47%	(–8%)	51%	(0%)	100%	(97%)
... by Year 15	64%	61%	(–4%)	64%	(0%)	100%	(56%)
... by Year 20	70%	68%	(–3%)	70%	(0%)	100%	(43%)

Table 6. Sensitivity Analysis Results: Yield Curve

	Benchmark	*Maximum biomass* 20% lower maximum	*Maximum biomass* 20% higher maximum	*Rate-of-growth parameter* 33% lower rate	*Rate-of-growth parameter* 33% higher rate	*Rate-of-decline multiplier* 33% lower multiplier	*Rate-of-decline multiplier* 33% higher multiplier
Starting yield (quintals)	30.500	30.500	30.500	30.500	30.500	30.500	30.500
Maximum yield	43.571	34.857	52.286	43.571	43.571	43.571	43.571
Growth rate parameter	0.075	0.075	0.075	0.050	0.100	0.075	0.075
Decline rate multiplier	5.000	5.000	5.000	5.000	5.000	3.333	6.667
Probability of abandonment							
... by Year 10	51%	25% (–50%)	61% (21%)	34% (–33%)	54% (7%)	27% (–47%)	64% (26%)
... by Year 15	64%	47% (–26%)	68% (6%)	57% (–10%)	62% (–3%)	43% (–33%)	76% (19%)
... by Year 20	70%	63% (–10%)	73% (4%)	69% (–2%)	65% (–7%)	52% (–26%)	81% (16%)

Table 7. Sensitivity Analysis Results: Constraints and Open-Loop Decision Rule

	Benchmark	*No subsistence constraint*	*No credit constraint*	*Open-loop decision rule*
Probability of abandonment				
... by Year 10	51%	1% (–99%)	0% (–100%)	49% (–3%)
... by Year 15	64%	1% (–99%)	0% (–100%)	63% (–1%)
... by Year 20	70%	11% (–85%)	0% (–100%)	70% (0%)

Table 8. Policy Analysis Results: Lowering Short-Term Intraperiod Interest Rates

	Benchmark	*No interest rate*	*Low interest rate*	*High interest rate*
Monthly interest rate	10%	0%	5%	20%
Probability of abandonment				
... by Year 10	51%	44% (–13%)	47% (–7%)	62% (22%)
... by Year 15	64%	56% (–13%)	60% (–6%)	73% (15%)
... by Year 20	70%	61% (–13%)	67% (–5%)	80% (14%)

Table 9. Policy Analysis Results: Access to Interperiod Credit

	Benchmark	*Low credit*			*Middle credit*			*High credit*		
Credit limit (pesos)		2,500			5,000			10,000		
Year policy start		1	5	10	1	5	10	1	5	10
Probability of abandonment										
... by Year 10	51%	35% (–30%)	49% (–3%)	51% (0%)	23% (–55%)	48% (–7%)	51% (0%)	8% (–84%)	47% (–8%)	51% (0%)
... by Year 15	64%	49% (–24%)	60% (–6%)	63% (–2%)	34% (–47%)	55% (–14%)	61% (–4%)	10% (–84%)	51% (–21%)	60% (–6%)
... by Year 20	70%	55% (–21%)	65% (–8%)	67% (–5%)	41% (–42%)	61% (–12%)	66% (–6%)	14% (–80%)	54% (–23%)	62% (–11%)

Table 10. Policy Analysis Results: Access to Price Premiums, with and without Certification Costs

	Benchmark	*5% price premium, NO certification costs*			*15% price premium, NO certification costs*		
Price premium (pesos)		37.5	37.5	37.5	112.5	112.5	112.5
Year of policy start		1	5	10	1	5	10
Probability of abandonment							
... by Year 10	51%	33% (–36%)	47% (–7%)	51% (0%)	13% (–75%)	42% (–17%)	51% (0%)
... by Year 15	64%	46% (–28%)	58% (–9%)	59% (–8%)	16% (–75%)	47% (–26%)	57% (–10%)
... by Year 20	70%	53% (–24%)	65% (–8%)	65% (–7%)	18% (–74%)	48% (–31%)	62% (–11%)
	Benchmark	*5% price premium, WITH 3 yrs of certification costs*			*15% price premium, WITH 3 yrs of certification costs*		
Price premium (pesos)			37.5	37.5		112.5	112.5
Year of policy start			5	10		5	10
Probability of abandonment							
... by Year 10	51%		50% (–1%)	53% (5%)		44% (–13%)	53% (5%)
... by Year 15	64%		63% (–2%)	62% (–3%)		53% (–17%)	59% (–8%)
... by Year 20	70%		67% (–5%)	68% (–3%)		55% (–22%)	65% (–8%)

Note: Certification costs precede access to premium prices, so if such costs are incurred, the price premium policy cannot start in Year 1.

Table 11. Policy Analysis Results: Access to Price Floor

	Benchmark	*Low-price floor*			*High-price floor*		
Price floor (pesos)		625.0	625.0	625.0	675.0	675.0	675.0
Year of policy start		1	5	10	1	5	10
Probability of abandonment							
... by Year 10	51%	32% (–37%)	46% (–9%)	51% (0%)	0% (–100%)	45% (–11%)	51% (0%)
... by Year 15	64%	37% (–42%)	49% (–23%)	59% (–7%)	0% (–100%)	47% (–27%)	59% (–7%)
... by Year 20	70%	37% (–47%)	50% (–29%)	61% (–12%)	0% (–100%)	47% (–33%)	60% (–14%)

Table 12. Policy Analysis Results: Agricultural Extension to Increase Productivity

	Benchmark	*11% increase in biomass (and yield)*			*22% increase in biomass (and yield)*		
Year of policy start		1	5	10	1	5	10
Probability of abandonment							
... by Year 10	51%	16% (–68%)	39% (–22%)	51% (0%)	7% (–87%)	27% (–47%)	51% (0%)
... by Year 15	64%	23% (–64%)	47% (–26%)	57% (–10%)	9% (–86%)	34% (–47%)	55% (–14%)
... by Year 20	70%	26% (–63%)	50% (–29%)	65% (–8%)	10% (–86%)	37% (–48%)	56% (–20%)

Table 13. Policy Analysis Results: Conservation Payments for Providing Forest Cover

	Benchmark	*Indefinite policy duration*		*Five-year policy duration*	
Size of payment (pesos/ha)		400	400	400	400
Year of policy start		1	5	1	5
Probability of abandonment					
... by Year 10	51%	25% (–51%)	43% (–14%)	35% (–32%)	43% (–14%)
... by Year 15	64%	33% (–49%)	51% (–20%)	48% (–25%)	56% (–13%)
... by Year 20	70%	36% (–49%)	57% (–19%)	55% (–21%)	61% (–12%)

Table 14. Policy Analysis Results: Joint Implementation of Price and Credit Policies, Varying the Size of Price Premiums and Year of Policy Implementation

Immediate implementation	*Benchmark*	*Price floor, price premium, no changes to credit*				*Price floor, price premium, inter- and intraperiod credit*			
Price floor (pesos)		675		675		675		675	
Price premium (pesos)		37.5		112.5		37.5		112.5	
Interperiod credit (pesos)	0	0		0		2,500		2,500	
Intraperiod credit rate	10%	10%		10%		5%		5%	
Year price floor starts		1		1		1		1	
Year price premium starts		5		5		5		5	
Probability of abandonment									
... by Year 10	51%	22%	(–57%)	17%	(–67%)	5%	(–89%)	1%	(–97%)
... by Year 15	64%	39%	(–39%)	21%	(–67%)	11%	(–82%)	2%	(–97%)
... by Year 20	70%	45%	(–35%)	25%	(–65%)	15%	(–78%)	3%	(–96%)
Five-year lag	*Benchmark*	*Price floor, price premium, no changes to credit*				*Price floor, price premium, inter- and intraperiod credit*			
Price floor (pesos)		675		675		675		675	
Price premium (pesos)		37.5		112.5		37.5		112.5	
Interperiod credit (pesos)	0	0		0		2,500		2,500	
Intraperiod credit rate	10%	10%		10%		5%		5%	
Year price floor starts		5		5		5		5	
Year price premium starts		10		10		10		10	
Probability of abandonment									
... by Year 10	51%	47%	(–8%)	47%	(–8%)	29%	(–43%)	29%	(–43%)
... by Year 15	64%	50%	(–22%)	48%	(–25%)	30%	(–53%)	29%	(–55%)
... by Year 20	70%	53%	(–24%)	49%	(–30%)	31%	(–55%)	29%	(–59%)

Figure 1. Historical Coffee Prices for Oaxaca, Mexico, 1989–2003

Note: 2000 pesos/quintal of pergamino.

Table 15. Case Study on Historical Prices: Farmer Decisions under Different Modes of Forming Price Expectations and with Different Starting Yields

	Benchmark yield								*Lower yield*							
	Price regime–unaware	*Price regime–aware*			*Recent average*	*Price trend–aware*			*Price regime–unaware*	*Price regime–aware*			*Recent average*	*Price trend–aware*		
Lag (years)		0	5	10		0	5	10		0	5	10		0	5	10
Decision in																
Year 1 (1989)	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM
Year 2 (1990)	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM
Year 3 (1991)	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM	HM
Year 4 (1992)	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO	HO
Year 5 (1993)	HM	HM	HM	HM	HM	HM	HM	HM	HO	HO	HO	HO	HO	HO	HO	HO
Year 6 (1994)	HM	HM	HM	HM	HO	HM	HM	HM	HM	HO	HM	HM	HO	HM	HM	HM
Year 7 (1995)	HM	HM	HM	HM	HM	HM	HM	HM	HM	HO	HO	HM	HO	HM	HM	HM
Year 8 (1996)	HM	HM	HM	HM	HM	HM	HM	HM	HM	HO	HO	HM	HO	HM	HM	HM
Year 9 (1997)	HM	HM	HM	HM	HM	HM	HM	HM	HM	HO	HO	HM	HO	HM	HM	HM
Year 10 (1998)	HM	HM	HM	HM	HM	HM	HM	HM	HM	A	A	HM	A	HM	HM	HM
Year 11 (1999)	HM	HM	HM	HM	HM	HM	HM	HM	HM	A	A	HM	A	HO	HO	HM
Year 12 (2000)	HM	HM	HM	HM	HM	HM	HM	HM	HM	A	A	HM	A	HO	HO	HO
Year 13 (2001)	HM	HM	HM	HM	HO	HO	HO	HO	HO	A	A	HO	A	HO	HO	HO
Year 14 (2002)	HO	HO	HO	HO	A	HO	HO	HO	HO	A	A	HO	A	A	A	A
Year 15 (2003)	HO	HO	HO	HO	A	HO	HO	HO	HO	A	A	HO	A	A	A	A
Year 16 (2004)	HO	HO	HO	HO	A	HO	HO	HO	A	A	A	A	A	A	A	A
Year 17 (2005)	HO	HO	HO	HO	A	A	A	A	A	A	A	A	A	A	A	A
Year 18 (2006)	HO	HO	HO	HO	A	A	A	A	A	A	A	A	A	A	A	A
Year 19 (2007)	HO	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Year 20 (2008)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

HM = “harvest and maintain,” HO = “harvest only,” A = “abandon plantation.

Appendix A. Sensitivity Analysis on Performance Parameters

This appendix discusses model simulations run on two key model performance parameters—the number of Monte Carlo iterations used in each simulation, and the number of years that the model farmer is forward-looking. Model performance improves by increasing both of these parameters, but so does the time it takes for the model to run; we performed sensitivity analyses to find an appropriate balance between model accuracy and computational cost.

For the simulations discussed in the main body of this paper, we ran 150 Monte Carlo iterations (representing 150 different randomly drawn price series) for a stylized farmer who incorporates 10 future years of expected values into decisions. Increasing these two parameters beyond these values effected minor changes in results, but took appreciably longer to run.

Holding all other variables constant, run time increases linearly with the number of iterations, as each iteration takes roughly the same amount of time to run (there is some variation due to variation in price series). Simulations with fewer than 100 iterations generate results that, although following the same general patterns as the benchmark with 150 iterations, differ substantially in magnitudes. For example, a simulation with only 20 iterations results in an increase in the probability of abandonment in Year 20 by 7 percent, compared with the benchmark (Table A1). Increasing the number of iterations beyond 150, however, neither generates qualitative nor large quantitative differences in outcomes; the probability of abandonment is within 5 percent of the benchmark in every year. For example, a simulation with 200 iterations results in a 1-percent deviation from benchmark results for Year 20, but takes nearly thirty minutes longer to run. This 29-percent increase in resource costs did not warrant the small improvement in accuracy of the benchmark and we chose 150 iterations for the benchmark.

The computational costs of increasing the number of years forward-looking are even larger than those for increasing the number of iterations, because the computation of future expectations uses a recursive routine that traverses the branches of a decision tree. In this decision tree, each node represents a decision period, and each branch from that node represents a different decision (HM, HO, or A); the node at that end of each branch represents another decision period, and so on. How far into the future this tree goes depends on the number of years that the farmer is forward-looking. Increasing another year adds another set of branches to each end node of each possible decision pathway. Although there are three possible farmer decisions, because abandonment is a trapping state the number of possible branches in the decision tree approaches 2^y, where y is the number of years forward-looking. As shown in Table A2, the benchmark case of 10 years forward-looking results in a per-iteration run-time of about 30 seconds. Decreasing this parameter to 5 years results in an iteration run time of 1 second, whereas increasing to 11 years requires a full minute per iteration. Although the five-year future window returned results nearly identical to those of the benchmark simulation, we wanted to ensure that we included enough future information in current decisions in simulations that were not identical to the benchmark case, such as the various policy scenarios in which the future may matter more or less than in the benchmark. A simulation of a farmer who is 15 years forward-looking, however, takes over 44 hours to run, compared with the hour and twenty minutes for a farmer who is 10 years forward-looking, and results in absolutely no change in farmer decisions.

Appendix B. Spiral: A MATLAB Simulation Model

We programmed the simulations described in this paper in MATLAB, a mathematical software application. Because of price uncertainty that is resolved in each period, we used a recursive method to compute the net present value of expected future earnings due to present and future decisions. The mental model is that of a decision tree, in which each branch is a decision leading to a future period. In any period (in which a farmer has not already abandoned), a farmer has three options—HM, HO, or A—and therefore the tree begins with three branches. Each HM and HO branch has these same three decision branches, whereas each A branch has only a single branch to A (because abandonment is a trapping state). Biomass grows and declines, according to a logistic growth function, along the branches of the decision tree, based on harvest and maintenance decisions. As biomass (along with farmers' expectations of future prices) defines present value of expected income, the present value of any branch is dependent on a likelihood weighting of all stemming (future) branches. Thus, the model propagates biomass growth and decline along the branches until it reaches the final leaves, which are defined by the degree to which the farmer is forward-looking. Thus, if a farmer is *n*-years forward-looking, the model propagates out to the *n*th branch, computes the present value of the leaves, recurses back to the (*n*–1)th branch, computes present value of that branch (which includes the present value of the *n*th branch), recurses back to the (*n*–2)th branch, and so on, until the model has recursed back to the decision period. [8]

[8] We did not include the programs used in the simulation model with this paper due to their length; they are available from the authors in print or electronic format, on request.

Appendix Tables

Table A1. Sensitivity Analysis: Number of Iterations

	Benchmark	*Low iterations*	*High iterations*
Years forward-looking	10	10	10
Iterations	150	20	200
Total run time (hh:mm:ss)	1:21:56	0:17:36	1:45:48
Average run time per iteration (m:ss)	0:33	0:53	0:32
Probability of abandonment			
... by Year 10	51%	60% (18%)	53% (5%)
... by Year 15	64%	75% (17%)	67% (4%)
... by Year 20	70%	75% (7%)	71% (1%)

Table A2. Sensitivity Analysis: Number of Years Forward-Looking

		Number of years forward-looking			
	Benchmark	*Much lower*	*Lower*	*Higher*	*Much higher*
Years forward-looking	10	1	5	11	15
Iterations	150	150	150	150	150
Total run-time (hh:mm:ss)	1:21:56	0:00:06	0:02:39	2:47:11	44:12:36
Average run-time per iteration (m:ss)	0:33	0:00	0:01	1:07	17:41
Probability of abandonment					
... by Year 10	51%	100% (–97%)	51% (0%)	51% (0%)	51% (0%)
... by Year 15	64%	100% (–56%)	64% (0%)	64% (0%)	64% (0%)
... by Year 20	70%	100% (–43%)	70% (0%)	70% (0%)	70% (0%)