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THE PRICE RESPONSIVENESS OF SÃO PAULO COFFEE GROWERS†

In this paper I describe the relationship between coffee prices and the number of coffee trees in the Brazilian state of São Paulo. From the end of the nineteenth century until the late 1950's, São Paulo was the largest coffee-producing region in the world; the data on coffee cultivation collected by the state government during the latter part of this period permit the estimation of a three-equation model of the determinants of change in the stock of coffee trees.[1]

São Paulo has been involved in coffee cultivation for more than one and one-half centuries. Coffee was introduced into the Rio de Janeiro portion of the Paraiba Valley in the mid-eighteenth century and its cultivation gradually spread to the surrounding territory; by the end of the eighteenth century coffee cultivation had begun in the São Paulo portion of the valley. In 1890, after a century of expansion, there were approximately 200 million bearing coffee trees in São Paulo; at the turn of the century there were 600 million trees producing coffee in the state. The last decade of the nineteenth century was the period of most rapid growth of the stock of coffee trees; further increases in the following thirty years, however, brought the stock to approximately 1,500 million. The stock of bearing coffee trees shows some decline after 1933, but the statistics on the planting of new coffee trees indicate that planting continued, although at a much lower rate than that which characterized the earlier period.

In Part I of this paper, the factors relevant to coffee tree stock changes in Brazil are discussed and used in the construction of equations for planting, abandonment, and removal of coffee trees in São Paulo. The estimated model and the data on which it is based are discussed in Part II.

PART I

Planting to Achieve a Desired Stock of Trees

Given a set of input and output prices, there is an area which would yield higher (positive) profits in the cultivation of a particular tree crop than in other

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[1] The data on coffee cultivation in Paraná, Minas Gerais, and Espirito Santo is more limited. See my dissertation (*1*) for a description of the simplified models used for these three states.

uses; corresponding to this area, there is a "desired" stock of trees. Were the tree stock at the desired level, there would be no economic rationale for the extension of tree cultivation.

Researchers have not always recognized this point explicitly. In Bateman's original formulation (2), the increase in the stock of cocoa trees, N_t, assumed to be equal to planting, is related to expected cocoa price, p_{1t}, and expected coffee price, p_{2t}:

$$N_t = a_0 + a_1 p_{1t} + a_2 p_{2t} \tag{1}$$

It is hypothesized that $a_1 > 0$ and $a_2 < 0$. Because there is no reference to *level* of the stock of cocoa trees, the implication of the model is unrealistic: the stock will increase *ad infinitum* for any set of coffee and cocoa price expectations which induces farmers to plant new trees in year t, i.e., any set of prices which makes the right-hand side of equation (1) positive.[2]

The French and Bressler equation for planting of new lemon trees in southern California (5), while not explicitly relating planting to tree stock, does so implicitly by using net return instead of price. Their equation relates the new lemon area–bearing lemon area ratio to the average net return per acre of lemon trees and the percentage of lemon tree area cultivated in older trees:

r_t = average net return per acre of lemon trees in year t.

N_t = number of acres of newly planted lemon trees in year t.

B_t = number of acres of bearing lemon trees in year t.

K_t = number of acres of old lemon trees in year t.

$$\frac{N_t}{B_{t-1}} = b_0 + b_1 r_{t-1} + b_2 \frac{K_t}{B_{t-1}} \tag{2}$$

Let π_{t-1} be the expected average net return adjusted for age distribution.[3] Now, consider any lemon price p_0. If more suitable lemon soil is used first, the larger the area planted in lemons the lower will be the average net return per acre of lemons. Of course, for any acreage in bearing trees, average net return would be higher the higher were lemon prices. Mathematically:

$$\pi_t = F(p_t, B_t) \tag{3}$$

$$\frac{\partial \pi}{\partial B} < 0; \ \frac{\partial \pi}{\partial p} > 0 \tag{4}$$

[2] Bateman has since changed his formulation. This mistake has its analogue in field crop supply estimation. Often, the rate of change in area planted is made a function of price. While this may take care of time trends, it does not yield a supply function.

[3] French and Bressler do not give a rationale for the influence of old trees on new planting of lemon trees in California.

Certainly, if old trees have lower yield, the *average* net return per acre will be lower the greater the number of old trees, *ceteris paribus*. The difference between expected return and average return will thus be positively correlated with the percentage of old trees, and a correction factor will be required. The timing of their causal relationship, however, suggests that they did not recognize this.

Given the equilibrium net return per acre of lemons, i.e., the return which leads to neither expansion nor contraction of the lemon sector, π_E, we can calculate the equilibrium level of the tree stock area, B_E, corresponding to any level of lemon prices:

$$B_E = f(p, \pi_E) \tag{5}$$

The relationship between B_E and p will be positive since the higher the p the greater must be the area planted to lemons in order that the net return be at the equilibrium level π_E. The planting mechanism may thus be described as follows: if expected average net return exceeds π_E, farmers plant additional acreage to lemon trees; additional planting raises B_{t-1} and lowers π_{t-1}; planting ceases when $\pi_{t-1} = \pi_E$ and $B_{t-1} = B_E = f(p, \pi_E)$.[4]

My first equation relates the planting of new coffee trees in São Paulo to the existence of available coffee soils. While basically a stock adjustment model, the formulation differs from that commonly used in agricultural supply studies. First, the concept of available "desired" area I use is different. Usually the change in area required to achieve the optimal acreage is expressed as the difference between a price-determined desired acreage, T^*, and the previous year's acreage in the crop, T_{t-1}:

$$T^*_t = f(p_t) \tag{6}$$

$$N^*_t = T^*_t - T_{t-1} \tag{7}$$

where p_t is the level of price expectations and N^*_t is the change required to reach the desired acreage. In the case of Brazilian coffee, acreage becomes "unavailable" when it is planted in coffee; land which previously supported coffee trees cannot generally be reused for coffee.[5] Hence, all land ever used for coffee must be subtracted from T^*_t to obtain desired available coffee areas. For coffee, the area which farmers desire to plant in new coffee trees is expressed as:[6]

[4] This argument is not strictly true given the timing relationships that French and Bressler have selected.

[5] After centuries, natural forces may revitalize depleted soils. While natural replenishment is not yet relevant to Brazilian coffee cultivation, the use of fertilizers may soon be.

[6] There is an alternative way to derive equation (8). Let $X^*_t\ (p)$ be the area desired at time t if expected price is p. With constant p, the desired area would gradually shrink over time as acres of trees are abandoned, A, or removed, R (since replanting is not often feasible):

$$X^*_t\,(p) = X^*_0\,(p) - \sum_0^{t-1} (A_t + R_t)$$

The difference between desired and actual acreage, N^*_t, is:

$$N^*_t = X^*_t\,(p) - T_{t-1}$$

$$= X^*_0\,(p) - \sum_0^{t-1} (A_t + R_t) + T_{t-1}$$

$$\text{But } T_{t-1} = T_0 + \sum_0^{t-1} N_t - \sum_0^{t-1} (A_t + R_t)$$

$$\text{So } N^*_t = X^*_0\,(p) - \left[T_0 + \sum_0^{t-1} N_t \right]$$

Define $T^*_t = X^*_0\,(p_t)$ and substitute to obtain equation (8).

Note that T^*_t is not dependent upon the history of cultivation: it is a "time independent" function of expected price.

$$N^*_t = T^*_t - \sum_{-\infty}^{t-1} N_j \tag{8}$$

where N^*_t is planting required to achieve the optimal coffee area, and N_j is the area planted in new trees in year j.

Second, the adjustment mechanism I assume is more complex. Usually, it is hypothesized that the annual change in acreage under a crop is a fixed fraction of the "desired" change:

$$N_t = \gamma N^*_t \tag{9}$$

where $0 < \gamma < 1$. In São Paulo the main barrier to the immediate expansion of coffee cultivation to the "desired" level was labor. The coffee sector which absorbed a large portion of São Paulo's labor force was not a perfect competitor in the labor market. Future labor costs thus depended significantly upon demand for labor in the coffee sector, *ceteris paribus*. In deciding whether to plant a new tree in year t or in a later year, $t + 1$, the rational farmer would consider, among other things, the probable demand for labor in the two years. The relative number of old trees is used as a proxy for short-run labor cost expectations. When a large per cent of the tree stock is old, it is likely that abandonment of old trees will make labor relatively plentiful in the near future; farmers would, therefore, plant desired areas more quickly when the tree stock is relatively old. Conversely, with a relatively young stock of coffee trees, expectation's of short-run labor cost would be less favorable and farmers would be likely to postpone planting desired trees. I use the per cent of coffee trees over ten years of age as a measure of the agedness of the tree stock.

Specifically, it is assumed that the per cent of trees over ten, D_t, affects planting decisions in two ways. First, the speed with which available desired areas are planted to coffee is proportional to the percentage of trees which are old. Second, there is additional impetus to planting (providing suitable land is available) if the tree stock is relatively old, i.e., if $D_t > \lambda$. The equation for new planting is thus:

$$N_t = \gamma_1 D_t \left[T^*_t - S_0 - \sum_{j = t_0 + 1}^{t-1} N_j \right] + \gamma_2 (D_t - \lambda) \tag{10}$$

where $S_0 = \sum_{-\infty}^{t_0} N_j$. Now assume that the relationship between desired coffee area and price is approximately linear in the range of prices under consideration:

$$T^*_t = a_0 + a_1 p_t \tag{11}$$

Substitute equation (11) into equation (10) to obtain the expression for newly planted area.

$$N_t = c_0 + c_1 D_t + c_2 (D_t p_t) + c_3 (D_t \Sigma N_j) \tag{12}$$

where

$$c_0 = -\gamma_2 \lambda \tag{13a}$$

$$c_1 = \gamma_1 a_0 + \gamma_2 - \gamma_1 S_0 \tag{13b}$$

$$c_2 = \gamma_1 a_1 \tag{13c}$$

$$c_3 = -\gamma_1 \tag{13d}$$

I assume that, although the density of coffee trees varies among farmers, the average number of trees planted per acre has been roughly constant over time. Then data on the number of new trees planted in years $t, t-1, t-2, \ldots,$ may be used to estimate equation (12).

Removal of Coffee Trees

The removal decision is based upon different criteria than the planting decision. When a farmer is considering the value of planting a tree crop versus the value of some other activity, it is quite relevant that there is a cost of planting and several years of gestation involved in tree crop cultivation. In the case of removal decisions these foregone costs are irrelevant; there are only maintenance and harvesting costs involved in continuing tree crop cultivation, whereas a switch of activity at this point involves the cost of tree removal. Hence, some trees that would not have been planted were price expectations less than p_0 at the time of planting may be maintained for several years at prices substantially below p_0.

Even if there were no trees whose planting was due to forecasting errors about prices, there might be trees removed. A tree's yield often declines as it ages. This decline usually determines a finite economic lifetime which may be estimated by the farmer at the time of planting more or less accurately, depending upon his knowledge of the soil and future prices.[7]

Both anticipated and unanticipated removal decisions depend upon price expectations and the age of existing coffee trees. French and Bressler attempted to explain the percentage of removals, R_t, by a linear function of net return and share of older trees in the total stock:[8]

$$\frac{R_t}{B_t} = C_0 + C_1 r_t + C_2 \frac{K_t}{B_{t-1}} \tag{14}$$

It was hypothesized that percentage of trees removed depended negatively on net return ($C_1 < 0$) and positively on the percentage of old trees ($C_2 > O$); however, neither coefficient was significantly different from zero, and they concluded that a fixed percentage of the bearing stock of trees was removed each year.

In the case of Brazilian coffee a different form for the removal equation is assumed. Age has two effects on the Brazilian coffee farmer's decision: first, the profitability of the existing tree depends upon its age; second, the fertility of the soil—and, therefore, its profitability in other uses—depends upon how long the soil has supported a coffee tree. While an old tree may have very low yields, it may often be more profitable to maintain it (or abandon it) than to remove it: the

[7] For fixed input and output prices, a finite lifetime is guaranteed if yields decline asymptotically to zero.

[8] Removals are net of those acres removed because of urban expansion. One might expect that the number of acres removed "because of urban expansion" would also depend upon net return on lemons.

expected yield of the soil in alternative uses is too poor to warrant incurring removal costs.

Let T^E denote the number of coffee trees in the age group for which removal (rather than abandonment) is the rational alternative to maintenance of the existing tree. It is hypothesized that the percentage of the tree stock, T^E, removed in each year is related to expectations of price and physical yield. In southern Brazil expectations of physical coffee yield are radically altered when a frost occurs; even when coffee prices are high, frost-injured trees may not be economical. I, therefore, write

$$R_t = R\,(p_t, F_{t-1})\, T^E{}_{t-1} \tag{15}$$

where $F_{t-1} = 1$ if there was a frost in year $t - 1$ and zero otherwise. Assuming linearity between price expectations, yield expectations, and per cent of $T^E{}_{t-1}$ removed, our estimating equation is:

$$R_t = (d_0 + d_1 p_t + d_2 F_{t-1})\, T^E{}_{t-1} \tag{16}$$

Abandonment of Coffee Trees

An abandoned tree is one which is permitted to remain standing but is not "cultivated": the area around the tree is not cleared of weeds. Without care, production of fruit ceases and the coffee tree eventually dies. Cattle may be permitted to roam between rows of abandoned coffee trees; although such areas do not provide good grazing, cattle may knock down dead trees and enable the area to become pasture more quickly. The farmer who desires to use coffee tree land for some immediate purpose, however, must remove the coffee trees.

As a coffee tree's annual yield begins to decline, so does its profitability. If its yield declines towards zero there will always be some age at which the value of the tree's annual yield is insufficient to cover the annual cost of maintaining the tree and harvesting the crop. When prices are low, the age of unprofitability occurs when annual yield is higher, i.e., the tree is younger. Let Z_t be the optimal abandonment age; then, mathematically:

$$Z_t = g^S\,(p_t) \tag{17}$$
$$\frac{dZ}{dp} \geqq 0$$

This age of "absolute unprofitability" is the one relevant to abandonment decisions when the farmer is a perfect competitor in the market for (non-land) factor inputs. Let $A^{MS}{}_t$ be the number of old trees, those over ten years of age, abandoned in year t by farmers who use the "absolute unprofitability" criterion; let $T^{MS}{}_{t-1}$ be the number of old trees on their farms at the beginning of year t. Then I assume that corresponding to each (price-determined) abandonment age there is a certain percentage of old trees selected for abandonment such that the older the optimal abandonment age the smaller the percentage of older trees abandoned:[9]

[9] See *1* for a detailed discussion of this approximation which was necessitated by the lack of data on age of coffee trees.

$$\frac{A^{MS}_{t}}{T^{MS}_{t-1}} = h\,(Z_t);\; \frac{d\left(\dfrac{A^{MS}_{t}}{T^{MS}_{t-1}}\right)}{dZ_t} < 0 \tag{18}$$

Annual abandonments, A^{MS}_{t}, may now be expressed as a function of price expectations and the number of coffee trees over ten years of age. Substitute equation (17) in (18) to obtain:

$$\frac{A^{MS}_{t}}{T^{MS}_{t-1}} = H^{S}\,(p_t);\; \frac{d\left(\dfrac{A^{MS}_{t}}{T^{MS}_{t-1}}\right)}{dp_t} < 0 \tag{19}$$

where H^S is the composite function hg^S.

In the case where markets are imperfect, the abandonment decision will be based on other considerations also. An owner of a large *fazenda* (plantation) may cultivate only a portion of his arable land because of his inability to obtain more workers. Profit maximization may dictate that labor be used intensively on some plots and other plots be left practically idle. Even if he were to rent out his idle land, labor shortage in the region would severely limit the possibilities for its use. Abandonment of one stand of trees would enable him to cultivate another area with the workers released from the abandoned stand. In deciding on the age at which to abandon existing coffee trees, the crucial element is maximizing the return from the scarce resource, labor. The *fazenda* owner will certainly not let annual profits on a stand of old trees fall to zero when positive profits could be earned were labor transferred to a currently unused plot.

When expectations of future real coffee prices change, the optimal abandonment will also change. Suppose alternative plots are not particularly well suited to coffee. Then, as coffee price expectations become more favorable, the expected annual profit on an existing stand of trees rises relative to the value of cultivation of an unused plot; hence coffee trees will be maintained longer than before the price rise. Suppose, however, the alternative plot is well suited to coffee. Then the rise in coffee price increases the expected value of both existing trees and new trees. Providing that the farmer plans to maximize the present discounted value of future earnings from coffee over an infinite horizon (constrained by labor but not by land), he may find it profitable to abandon trees at an earlier age the higher are real coffee prices: when coffee price is high it pays him to incur planting costs more frequently in order to reap only the highest yields of each tree. The farmer will maintain each tree for a longer period when prices fall, providing, of course, that they do not fall so low as to convince him to forget future coffee cultivation.[10] For these farmers there may well be a range of coffee prices for which the relationship between optimal abandonment age and price is negative:

$$Z_t = g^L\,(p_t)\frac{dZ}{dp} \leqq 0 \tag{20}$$

Let A^{ML} be the number of old trees abandoned by farmers who own large tracts of available coffee soils; T^{ML} the number of old trees on their farms. Assuming,

[10] If available plots are not suited for coffee cultivation at the lower price, we return to the criterion under which abandonment age and coffee price are positively correlated.

as above, that abandonment age is reflected in the percentage of older trees abandoned, profit-maximizing behavior for plantation owners of this sort is:

$$\frac{A^{ML}{}_t}{T^{ML}{}_{t-1}} = H^L(p_t);\; \frac{d\left(\frac{A^{ML}}{T^{ML}}\right)}{dp} > 0 \qquad (21)$$

The above discussion concerned abandonment of "old" trees; coffee trees over ten have, for the most part, already reached their peak yields. It can be shown that at the time of planting a farmer will never plan to abandon the tree before its yield begins to decline. Yet, a farmer may decide to abandon a tree which is still young. It may be that actual yields are much below those expected at the time of planting because a frost or disease has injured the tree; or prices may have fallen so low that the farmer does not expect returns sufficiently high to justify maintaining the tree. Whether the farmer is the owner of a large *fazenda* or a small farm, the number of young coffee trees he abandons should vary inversely with price. Let A^Y be the number of young trees abandoned; let T^Y be the number of coffee trees between three and nine years of age. Then:

$$\frac{A^Y{}_t}{T^Y{}_{t-1}} = H^Y(p_t);\; \frac{d\left(\frac{A^Y}{T^Y}\right)}{dp} < 0 \qquad (22)$$

Since the age of abandoned trees is not known, we assume that the recorded number of abandonments reflects abandonment of young as well as old trees. The ratio of total abandonments to total tree stock may thus be written:

$$\frac{A_t}{T_{t-1}} = \frac{T^M{}_{t-1}}{T_{t-1}} H^M(p_t) + \frac{T^Y{}_{t-1}}{T_{t-1}} H^Y(p_t) + b_0 \qquad (23)$$

where function H^M depends on the functions H^L and H^S which describe the relationship between price and percentage of trees abandoned for "large" farmers with available coffee soils and "small" farmers, respectively, and b_0 is the average per cent of trees abandoned because of exogenous forces.[11] On the assumption of a linear relationship between price and per cent of trees in age group abandoned, our estimating equation is:

$$\frac{A_t}{T_{t-1}} = (b_1 + b_2 p_t)\frac{T^M{}_{t-1}}{T_{t-1}} + (b_3 + b_4 p_t)\frac{T^Y{}_{t-1}}{T_{t-1}} + b_0 \qquad (24)$$

PART II

Data

Annual cruzeiro coffee prices were obtained by applying the Brazilian exchange rate for coffee earnings to the dollar price for Santos 4 coffee (New York Coffee & Sugar Exchange) and subtracting the relevant export tax. From this basic cruzeiro coffee price series, several adjusted series of undeflated coffee prices were constructed according to alternative assumptions about the effect of taxes in kind upon farmers' expectations as to future coffee prices. For example, one

[11] There are no annual data on tree holding or abandonment by size of farm.

assumption was that farmers used the past year's average earnings per bag produced (rather than price per bag sold or market price) as indicative of future coffee prices. Thus, if the São Paulo farmer were permitted to sell only 40 per cent of his crop, and market price of coffee were 200 cruzeiros/bag, the 200 cruzeiros would represent the current earnings on 2½ bags of coffee, or earnings of 80 cruzeiros per bag produced.

The adjusted coffee prices series were deflated by an index of the cost of living in Brazil (Rio de Janeiro prior to 1939, São Paulo thereafter). Then average real prices were calculated for periods one to eight years in length.

The Superintendência dos Serviços do Café do São Paulo (SSC) collected and published annual data on the number of coffee trees planted, abandoned, and removed in each municipality of the state from 1933 through 1951. In addition, annual statistics on trees entering into bearing and total number of bearing coffee trees are available from the SSC. All but two of the planting observations are directly obtained from this source. Published planting data (SSC) was used for 1933 to 1949; the number of trees entering into bearing (SSC data) was used to obtain planting estimates for 1930–32. In the FAO cross-section study of São Paulo coffee cultivation in 1958 (*4*) there are estimates of the number of coffee trees planted in 1950–52 and 1953–55 periods, which seem consistent with the SSC statistics on the number of producing trees in the middle and late fifties. These estimates provided two additional "planting" observations.

Age distribution variables were required for the explanation of each of the components of changes in the stock of coffee trees. Such variables were constructed from the SSC data on annual planting of coffee trees and number of producing coffee trees. Had frequent coffee tree age breakdowns been available, a much more sophisticated model for explanation of planting, removal, and abandonment of coffee trees could have been estimated.

The Price Responsiveness of the Stock of São Paulo Coffee Trees

I now turn to the structure of the equations explaining the planting, abandonment, and removal behavior of São Paulo coffee farmers. Each of these has been estimated by ordinary least squares. The standard error of each estimated parameter appears in parentheses below the relevant parameter; the R^2s which appear below each estimated equation are not adjusted for degrees of freedom. A single star indicates significance at the 1 per cent level; two stars indicate significance at the 5 per cent level. The Durbin-Watson statistics did not indicate that the residuals were autocorrelated.

The planting equation was estimated using observations for the 1930–55 period; observations for 1937, 1942, and 1943, however, were not included. In August, 1937, the Pan American Coffee Congress again failed to reach agreement on a joint coffee price support program, thus quashing Brazil's hopes for a lighter support burden. Expectations of future prices may well have changed radically at that time. Following severe drought and frost, 1942 and 1943 were years in which some planting was undoubtedly replanting of young trees. Since the model is basically designed for planting, not replanting, I have excluded these two years.[12]

[12] See *1* for a fuller explanation.

With plantings measured in millions of trees and expected price as average (2-year) real earnings per bag produced, equation (25) is estimated to be:

$$N_t = -71.48 + 93.32D_t + 0.37\,(D_t\,p_t) - 0.07\,(D_t\,\Sigma\,N_j) \qquad (25)$$
$$(29.19)\quad (37.29)\qquad (0.05)\qquad\qquad (0.02)$$
$$R^2 = .84\bigstar$$

The significance of the postulated relationship between real coffee price expectations and planting is quite clear.

From the estimated equation, both the relationship between expected coffee price and desired coffee tree stock and the relationship between desired coffee tree stock and annual planting may be determined. Each unit change in the measure of coffee price expectations produces a 5.34 million tree change in the desired stock of coffee trees (0.37/0.07); the (asymptotic) standard error of this estimated coefficient is 1.16.[13] At the mean level of expected real coffee price over the period, a 1 per cent change in the level of price expectations produced a change of approximately 6.5 million in the desired coffee tree stock.[14]

The relationship between annual planting and desired coffee area may be described as follows: (a) in any year suitable coffee soils available for planting are the difference between the price-determined desired coffee area and that area already used for coffee; (b) what fraction of this available and profitable area will be planted depends upon the agedness of the stock of coffee trees. For every 10 per cent of the coffee tree stock above ten years of age, São Paulo farmers planted approximately 0.7 per cent of the available coffee area. Even with 70 per cent of the tree stock above ten years of age, the speed of adjustment is therefore fairly low, about 5 per cent per annum (assuming that $D_t = \lambda$).

Equation (16), relating coffee tree removals to price expectation, was estimated for the 1933–50 period; alternative age groups of coffee trees were substituted for T^E. It appeared that trees between two and nine years of age best described the "tree stock" that was subject to removal due to unfavorable price and weather conditions:[15]

$$\mathrm{R}_t = (0.43 - 0.00027\,p_t + 0.43\,F_{t-1})\,T^E{}_{t-1} \qquad (26)$$
$$(0.10)\quad (0.00008)\qquad (0.07)$$
$$R^2 = .69\bigstar$$

where tree magnitudes are measured in millions.

When the number of trees between two and nine was replaced by the total coffee tree stock or by the number of trees above nine years of age the basic model

[13] The standard error of C_2/C_3 is calculated as follows:

$$\frac{-2C_2}{(C_3)^3}\,\mathrm{cov}\,(C_2C_3) + \frac{1}{(C_3)^2}\;\mathrm{var}\,C_2 + \frac{(C_2)^2}{(C_3)^4}\,\mathrm{var}\,C_3.$$

[14] The model does not lend itself to the calculation of an elasticity of desired tree stock with respect to coffee price expectations.

[15] The most significant measure of price expectations was a 2-year average real cruzeiro price adjusted for "sacrifice" quota expectations only. It appears that farmers were more pessimistic in regard to planting than in regard to removal. A new tree could be planted later; a removal decision is usually irrevocable.

did not explain annual removals as well as did equation (26). To see whether older trees, T^M, might have been removed on the basis of a different criterion than that which applied to younger trees, T^Y, the basic model was rephrased in a fashion similar to the abandonment model discussed above:

$$R_t = R^Y(p_t, F_{t-1})\, T^Y_{t-1} + R^M(p_t, F_{t-1})\, T^M_{t-1} \qquad (27)$$

According to this formulation the relationship between price and the percentage of trees removed could be different for trees in the older age group and those between two and nine years of age. However, there was no significant increase in the percentage of annual variation of removals explained by this model.

During the 1933–50 period it appears that São Paulo farmers' annual removal decisions were dependent upon the number of younger trees and the level of price expectations prevailing at that date. The price elasticity of coffee tree removals measured at the mean level of price expectations in this period is $(-0.00892)\, T^Y$.

The abandonment equation [equation (24) above] was estimated for the 1933–50 period. The fraction of the coffee tree stock abandoned each year depended upon price expectation and age distribution in the following way:[16]

$$\frac{A_t}{T_{t-1}} = (\underset{(0.12)}{-0.47} + \underset{(0.000025)}{0.000067}\, p_t)\frac{T^M_{t-1}}{T_{t-1}} + (\underset{(0.00010)}{0.00012} - \underset{(0.00000011)}{0.00000044}\, p_t)\frac{T^Y_{t-1}}{T_{t-1}} + \underset{(0.1)}{0.4}$$

$$R^2 = .71^{\star\star} \qquad (28)$$

Expected price had a quite different effect upon the number of older trees abandoned and the number of young trees abandoned. The terms in the second parentheses indicate the relationship between expected price and the percentage of younger trees abandoned. As was hypothesized above, abandonments of younger trees are inversely related to farmers' price expectations, indicating a systematic increase in young coffee tree abandonments as expected coffee prices fall. The coefficient of price in the first parentheses, however, is positive. It appears that farmers abandon a greater number of old coffee trees the higher are real coffee price expectations. This would suggest that a large percentage of old coffee trees is abandoned by owners of large, only partially cultivated plantations on which good coffee soils are plentiful. These farmers may well find the planting of a new tree more profitable than maintenance of an old one when coffee prices rise; they, therefore, choose to shift labor and abandon old trees in greater numbers when prices are high.

An examination of the 1934 São Paulo census of agriculture and livestock (7) brings to light two factors which are relevant to this interpretation of the positive effect of the level of coffee price expectations on the number of older coffee trees abandoned. First, the age distribution of coffee trees on farms in different size categories indicates that large farms had a greater percentage of coffee trees in the

[16] The price measure which was most significant is based upon the assumption that real cruzeiro price would be at the average level prevailing over the previous 2 years and that the proportion of future crops sold would be the average market quota over the previous 2 years.

TABLE 1.—COFFEE TREE AGE DISTRIBUTION AND LAND ALLOCATION, BY SIZE OF FARM, 1933–34

Size of properties in hectares	Ratio of trees over 40 to total tree stock	Ratio of coffee area to total area[a]
Under 5	.047	.71
5–10	.047	.43
10–25	.044	.49
25–50	.068	.28
50–200	.161	.20
200–500	.195	.16
Over 500	.197	

[a] Total area calculated as midpoint of area category times number of properties. Basic data from *Recenseamento Agricolo-Zootechnico,* 1934.

older age groups in 1934 (see first two columns of Table 1). This suggests that decisions made by plantation owners as to the maintenance or abandonment of old trees had a disproportionately large effect (compared to their share of the total number of trees) on the number of older coffee trees abandoned in the 1933–50 period. Second, the data from this census indicates that larger farmers had a small percentage of farm area planted in coffee trees (see first and third columns of Table 1). If these larger farms had their proportionate share of good coffee soils, the small percentage planted in coffee would suggest either that such farms had large areas available and suitable for coffee in 1934 or that many thousand hectares of coffee trees had been abandoned prior to 1934.

Thus, there is some basis for assuming that large farmers still had extensive area available for coffee in 1934. With labor scarce and land plentiful, the owners of these large farms made profit-maximizing decisions in abandoning trees at an earlier age when coffee price expectations were high. Small farmers may have used the more obvious criterion of abandoning at a later age when coffee price expectations were high, but, since such small farmers had a small proportion of the older trees, the total relationship between price and per cent of older coffee trees abandoned reflects more strongly the decisions of large farmers. As available coffee soils are brought into cultivation and land constraints become more universal, one would expect that the coefficient relating price and abandonments of older trees would become negative.

From the estimated equation one may calculate the price elasticity of coffee tree abandonments in the 1933–50 period; this elasticity depends upon the age distribution of coffee trees. Using the mean level of expected coffee price in the period, the elasticity of abandonments with respect to expected price, e_{Ap}, is:

$$e_{Ap} = \underset{(.00170)}{.00449}\, T^{M} - \underset{(.0000074)}{0.0000295}\, T^{Y} \qquad (29)$$

Expected levels of real coffee price seem to have had an important influence on the planting, abandonment, and removal decisions of São Paulo coffee farmers during the second quarter of this century. Planting decisions were related to a price-determined, desired coffee area; abandonments of both old and young trees were influenced by price considerations; and removals consisted of a price-determined fraction of the number of young trees. Given a time pattern of prices, one may calculate the time path of the stock of coffee trees from the estimated equations.

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