Why did Big Coffee Seek Regulation?
A theory of dynamic monopsony pricing without commitment.

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Abstract

Coffee beans must be roasted before they can be used by consumers. The roasting industry is highly concentrated, so that the large firms in it have market power over the beans they buy. This creates a potential time inconsistency problem: at planting time, roasters would like to promise planters a remunerative price but that will not be credible given roasters' incentives to push the price down at harvest time. It is argued that this problem survives in an infinite horizon; a folk theorem exists but it is fragile. Finally, it is shown that an intervention akin to the International Coffee Agreement (ICA) can help solve the time inconsistency problem. This may help explain the agitation of roasting firms for the establishment of the ICA, which would otherwise appear to run counter to their interests.
1. Introduction.

This paper offers a theory of pricing in the world coffee market.

It is argued that three features of the coffee market are key to understanding it:

(i) Coffee is grown by millions of farmers worldwide, none of whom has any market power.
(ii) The crop is perennial, so that much of the farmer's cost is sunk long before the harvest. Indeed, a planter must endure a few years of zero output while incurring costs before a tree will bear fruit. This is much longer than the term of any futures contract for the commodity.
(iii) The processing, or "roasting", of raw beans into a form consumers can enjoy is a highly concentrated industry which appears to have significant costs to entry.

These three features combine to create the potential for a serious time consistency problem. Since farmers must incur costs of planting and maintenance long before the crop matures, and since they may face a low oligopsony price when that time arrives, they may abandon the crop altogether and plant some alternative crop that would deliver the normal return on their land. This may happen even if the processing firms would be willing *ex ante*, to pay a price that would make planting coffee profitable. The problem is that planters know that once their initial outlays have been met, the processors can acquire the crop at a price much lower than that and will have every incentive to do so. Thus, in the absence of an ability to commit, the processors and planters both may suffer. There are grounds for policy intervention that could facilitate such commitment.

The argument can be put across in two-period language as follows. To make the point simply, suppose there was only one roaster of coffee beans and there were no speculators; there are millions of atomistic coffee planters who must incur a fixed cost in period one in order to
obtain a harvest in period two. The marginal cost of harvesting the crop once it has sprouted is zero, so that in period two the roaster faces a vertical supply curve. If the game ends there, the roaster will surely obtain the entire crop at the monopsony price of zero (or ε) and process it to make large profits; but since planters know in period one that this will occur, they will not plant. In a precise sense, the market has "collapsed". In this case, the roaster, planters and consumers would all be better off if only the roaster could commit credibly to the promise that it would not indulge in the monopsony price in period two.

This argument, as stated, is crude and faces two strong objections. First, the model sketched above has a unique, degenerate equilibrium because it has a terminal date, but there is no terminal date for the real world coffee market. Second, real world roasters do not really have as much control over the price as is assumed above. They must compete in an open market with a large number of trader/speculators who may outbid the roasters if they expect high prices in future. The interaction between these traders and the roaster could conceivably be quite complex, and might limit the ability of roasters to squeeze rents out of farmers and thus might mitigate the commitment problem. To address these issues, we will build an infinite horizon model including atomistic traders who operate on a Walrasian spot market. The roaster cannot set the price of coffee beans but can manipulate it by adjusting the quantities it buys on the spot market. We will find that although there arise a large number of equilibria, the degenerate one still exists and we will argue that it is somewhat more plausible than the others. Finally, it will be shown that a Pareto-improving policy intervention may be available.

This study is motivated partly by some elements of the history of the coffee industry. There have been periods in which roasters as a unified block have lobbied governments in
support of the International Coffee Agreement, which has always been described by negotiators
and commentators as a way of keeping prices of raw beans, called "green" coffee, from falling
too low. Roasters expressed repeated worries that coffee prices "too low" could lead the market
to "collapse", and thus pushed for ratification of the Agreement. It seems most unusual for a
manufacturing concern to lobby against low prices for its inputs, and the concept of a market
"collapse" in the absence of terrible cost shocks or flagging popularity of the good seems
mysterious. It will be argued that these features can be explained easily with a theory of time-
inconsistent monopsony pricing, but not easily with other models.

This argument bears a close relation to some important strains of industrial organization
theory. One strain is the theory of the durable goods monopolist. It has been shown (e.g.,
Stokey (1981)) that a monopolist selling a durable good may find it very difficult to exercise its
market power if it can adjust its price and quantity frequently but cannot credibly commit to
output restraint in the future. This is the "Coase Conjecture." The same type of reasoning and
the same concept of equilibrium will be used here as is used in Stokey, but the results have a
curious "mirror image" effect: the monopolist without commitment will have trouble exercising
market power, but the result will not be the happy competitive outcome of the Coase Conjecture,
but an outcome worse than successful monopoly. A second strain is the literature on monopoly
in goods whose use requires irreversible investments by consumers (e.g., Farrell and Gallini,
1988). There if the investment required by consumers is sufficiently costly, the monopolist must
find a way of committing to a price below the monopoly price for future sales. Mechanisms
suggested include licensing to bring new competitors into the market, which sacrifices market
power but may be in the monopolist's interest if it convinces prospective customers that they can
safely invest in the use of this product. The relationship of these literatures to the present model will be drawn as the analysis proceeds.

The following section will summarize the relevant history of the market. Section 3 discusses some possible alternative explanations for the roaster's efforts to raise the price of their principal input. Section 4 presents the model, 5 and 6 show two different equilibria under laissez faire which illustrate the concept of market "collapse", section 7 shows how the commitment problem can be overcome by an intervention like the International Coffee Agreement, and section 8 summarizes.

2. Some background, and a puzzle.

A. The industry.

Coffee beans off the tree are known as "green" coffee. Green coffee must be roasted before it can be used by consumers. Although there are many coffee roasters in the world, three dwarf all others: Nestlé of Switzerland, owner of the Hills Brothers brand and others; Procter and Gamble, maker of Folger's; and General Foods, maker of Maxwell House and Sanka. The market is quite concentrated; for example, in 1989 these three firms supplied about 80% of ground coffee in the U.S. market, the latter two firms alone supplying 66% (Fortune, May 21, 1990, p.100). General Foods is still the largest roaster and has been for many decades, but Procter and Gamble has emerged as a fairly close second.

Why the market should be as concentrated as it is remains an open question. It is quite
possible that there are cost advantages to roasting beans in large numbers, and these firms do keep large plants. It is certainly true that the production of instant coffee requires a large scale to be profitable (Short, 1987, p. 64; Sutton, 1991, p.489). If there is a large minimum efficient scale that limits the number of significant players to two or three, then the market is a natural oligopoly\(^1\). This possibility is consistent with the large number of small roasters in the market, since they tend to charge much higher prices than the big two and to produce a product with a much higher quality, selling to small, idiosyncratic blocks of consumers (see Wall Street Journal, November 6, 1989, p. B1, and Fortune, May 21, 1990). Thus, there are really two coffee markets, whose products are imperfect substitutes, and the market with large scale production is the one with the low prices.

However, some observers explaining concentration stress enormous sunk costs in positioning a brand in the retail market\(^2\). For example, some market observers reportedly estimate that an investment in advertising of $50 million is required to capture one percent of the U.S. consumer coffee market (Business Week, March 4, 1985, p.76). Hilke and Nelson (1989) argue that the Maxwell House brand has a special place in the market due to customer familiarity with it, and that this brand-name capital confers an enormous advantage over any potential entrant. A third reason for the concentration may be a reputation among the two largest roasters for aggressive predatory response to any serious newcomer. Hilke and Nelson (1989) describe the

\(^1\)Sutton (1991, p. 489) argues that setup costs may be quite small for roasting per se, but large for the accompanying packaging operation if it involves vacuum packing for long shelf life.

\(^2\)See Sutton (1991, ch. 3) for an exposition of the theory of such "endogenous sunk costs" and how they will tend to result in a concentrated industry even if the size of the market is allowed to be arbitrarily large relative to exogenous setup costs. See his chapter 12 for an illuminating analysis of the coffee industry in light of that theory.
militant response of General Foods to attempts by Procter and Gamble to introduce Folger's into U.S. markets traditionally dominated by Maxwell House; in some instances in the contested markets General Foods even priced its roasted coffee below the price of the green coffee required to produce it (p. 222). When Procter and Gamble withdrew from one of these markets, the price of Maxwell House abruptly returned to its previous high levels (pp. 223-4). Apparently, this reputation for "toughness" or ability to commit to painful post-entry retaliation is now accepted wisdom in the coffee roasting business (Business Week, March 4, 1985, p. 76).

Whichever working paradigm one adopts for the roasting industry, it must clearly feature market power. The largest roasters clearly are not price takers, either in their output market or in the green coffee market. For example, one can look at the extensive output price manipulation described in Hilke and Nelson (1989), and the occasions on which a change in General Foods' price policy for Maxwell House has caused sudden, sharp changes in green coffee futures prices (Wall Street Journal, December 24, 1985).

Further, for the period which will be the focus of this paper, the late 1950's and early 1960's, it is plausible to think of the market as having one dominant firm, General Foods. At the time Procter and Gamble had not yet even entered the market, and General Foods was clearly the dominant player in the American market. Generally, when General Foods announced a price change for a particular size of its coffee, the other American roasters would quickly follow it with a virtually identical price change for their own brands (Wall Street Journal, June 21, 1962, p. 5; July 20, 1960, p. 2). The world's largest roaster thus held disproportionate sway over the American market, roughly one-third of the world market, while Neslé, the leading producer in Europe, did not have a corresponding role there because of the fragmented character of that market.
Some empirical work backs up this view. Gollop and Roberts (1979) argued that data on the U.S. roasting industry fit best with a model of a dominant firm facing a competitive fringe (they were not allowed to name the dominant firm, but it is not hard to guess). The data were from 1972, after Proctor and Gamble had entered the market but before it undertook its major expansion. Roberts (1984) rejected the hypothesis of price-taking behaviour for the two largest roasters but not for any others, and suggested that a duopoly model with a competitive fringe would be the most realistic.

B. The International Coffee Agreement.

In the first half of the century, Brazil essentially ruled the world coffee market. With its 75% share of the world market it could, through storage and destruction of stocks, exert a powerful influence on world price. However, the mid-century entry of many competing producers shattered that monopoly power, and Brazil found itself throughout the 1950's pleading with a wide array of producers for cooperation. In the late 1950's green coffee prices began a long and devastating slide, and producer countries signed a succession of agreements to withhold stocks through export quotas (see Baranyai and Mills (1963, pp. 151-5)). These agreements appear to have had no effect, and the slide worsened. In 1962, the first agreement that included consumer governments was signed; this has always been called the first International Coffee

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3See, for example, Economist Intelligence Unit, 1987, p. 40.

4A useful account of the wave of mid-century entry with references is found in Gordon-Ashworth (1984). As of 1950, Brazil's market share had slid to 54%, while now it is closer to a quarter. See Economist Intelligence Unit (1987, pp. 6,40).
Agreement (ICA). The main function was similar to that of the failed producer agreements, but the addition of the consumer countries helped the prospects for success because they provided an enforcement mechanism. Under the agreement, importers of green coffee would require a certificate of origin which would then be shown to the International Coffee Organization, thus making it difficult for exporters to cheat on their export quotas. See Baranyai and Mills (1963, pp. 159-60) or Gordon-Ashworth (1984, pp. 213-4).

A natural question is why the consuming governments would wish to be party to what sounds like a producer cartel. As the largest consumer, the U.S. was the key to the process. The ICA happened to fit into the Alliance for Progress, which was a major goal of the Kennedy administration and was supposed to help Latin America to its feet in various ways and thus stave off repetitions of Castro's victory in Cuba. Because of the sensitivity of the American government to political unrest in Latin America, combined with the abnormally long and deep trough in green coffee prices and attendant consensus that the coffee market was in "crisis," the government was eager to be seen as helping Latin American countries in any way (Short, 1987, pp. 141-6). Whether or not participating in a commodity agreement was a more socially efficient way of doing this than lump sum transfers is a question we will not explore right now. What is relevant for our purposes is that the roasting industry was one of the driving forces behind the Agreement.

The National Coffee Association (NCA) represented American roasters and traders and had a very close relationship with the State Department (Short, 1987, pp. 159-65). It lobbied tenaciously and effectively for U.S. participation in the ICA and for concessions to make the Agreement possible. One of the leading figures in the NCA was George Robbins, the Director
of Green Coffee Operations for General Foods (Short, 1987, p. 151). He was personally one of the driving forces behind the negotiations (Short, 1987, pp. 99, 134-3) and in later years liked to call himself the "Father of the Coffee Agreement" (Short, 1987, p. 152). This commitment was not new; Robbins had earlier convinced Eisenhower to support moves for an ICA (Short, 1987, p. 166).

Now the question is: why? The strongest support for the ICA in the NCA came from the roasters (Short, 1987, pp. 123-4), and Robbins himself was the chief buyer for (by far) the largest coffee roaster in the world. Why then would they push aggressively for a policy that seemed sure to push up the price of green coffee, their principal input? Note that there was no ambiguity in that aspect of the negotiations; there was talk of "stabilization", but it always meant keeping the price from going too low, not too high, and all participants agreed that a floor should be established at least at the then current price (Short, 1987, p. 134).

It is unusual for a coalition of business firms to lobby for a policy that is designed to raise artificially the price of their principal input. The National Turkey Federation has lobbied against policies leading to high feed prices (Guither, 1980, p. 271). The American Bakers Association and the Independent Bakers Association have lobbied for policies leading to lower wheat prices (Guither, 1980, p. 56). The National Association for Milk Marketing Reform, representing processors of milk, has lobbied against policies which encourage imperfectly competitive milk production and hence higher milk prices (Guither, 1980, p. 57). The Peanut Butter Manufacturers and Nut Processors Association and the National Confectioners Association have lobbied against government peanut acreage restrictions which lead to artificially high peanut prices (Guither, 1980, pp. 59-60). Sugar refiners have generally lobbied against protection of domestic sugar
growers, which raises domestic sugar prices, and lobbied for production subsidies instead, which lower them. The Corn Refiners Association, on the other hand, has lobbied for sugar protection and against production subsidies -- always prepared to see rivals' input costs go up (Guither, 1980, pp. 60-2). In short, although there are exceptions, it is not normal for a firm which processes an agricultural good to lobby in favor of a rise in its price, but the coffee roasters did just that.

Robbins himself suggested that General Foods lost money on the ICA, but did what it did for the good of humanity (Short, 1987, p. 154). We will not rebut that theory but will decline to adopt it as a working hypothesis. Rather, the reason that will be suggested here is that the large roasters had assimilated enough market power that they could credibly be expected to squeeze planters in future; that this led to the fear (documented throughout Short (1987)) that there would be few trees planted over the next several years, and thus little to roast for a long time; and that the ICA provided a way out because it helped the producer countries to exercise their own market power, thus guaranteeing that there would not ever be a squeeze by the roasters. This will be formalized in sections 4 through 7, but first we will discuss a few alternative explanations.
3. Some alternative explanations for the puzzle.

A. Stability.

This is the first word to be tossed around in discussions of International Commodity Agreements. Prices of agricultural goods like green coffee are extremely volatile, and it is often asserted in policy debates that producers and consumers of primary goods can both benefit by stabilization of the price (a debate which will be avoided here at all costs). However, it is difficult to see even a mean-preserving stabilization of green coffee prices as very much in the interest of roasters. It seems that even if the roasters were to see stabilization as in their interest, that would presuppose that they had market power in the green coffee industry, and hence the issues in this paper would necessarily arise anyway. This is because for a competitive industry, the profit function is *convex* in input prices, so that a mean-preserving *spread* would be desired. A similar argument can be made for a simple-minded monopsonist if there is not too much curvature in the supply curve it faces. Ignore roaster inventories, and suppose the supply curve faced by the roaster is \( P(Q-\theta) \), \( P'>0, P''>0 \), where \( Q \) is the amount procured and \( \theta \) is a random term that shifts the supply curve horizontally. Under laissez-faire this would be the crop size, and under a stabilization policy, the harvest net of public storage, which would have less dispersion than the harvest. The idea is that the marginal cost of harvesting rises as one harvests more and more of the crop. Suppose the roaster receives profits \( \pi(Q) \) from roasting and selling a quantity \( Q \) of coffee. If it maximizes \( \pi(Q) - P(Q-\theta)Q \) with each realization of \( \theta \), then its profit function is a function of \( \theta \) and has second derivative equal to -\( P''(Q-\theta)Q(1-dQ'/d\theta) + \)
P'(Q-θ)dQ'/dθ, where Q* is the optimal quantity. If the first term, which is the curvature term, does not dominate, the roaster will still prefer a mean preserving spread of θ. Even if it does, the cost of risk is greatly attenuated by the second term, which is the quantity adjustment term. We have omitted the possibility of inventory adjustments, which attenuate it further. Moreover, General Foods has long had enviable access to risk and credit markets. Even if it did not, risk averse shareholders would care only to the extent that green-coffee-price risk was correlated with returns in the rest of their portfolio, which seems unlikely. All of this makes it seem unlikely that the firm would strive desperately for a mean-preserving stabilization of the green coffee price -- and the proposal they did clamor for had the earmarks of a mean-increasing stabilization. The model which will be developed in the next section, on the other hand, shows an unambiguous benefit from an ICA without any risk whatsoever.

B. Raising rivals' costs and comparative statics.

Williamson (1968) studied an antitrust case in which it had been alleged that some large coal mining companies had conspired with the coal miners' union to apply a uniform high wage across the industry to force smaller firms with more labor intensive technology out of the market. He concluded that it was plausibly a profit-maximizing strategy and plausible that the charge was true. Salop and Scheffman (1983) studied the conditions under which a dominant firm would profit from a general rise in industry costs which would draw back production in the competitive fringe producers. In principle, this is a possible reason the large roasters may have wanted a rise in green coffee prices. It seems unlikely that the Williamson argument could be applied here,
since their was little dissent among roasters in the NCA as to the desirability of the ICA, while if the idea was to squeeze small ones out of the market they would seem rather likely to object. However, Salop and Scheffman pointed out that in principle the fringe may benefit, if equilibrium output prices rise by enough to outweigh the *prima facie* effect of the rise in the input price. A similar point has been noted in the comparative statics of simple oligopoly models (for example, Dixit, 1986). An increase in costs can result in an output discipline effect that moves the oligopoly equilibrium somewhat closer to the monopoly outcome, and this effect may compensate the members for the increase in their costs. It seems difficult to rule out such effects *a priori*, but they do not seem plausible in this case because the roasters were recording record earnings with the low green prices of the day (see, for example, *Wall Street Journal*, April 13, 1962, p. 5). Thus, their lobbying must have reflected a worry that something bad would happen to future profits, not that low green prices were hurting current ones.

It is possible to build a case that the roasters' lobbying was profitable, but the case is not compelling, while the roasters were very eager. We now offer a reason which has not, apparently appeared in the literature, and illustrate it with a very stylized model.
4. A sketch of a world coffee market.

The coffee industry involves four groups of participants: consumers, a roaster, traders, and planters. We model each in turn.

Consumers are atomistic and passive, consuming a quantity $Q$ when the price is $f(Q)$, where $f$ is a bounded and strictly decreasing demand curve. They can not consume green coffee, hence the role of the roaster.

The roaster can convert green coffee into a form fit for consumption. It has a monopoly on this function, either because of large fixed costs or minimum efficient scale giving rise to natural monopoly or because of some successful scheme of entry deterrence. This is patently untrue in the real world, but all that is really important here is that at least one roaster has significant market power in the market for green coffee, which appears to be very much the case. The monopoly assumption is made for ease and elegance. The roaster buys a quantity $B$ and roasts a quantity $Q$ of beans at a cost of $C(Q)$, with $C$ nondecreasing. It can also store green coffee, at a marginal cost of $k$ per unit. A fraction $\delta$ of beans stored deteriorate in a year. Roasted coffee cannot be stored at all. This last assumption is ludicrous but will greatly simplify the model without sacrificing anything of importance. Storage on the green side of the market, however, is crucial.

There is a block of competitive traders who buy, store and sell green coffee for a living. Their storage technology is identical to that of the roaster. The traders work in a spot auction market which generates a price each period which clears the market. The presence of a large number of traders dealing with a small number of processors is a persistent feature of the world
coffee market, and we could not do away with either the presence of the traders or their ability to store without tossing doubt on the results.

Finally, there are a large number of infinitely-lived planters. These are the people who actually grow the coffee. Each farmer has an identical plot of land, on which may be planted one coffee tree or some alternative crop which we will call corn. The limit of one tree per farmer simplifies the exposition without changing the results at all. It also does not matter whether planters can store coffee or not; if they do, then to the extent that they do, they double as traders. A coffee tree will live for one year after it is planted, in that year it will produce one unit of green coffee\(^5\). The deterministic nature of the yield and the fact that it does not depend on variable inputs are obviously unrealistic, but they hugely simplify the analysis and help to isolate the key issues of the model.

At the beginning of each year, each planter currently with a tree must choose between two options. He can replant it, incurring a cost \(K\) and enjoying a one-year old tree next year, or he can plant corn instead\(^6\). The farmer currently with corn must choose between continuing in corn and planting coffee. A plot planted in corn for a year will yield zero profits. Let the total number of plots be normalized at one and let \(\alpha\) be the fraction of plots currently planted in coffee (and hence currently producing coffee).

Table I gives a list of notation. In summary, the plot unfolding in each period is:

\(^5\)An earlier version of the paper allowed for an arbitrary yield profile for trees over a possibly infinite life. This greater generality has no effect on the results presented here, but greatly clutters the notation. The key feature of the lifetime of the tree is that it is longer than the longest maturity futures contract available, which is overwhelmingly the case in the real world coffee market, and is true here simply because here there is no futures market.

\(^6\)In the case of long lasting trees, the farmer has a third option: keeping the current tree.
(Harvest comes in) ⇒ (Roaster chooses B,Q) ⇒ (Spot market price emerges and transactions take place.)

(Planters choose next period crop)

Of course, in the real world, roasters adjust their quantity decisions many times as the year goes on. The idea behind assuming that they move simultaneously with the planters is that the planters cannot wait for the final roaster decisions and for the diffusion of that information to the coffee hinterland before they get started on their preparations for next year's crop. Traders, on the other hand, here as in the real world, watch the roaster and respond to its decisions instantly.

Now to define equilibrium, we must first make clear the laws of motion of the system and the nature of maximizing behaviour on the part of each agent. The notation here developed is summarized in Table I.

A. Laws of motion.

Each character in this drama will choose behaviour to maximize the present value of his or her income given the environment. Since this environment may be changing, the calculation of optimal behaviour requires some conjecture as to how it is evolving, and this must include some conjecture as to what all of the other agents in the market are doing. Thus, we write down the laws of motion for the state variables in the system. There are three state variables to keep track of. First, there are the beginning of period inventories of green coffee by the roaster, $I_R$. Correspondingly, there are the beginning of period holdings $I_T$ by traders. Finally, there is the share $\alpha$ of plots allocated to coffee. We will normalize total acreage to 1. With the assumptions
above, the current crop is then $\alpha$, so these together determine total availability, $x$, by $x = I^R + I^T + \alpha$.

We thus define the state vector $s = (I^R, I^T, \alpha)$. We will allow in the most general case for equilibrium behaviour to depend on history, and thus we define the sequence of history vectors $\{H_t\}_{t=0}^{\infty}$, with $H_0 = s_0$, and $H_{t+1} = (B_t, Q_t, H_t)$ for $t \geq 0$, where $B_t$ gives the roaster's purchases of green coffee and $Q_t$ its roastings, and dates are denoted by subscripts. We wish to write down the components of $s_{t+1}$ as functions of the components of $s_t$ and $H_t$. However, the transition is not mechanical, since the time $t+1$ state vector will depend on choices of agents throughout the market in period $t$. We will thus for the moment conjecture the existence of a behavioural rule for each agent to follow and defer discussion of optimality to the next section.

The first behavioural rule gives the purchases, $B_t$, of green coffee by the roaster in a given period. The second gives the amount $Q_t$ which the roaster chooses to roast (and hence to sell to consumers in that period, since roasted coffee is not stored). These rules will be functions $B_t(\cdot)$ and $Q_t(\cdot)$ of the state space and of history, and will everywhere satisfy $-I^R \leq B_t(s,H) \leq x-I^R$ (because the roaster can not sell more than it has or buy more than there is on the open market) and $0 \leq Q_t(s,H) \leq I^R + B_t(s,H)$ (because it can not roast more than its stocks plus procurement).

The time subscripts indicate that in principle these may be different functions in each period because of the dependence on history; for example, $B_t$ is a function of the state and the first $t$ periods of history, but $B_{t+1}$ is a function of the state and the first $t+1$ periods of history. Third, there will be an equilibrium price rule $\psi$ which will clear the spot market given the physical state of the market, history, and the roaster's announced current period behaviour, so that $p_t = \psi_t(s_t, H_t, B_t, Q_t)$ for all $t$, where $p_t$ is the price of green coffee. This allows for the possibility that
the spot market will respond instantly to purchases or other decisions by the roaster, which as a monopolist is aware of its effect on prices. It is convenient to define \( \psi_t(s, H) = \psi(s, H, B_t(s, H), Q_t(s, H)) \) for all \( s \), so that \( \psi_t \) is a kind of "reduced form" price rule, a function of the current state and history alone. The final behavioural rule is the crop rotation rule for the planters. Let \( \rho_t(S_t, H_t) \) be the fraction of farmers who will plant coffee in period \( t \). This will normally take values of zero or one, but we allow for mixed equilibria for completeness.

It is now straightforward to write laws of motion for the state variables. First, inventories:

\[
(4.1.a) \quad I_{t+1}^R = (1 - \delta)(I_t^R + B_t - Q_t) \forall t.
\]

Current inventories carried in are given by past inventories carried in, plus net additions, minus the fraction \( \delta \) lost in storage. Trader inventories are determined analogously:

\[
(4.1.b) \quad I_{t+1}^T = (1 - \delta)(I_t^T + \alpha_t - B_t) \\
= (1 - \delta)(x_t - I_t^R - B_t) \forall t.
\]

Finally, there is the law of motion for the coffee stock \( \alpha \). Clearly, the number of next period trees of age 1 must equal the number of farmers who planted coffee this period. Thus:

\[
(4.1.c) \quad \alpha_{t+1} = \rho_t(S_t, H_t).
\]

These complete the laws of motion for the system. Any agent knowing these relations will have all of the information necessary to behave optimally.

\[\text{\footnotesize In the case of long-lived trees, this simple law of motion is replaced by a very cumbersome set of equations relating next year's vintage profile of the tree population to this year's profile.}\]
B. Optimal behaviour and market clearing.

The roaster receives revenue from the sale of consumer coffee and incurs costs from purchasing green coffee, from storage, and from the roasting process. Accordingly, its Bellman equation is:

\[
V_R(S_t, H_t) = \max_{t} \{ R(Q)Q - C(Q) - \psi_t(S_t, H_t, B, Q)B - k(I_t^R + B - Q) \\
+ \beta V^R_{t+1}(I_{t+1}, I_{t+1}, \alpha_{t+1}) \}
\]

subject to \(0 < Q < I_t^R + B, -I_t^R < B < \bar{x}_tI_t^R\), and the laws of motion (4.1), where \(V^R_{t}(:,:, :)\) is the roaster's value function at time \(t\).

Traders maximize the present value of their capital gains on coffee beans net of storage costs. Since they take prices as given and have constant returns technology, if there were ever expected capital gains exceeding storage costs they would have an unbounded demand for beans, so the market could not clear. Thus, the only way markets can clear is if prices adjust to provide for expected capital gains of at most zero, net of storage costs, at all times. If this condition is met, the optimal storage rule for each trader says simply to sell everything when there are expected capital losses, and store any amount otherwise. Thus, we have the intertemporal arbitrage condition:

\[
\psi_t(S_t, H_t, B, Q) + k \geq \beta(1-\delta)\psi_{t+1}(S_{t+1}, H_{t+1})
\]

for any \(S_t, H_t\) and feasible \(B\) and \(Q\), where \(S_{t+1}\) and \(H_{t+1}\) are calculated from \(S_t, H_t\) and \(B\) and \(Q\) by (4.1). Note further that whenever there is green coffee left on the market at the end of the period, market clearing requires that the traders be willing to hold it. Thus, whenever the roaster buys less than \(x-I_t^R\), the amount on the open market at the beginning of the period, (4.3) must
hold with equality. This gives:

$$(4.3)' \quad (x-I_8-B)>0 \Rightarrow \psi_i(S_t,H_t,B,Q) + k = \beta(1-\delta)\hat{\psi}_{t+1}(S_{t+1},H_{t+1}).$$

A final note on market clearing prices concerns their lower bound. This is important in a problem such as this where monopsony power may be exercised over inelastic supply. Here we have not given traders the opportunity to throw away stocks that are unprofitable to carry, and with the positive holding costs we have the result that at some nodes in some equilibria the price may be negative. This is not important, and could be done away with by allowing for free disposal or by adding a positive marginal harvest cost to the planter's problem, so that some positive price would have to be offered each year for any new coffee to emerge on the market. We do this for simplicity and will point out where it is relevant what difference free disposal would make. For now, note that if the price was ever less than $-k/(1-\beta(1-\delta))$, a trader could purchase a unit (receiving payment), store it in perpetuity, and make positive profits. There would thus be an unbounded demand for the good regardless of future expectations. Thus, such prices are inconsistent with market clearing, and we have:

$$(4.3)'' \quad \psi(\cdot) \geq p^* = -k/(1-\beta(1-\delta)) \text{ everywhere.}$$

Now we return to planters. It will be optimal for them to plant coffee if and only if the anticipated revenue from the tree exceeds the cost of planting. Thus:

$$(4.4) \quad \beta\hat{\psi}_{t+1}(S_{t+1},H_{t+1}) > K \Rightarrow p_i(S_t,H_t) = 1;$$

$$\beta\hat{\psi}_{t+1}(S_{t+1},H_{t+1}) < K \Rightarrow p_i(S_t,H_t) = 0.$$
C. The definition of equilibrium.

Clearly, an equilibrium will be a cluster of behavioural functions as outlined above which are mutually consistent and consistent with individual optimization. We preface a definition by defining some domains. Let $\Sigma = \{I^R, I^T, \alpha | I^R, I^T \geq 0, \alpha \in [0,1]\}$. This contains all possible values of the state vector. Let $\Sigma' = \{I^R, I^T, \alpha, B, Q | (I^R, I^T, \alpha) \in \Sigma, -I^R \leq B \leq x - I^R, 0 \leq Q \leq I^R + B\}$. This contains all possible values of the vector $(S, B, Q)$, where $S$ is the state vector. Define $D_0^* = \Sigma$ and $D_{t-1}^* = \{B, Q | B, Q \geq 0\} \times D_t^*$ for $t \geq 0$. Then the $D_t^*$ contain all possible values of the vector $H_t$, and $\Sigma \times D_t^*$ contain all possible values of the vectors $(S_t, H_t)$. Then the sets $\Sigma \times D_t^*$ form a sequence of maximal domains for the equilibrium behavioural functions. It is quite possible, and likely useful, to define equilibrium on some smaller domains, however.

Now, define equilibrium as a system of functions $\Lambda$ as follows:

\[
\Lambda = \{ V_i^R, B_i, Q_i : D_i \rightarrow \mathbb{R};
\psi_i : D_i \times \mathbb{R}_+ \rightarrow \mathbb{R};
\rho_i : D_i \rightarrow (0,1) \}_{i=0}^\infty \text{ with } D_i \subseteq \Sigma \times D_i^* \forall t
\]

is an equilibrium if and only if:

(i) $(S_t, H_t) \in D_t \Rightarrow (S_{t+1}, H_{t+1}) \in D_{t+1}$ for all feasible $B, Q$ as computed by equations (4.1) using the functions $\Lambda$. This ensures that next-period values of all variables can be computed under each contingency, and can be called "closure of the domains".

(ii) The roaster's behaviour is optimal, that is, (4.2) is satisfied with $B = B_t(S_t, H_t)$ and $Q_t = Q_t(S_t, H_t)$.

(iii) The spot market clears. That is, (4.3), (4.3)' and (4.3)" always hold.

(iv) (4.4) is satisfied by $\rho_i$
The setting is rather more complicated, but the equilibrium concept here is exactly the same as the "perfect rational expectations equilibrium" of Stokey (1982) or what Chari and Kehoe (1990) call a "sustainable plan" (although here we have a monopolist instead of a government). The traders and planters have expectations as to what the roaster would do in any conceivable situation, and the roaster, understanding these expectations, makes decisions to maximize its wealth. What makes it an equilibrium is that the traders' and planters' expectations and the roaster's decisions coincide. It is well known that this type of game tends to have a very large number of equilibria. The following two sections develop two that are of special interest.

5. A Pessimistic Equilibrium.

First, imagine an isolated monopolist. Imagine that there were no planters or traders, just the roaster, and that the roaster had on hand initially $y$ units of green coffee. Then the roaster would solve the optimal depletion problem of roasting and selling these beans so as to earn the maximum possible present value. Its Bellman equation would be

$$W(y) = \max_{Q \in [0,y]} \{Qf(Q) - C(Q) - k(y-Q) + \beta W((1-\delta)(y-Q))\}.$$  

Let $Q^{IM}(y)$ be the choice of $Q$ and $W$ be the value function that solve this equation. They characterize the optimum in the isolated monopolist's problem.

Let $p^* = -k/(1-\beta(1-\delta))$. Define the following cluster of functions $\Delta^*$:
\[ \Lambda^* = \{ V_t^*, B_t^*, Q_t^* : \Sigma \to \mathbb{R} ; \psi_t^* : \Sigma' \to \mathbb{R} ; \rho_t^* : \mathbb{R} \to [0,1] \}_{t=0}^\infty \]

with \( V_t^*(s) = W(x) - p^*(x - I^R) \), \( Q_t^* = Q^M(x) \), \( B_t^* = x - I^R \), \( \psi_t^* = p^* \), and \( \rho_t^* \equiv 0 \) for all \( t \).

The behaviour described by \( \Lambda^* \) is simple: no-one ever plants coffee, the spot market always reaches a price of \( p^* \), and the roaster buys what can be found on the market and then acts like an isolated monopolist. If the roaster were to buy less than the total availability, the traders would store the rest. We offer:

**Proposition 1.** The cluster of functions given by \( \Lambda^* \) is an equilibrium.

**Proof:** We verify the various equilibrium requirements in turn.

(i) Closure of the domains is trivial because they contain all possible values of the state vector.

(ii) We need to verify that \( V_t^*, Q_t^* \) and \( B_t^* \) together solve the roaster's Bellman equation. Noting that the roaster's end of period storage equals \( I^R + B - Q \), next year's value of \( x \) is given by the sum of (4.1.a) and (4.1.b), and next year's value of \( (x - I^R) \) is given by (4.1.b), the right hand side of the roaster's Bellman equation (4.2) is:

\[
\max_{Q_t^*} \{ Qf(Q) - C(Q) - p^*B - k(I^R + B - Q) + \beta W((1-\delta)(x-Q)) - \beta p^*((1-\delta)(x-B-I^R)) \}.
\]

The terms in \( B \) cancel out. The problem is thus:

\[
\max_{Q_t^*} \{ Qf(Q) - C(Q) - k(I^R - Q) + \beta W((1-\delta)(x-Q)) - \beta p^*((1-\delta)(x-I^R)) \}
\]

---

\( ^8 \)If we had free disposal, a similar equilibrium could be constructed with \( \psi_t^* \equiv 0 \) and traders burning, rather than storing, any beans not bought by the roaster.
max(Q)\{Qf(Q) - C(Q) - k(x-Q) + \beta W((1-\delta)(x-Q)) + k(x-I^R) - \beta(1-\delta)p^*(x-I^R)\}

= \max(Q)\{Qf(Q) - C(Q) - k(x-Q) + \beta W((1-\delta)(x-Q))\} - p^*(x-I^R)

= W(x) - p^*(x-I^R),

which is the assumed value function. Thus, the planters' Bellman equation is satisfied.

(iii) The spot market always clears, regardless of the number of beans on the market, because if \psi_t = p^*, (4.3) always holds with equality.

(iv) With coffee prices never going above zero, it clearly is never in the interest of planters to plant coffee. Thus \rho_t=0 is strictly optimal for all t.

Thus, \Delta^* is consistent with spot market clearing and optimal behaviour on the part of all agents. Q.E.D.

What we have found here may be called a monopoly failure result: the monopolist is unable to extract any profits at all due to its lack of commitment. It is somewhat more akin to monopoly failure results when consumers need to make an investment before using the good (Farrell and Gallini, 1988) than to Coase conjecture results because in the former case the monopoly failure results in less social surplus being extracted than under a monopoly with commitment, while under the Coase conjecture the failed monopolist extracts all of the social surplus (although it does not get to keep any for itself). Note that this result is somewhat more robust than those other forms of monopoly failure. It does not require a sufficiently small period length (in contrast to Stokey (1981) and Ausubel and Deneckere (1989)) and it does not need a sufficiently small fixed cost for the planters (in contrast to the consumers in Farrell and Gallini).

This is a "pessimistic" equilibrium because in it no surplus is extracted at all. By accident
there may be in period 0 some coffee left over from some previous history, or dropped as manna, but none is ever produced. We may ask whether such an equilibrium is a reasonable outcome of this system in which there is so much surplus to be extracted; surely there must be other equilibria in which coffee is actually grown. The next proposition states that in a certain sense, the outcome of $\Delta^*$ is the only outcome possible in a "well-behaved" equilibrium. Specifically, if the roaster's value function and the "reduced form" price function are both continuous, then no one will ever plant coffee in equilibrium.

Proposition 2. Let $\Delta$ be an equilibrium with $V^R_t$ continuous for all $t$. Suppose further that $\psi_t(S,H)$ (given by $\psi_t(S,H) = \psi_t(S, H, B_t(S,H), Q_t(S,H)) \forall S,H \in D_t$) is continuous for all $t$. Then we must have $p_t = 0$ for all $t$.

To prove this we need a lemma. It states that in such an equilibrium, whenever the roaster buys, the intertemporal arbitrage condition (4.3) must hold with equality.

Lemma 1. Let $\Delta$ be an equilibrium as assumed in Proposition 2. Then for any $t$ and for any $(S_t,H_t) \in D_o$ if $B_t(S_t,H_t) > 0$, we must have $\psi_t(S_t,H_t) + k = \beta(1-\delta)\psi_{t+1}(S_{t+1},H_{t+1})$.

Proof: Assume otherwise. Consider $S_t$ and $H_t$ such that

\begin{align}
(5.1) & \quad B_t(S_t,H_t) > 0 \quad \text{and} \\
(5.2) & \quad \psi_t(S_t,H_t) + k > \beta(1-\delta)\psi_{t+1}(S_{t+1},H_{t+1}).
\end{align}

For convenience denote the equilibrium choice of $B$ and $Q$ at this point as $B'$ and $Q'$. Denote
the equilibrium values of $I_{t+1}^R$, $I_{t+1}^T$ and $\alpha_{t+1}$ by $(I^T)^\prime$, $(I^T)^\prime\prime$ and $\alpha''$, derived from $S_t$ and $H_t$ by (4.1), and call their concatenation $S''$. Similarly denote the equilibrium value of $H_{t+1}$ as $H''$. Note that $(I^T)^\prime\prime = 0$ by (4.1 b), (4.3)' and (5.2). Now suppose the roaster chose to purchase $\epsilon > 0$ less than the equilibrium amount. Then, by (4.1), we would have $I_{t+1}^R = (I^R)^\prime\prime - (1-\delta)\epsilon$, $I_{t+1}^T = (1-\delta)\epsilon$, and $\alpha_{t+1} = \alpha''$, which we can concatenate as $S_{t+1}(\epsilon)$. Note that $S_{t+1}(\epsilon)$ takes a limit of $S''$ as $\epsilon \to 0$. Similarly we will denote $(B'-\epsilon, Q', H_t)$ by $H_{t+1}(\epsilon)$, and note that its limit as $\epsilon \to 0$ is $H''$. Since in equilibrium the roaster is acting optimally, it must be true that

$$G(\epsilon) = f(Q')Q' - C(Q') - (B'-\epsilon)\psi_t(S_t, H_t, B', Q')$$

$$- k(I^R_t + B'-\epsilon - Q') + \beta(1-\delta)V_t^R(S_t, H_t, B', Q')$$

is maximized at $\epsilon = 0$. Since the first two and last two terms of $G(\epsilon)$ are continuous in $\epsilon$, the limit of $G(\epsilon) - G(0)$ as $\epsilon \to 0$ is

$$\zeta = \lim_{\epsilon \to 0} \{ (B')\psi_t(S_t, H_t, B', Q') - (B'-\epsilon)\psi_t(S_t, H_t, B'-\epsilon, Q') \},$$

the limit of the difference in procurement costs. Now, when $\epsilon > 0$, since $B'-\epsilon < B' \leq x_t - I_t^R$, we must have

$$\psi_t(S_t, H_t, B'-\epsilon, Q') + k = \beta(1-\delta)\psi_{t+1}(S_{t+1}(\epsilon), H_{t+1}(\epsilon))$$

by (4.3)'. In other words, if the roaster leaves some positive quantity $\epsilon$ on the market at the end of the period, spot market prices must adjust to make traders willing to hold it to the next period. Since the right hand side of this is continuous in $\epsilon$ by the assumed properties of $\Delta$, the limit of $\psi_t(S_t, H_t, B'-\epsilon, Q') + k$ as $\epsilon \to 0$ is $\beta(1-\delta)\psi_{t+1}(S'', H'')$. Thus, we find that

$$\zeta = (B'\{ \psi_t(S_t, H_t, B', Q') - [\beta(1-\delta)\psi_{t+1}(S'', H'') - k] \} > 0$$

by (5.1) and (5.2). Thus, the limit of $G(\epsilon) - G(0)$ as $\epsilon \to 0$ is positive. But this contradicts the requirement that $B'$ be the optimal level of purchases for the roaster in this situation. Thus, (5.1)
and (5.2) cannot hold at the same point, and the lemma is proved. Q.E.D.

Proof of Proposition 2.

Let $\Delta$ be an equilibrium as described in the statement of the proposition. Let $\{p_t\}_{t=0}^\infty$ be a sequence of equilibrium green coffee prices starting from some state and history. In any year $t$ in which a positive quantity of green coffee is produced, we will have $p_t + k = \beta(1-\delta)p_{t+1}$. This is so because a positive coffee harvest must either be held by the traders or bought by the roaster. In the former case, the equality must hold to make traders willing to store (see (4.3)'), and in the latter case the result comes from Lemma 1. (Formally, $\alpha>0$ implies that $x>1^{k+I_T}$. Thus, if $B\leq 0$, $x-1^{k-B}> 0$ and so (4.3)' applies. If $B>0$, Lemma 1 applies.)

Now we claim that under the conditions of the proposition, if $\rho_t(S_t,H_t)>0$ for any $t$, then $\rho_{t+1}(S_{t+1},H_{t+1})>0$, so that if planting coffee is ever optimal in equilibrium, then it always will be thereafter. Suppose not. Then there exists $t$ such that $\rho_t(S_t,H_t)>0$ and $\rho_{t+1}(S_{t+1},H_{t+1})=0$. Then the present discounted value of a planter's income at time $t$ is given by $V = \phi p_t - K + \beta p_{t+1} + \beta^2 \Pi_{t+2}$, where $\phi = 1$ if the farmer has a coffee tree at $t$ and 0 if not, and $\Pi_{t+2}$ is the present discounted value of a farmer planted in corn as of time $t+2$. Now the present discounted value of the same farmer at $t$ if he plants corn at $t$ and coffee at $t+1$ instead of the other way around is: $V' = \phi p_t - \beta K + \beta^2 p_{t+2} + \beta^2 \Pi_{t+2} = \phi p_t - \beta K + \beta^2 [p_{t+1}+k]/[\beta(1-\delta)] + \beta^2 \Pi_{t+2} > V$. But this is incompatible with the requirement (4.4) that the planter behave optimally at all times in equilibrium.

Now suppose that $\rho_t(S_t,H_t)>0$, so that $\rho_{t+j}(S_{t+j},H_{t+j})>0$ for all $j\geq 0$. Then the present discounted value of a planter at time $t$ is given by $V = \phi p_t + \sum_{t=0}^\infty \beta p_{t+j} - K/(1-\beta)$. If a planter
decided to wait one year before planting coffee and then planted coffee every year thereafter instead of planting it right away, his present discounted value would be $V' = \phi p_t + \sum_{t=0}^{\infty} b^t p_{t+j+1}$ - $\beta K/(1-\beta) = \phi p_t + \sum_{t=0}^{\infty} \beta^t [p_{t+j} + k]/[\beta(1-\delta)] - \beta K/(1-\beta) > V$. But this would contradict the requirement that planters behave optimally in equilibrium, (4.4).

Thus, the only possibility that does not contradict planter optimality is $p_t(S, H_t) = 0 \forall t$. Q.E.D.

The root of this result is found in Lemma 1. If there was production in equilibrium and if the future was continuous in the present, so that the roaster faced no discrete punishment for small deviations, then the roaster would have an incentive to force the green price down abruptly by an $\epsilon$ forbearance. But if traders and planters understood that, the roaster would never get the chance.

Proposition 2 says that in order for coffee to be planted there must be some jump in the functions describing equilibrium. That has a tremendous bearing on the plausibility of equilibria with coffee planting, but this will be discussed in the next section after we have shown an example of such an equilibrium.
6. Some optimistic equilibria.

We will here construct a family of equilibria in which the planters produce coffee permanently. These equilibria will have a simple structure of an equilibrium path supported by a "punishment" which is called into play if the roaster ever defects. This sort of equilibrium is also sometimes interpreted as being supported by "reputation" (for example, Ausubel and Deneckere (1989)), with the monopolist losing a reputation for fair dealing as soon as it steps off the equilibrium path. What will be presented here is a type of "Folk Theorem", since it will be shown that any outcome in which the roaster makes non-negative profits and the planters are willing to plant coffee can be supported by an equilibrium if \( \beta \) is close enough to 1.

Define \( \tilde{p} = K/\beta \). This is the only price at which it is possible to have both coffee and corn produced in equilibrium. We will introduce an abbreviated version of the history variable, \( H \), which will be constrained to equal 1 if the roaster has never deviated from its equilibrium behaviour and 0 if it ever has. In addition, define \( S' = (0,0,\alpha') \), \( \alpha' \in (0,1) \). Consider the following cluster of functions:

\[
\Delta' = \{ V_i^{R'}, B_i^{R'}, Q_i^{R'} : \Sigma \times \{0,1\} \rightarrow \mathbb{R}; \psi_i' : \Sigma \times \{0,1\} \rightarrow \mathbb{R}; \rho_i' : \Sigma \times \{0,1\} \rightarrow [0,1] \}_{i=0}^\infty
\]

with:

\[
V_i^{R'}(S,H) = \frac{f(\alpha')\alpha' - C(\alpha') - \tilde{p}\alpha'}/(1-\beta) \text{ if } H=1 \text{ and } S=S', \text{ and } V_i^{R'} = V_i^{R*} \text{ otherwise;}
\]

\[
B_i^{R'} = x - f_i^{R} \text{ everywhere;}
\]

\[
Q_i^{R'}(S,H) = x \text{ if } H=1 \text{ and } S=S' \text{ and } Q_i^{LM} \text{ otherwise;}
\]
\( \psi'(S,H,B,Q) = \bar{p} \) if \( H=1, S=S', B=B'(S,H), Q=Q' \) and \( p^* \) otherwise;

\[ \rho_t' = \alpha' \text{ if } H=1 \text{ and } S=S' \text{ and } 0 \text{ otherwise} \]

for all \( t \geq 0 \).

The behaviour described by \( \Lambda' \) can be summarized thus: if the state of the market is \( S' \)
and the roaster has never deviated from equilibrium, then it buys and roasts all green coffee
available every year, and it always pays the price \( \bar{p} \). The planters understand this and plant
accordingly. If the roaster ever deviated from the equilibrium in any way or if the state vector
ever was found to be different from \( S' \), then planters would switch into corn permanently at the
earliest convenience, and in all respects the "pessimistic equilibrium" \( \Lambda^* \) would be played.

**Proposition 3.** \( \Lambda' \) is an equilibrium if and only if

\[
W(\alpha' + \alpha'/(1-\delta)) - p^*(\alpha' + \alpha'/(1-\delta)) \leq \left[ f(\alpha')\alpha' - C(\alpha') - \bar{p}\alpha' \right]/(1-\delta).
\]

For any \( \alpha' \) such that \( [f(\alpha')\alpha' - C(\alpha') - \bar{p}\alpha'] > 0 \), this condition will be satisfied provided that \( \beta \) is close enough to 1.

**Proof:** The behaviour of planters is optimal by construction. The spot market always clears
because (4.3) always holds and the only condition in which there would be stocks left on the
open market at the end of the period \( (B<x-I^8) \) is if the roaster was deviating from equilibrium;
but then the price would be \( p^* \) then and thereafter, and so then stocks would be willingly held.

Thus (4.3)' also holds. If \( H=0 \) or \( S\neq S' \), roaster behaviour is optimal by Proposition 1, since
then and thereafter equilibrium \( \Lambda^* \) will be played. The only question is the optimality of roaster
behaviour when \( H=1 \) and \( S=S' \). If it was to deviate, the price would immediately drop to \( p^* \).
It would then solve:

$$\max_{Q,B} \{ f(Q)Q - C(Q) - k(B-Q) - p^*B + \beta W((1-\delta)(\alpha' - Q) + \alpha') - \beta p^*((1-\delta)(\alpha' - B) + \alpha') \},$$

where the last two terms come straightforwardly from the expression for $V^*$. Note that if the roaster deviates this period, the planters will switch to corn next period, so next period there will be one last coffee crop. Thus $(1-\delta)(\alpha' - Q) + \alpha'$ gives next period's total availability (next period's $x$) and $(1-\delta)(\alpha' - B) + \alpha'$ next period's availability net of roaster inventories (next period's $x-I^R$).

Now note that the B terms in the maximand all cancel out. The deviating roaster is then indifferent between all levels of current procurement, provided that enough is purchased to support the optimal roasting quantity ($B \geq Q$). The problem is now:

$$\max_{Q} \{ f(Q)Q - C(Q) + k(Q) + \beta W((1-\delta)(\alpha' - Q) + \alpha') - \beta p^*((1-\delta)\alpha' + \alpha') \}$$

$$\max_{Q} \{ f(Q)Q - C(Q) - k(\alpha' + \alpha'/(1-\delta) - Q) + \beta W((1-\delta)(\alpha' - Q) + \alpha') - \beta p^*((1-\delta)\alpha' + \alpha') + k(\alpha' + \alpha'/(1-\delta)) \}$$

$$= W(\alpha' + \alpha'/(1-\delta)) - \beta p^*((1-\delta)\alpha' + \alpha') - p^*(\alpha' + \alpha'/(1-\delta)).$$

That this is no greater than the payoff from not deviating is the condition (6.1).

The second statement of the proposition follows if we can establish that for any $y$, $W(y)$ is uniformly bounded above for all values of $\beta$. Fix a value of $\beta \in (0,1)$, and let $q_t$ be the optimal sequence of roasting quantities for the isolated monopolist starting from an endowment of $y$. Then $W(y) \leq \sum_{i=0}^{\infty} \beta^i f(q_i)q_i \leq \sum_{i=0}^{\infty} \beta^i f(0)q_i \leq \sum_{i=0}^{\infty} \beta^i(1-\delta)^i y_f(0) \leq \sum_{i=0}^{\infty} (1-\delta)^i y_f(0) = y_f(0)/\delta$. Since this quantity does not depend on $\beta$, the Proposition is proven. Q.E.D.

Thus, there are equilibria which support a permanently functioning coffee industry (provided (6.1) holds for some $\alpha'$). Note that except possibly for some knife-edge value of $\beta$,
if any level of production can be sustained in this way, then a whole range of different levels of output can be. For sufficiently high discount rates, it will be possible to support: the competitive level of output; the monopolist's first best (which maximizes profits subject to the planters' participation constraint); levels below the monopolistic level and levels above the competitive level. Thus, if we believe that equilibria of this sort are what drive the real-world coffee market, then we must abandon the Marshallian presumption that monopoly power in roasting necessarily will provide less than the socially efficient amount of coffee.

Proposition 3 gives some hope that the monopolist's first best can be attained simply through reputation. However, there is no guarantee that this will work in practice, for a variety of reasons. First, the proposition is a limiting result, which shows that the first best will be an equilibrium if \( \beta \) is high enough, and there is no guarantee of that. Second, even if the first best is an equilibrium, there is no guarantee that that is the equilibrium that will actually be played, since \( A^* \) is always an equilibrium and the system could get caught in that one instead. This is a way of saying that if planters simply do not trust the roaster to begin with, there may be nothing it can do to change that.

Two more reasons reputation may not "work" result from special features of the model. First, it is necessary that they involve some sort of discrete punishment for even tiny deviations. Note the abrupt discontinuity in the entire nature of the system as the state vector moves even slightly away from \( S' \). This is not a special feature of this equilibrium; Proposition 2 shows that it is a general feature of equilibria that keep coffee production going. Thus, they would not survive the addition to the model of any imperfection in monitoring at all. Suppose that the traders could observe only \( B' = B + \mu \), rather than \( B \), in any period, with \( \mu \) representing some
random noise. Then they would never know whether the roaster had played its equilibrium strategy or had deviated by some tiny amount, and so the kind of equilibrium represented by A' could not exist. We could in that case construct an equilibrium with traders acting as if a defection had occurred when seeing that B' was below some critical value, by analogy with models of oligopolistic collusion with imperfect monitoring. However, such an equilibrium would have to involve "collapses" or "punishments" a certain fraction of the time as the noise randomly pushes B' below the threshold. Thus, the equilibrium would not support an outcome equivalent to that from full commitment. There would still be unexploited gains from trade between the planters and the roaster.

Finally, note that in the language of game theory, this equilibrium requires planters to play weakly dominated strategies. Consider a planter about to replant his coffee tree. If his conjecture about the simultaneous move of the roaster is correct, namely, that the roaster will obey the equilibrium plan, then this choice will make the planter exactly as well off as he would have been had he switched to corn. However, if that conjecture was incorrect, and the roaster (suppose by error) had deviated, even slightly, the plunge in the coffee price would mean that the planter would have been strictly better off planting corn. The reliance of the equilibrium on weakly dominated strategies reduces its appeal somewhat as a reasonable portrayal of rational behaviour because it means that if there were even the slightest doubt that the roaster might make even the slightest error, the proposed planter behaviour would not be optimal.\footnote{Here we are using the term "weakly dominated" very loosely, because we are not considering deviations by anyone other than the roaster. Since everyone in this model except for the roaster is atomistic, deviations by those other players do not seem interesting.}

In summary, there are sometimes equilibria which provide a reputational solution to the
commitment problem, but they do not offer any guarantees.

7. Equilibrium under an international treaty.

Recall the proof of Proposition 2. The key mechanism was the fact that under a continuous equilibrium, whenever the roaster was purchasing and traders strictly preferred not to store, the roaster could force the price down by a slight forbearance, leaving a small amount on the market at the end of the period. This would cause a price adjustment that would allow the left over beans to be willingly held. In other words, the key is the roaster's ability to create an artificial glut that forces the price to the floor. Since everyone knows that this is possible and always in the roaster's short run interest, no planter invests in coffee. Now suppose that an international agreement was signed under which any glut would be absorbed, as long as it lasted, by the signatory governments at the prevailing price? That would seem to break the mechanism of Proposition 2. One wonders whether or not a continuous equilibrium with permanent coffee production would then be possible. The answer is "Yes".

Define \( \hat{\Sigma} = \{I^R, I^T, \alpha \mid I^R, I^T \in [0, \infty)\} \), where \( \alpha = \arg\max_{\alpha} \{f(\alpha)\alpha - C(\alpha) - p\alpha\} \). In other words, \( \alpha \) is the harvest size that maximizes the roaster's profits subject to the planters' participation constraint. Accordingly, define \( \tilde{\Sigma}' \) as \( \{S, B, Q \mid S \in \hat{\Sigma}, -I^R \leq B \leq x - I^R, 0 \leq Q \leq I^R + B\} \), the analogue to \( \Sigma' \).

Now, if governments have decided to purchase whatever is left on the open market at the end of each period, namely \( x - I^R - B \), the third condition for equilibrium is weakened somewhat. Inequality (4.3) will still have to hold at all times, but (4.3)' will no longer be necessary. Even
if the market is strictly unwilling to hold the left over stocks, the governments by resolution will do so. Under these relaxed requirements for equilibrium, all equilibria that existed in the absence of a treaty still exist. We will now see that there is at least one new one. Consider the following cluster of functions:

\[ \Lambda = \{ \hat{V}_i^R, \hat{B}_i, \hat{Q}_i, \hat{\psi}_i, \hat{\beta}_i \}_{i=0} \]

with:

\[ \hat{V}_i^R = \{ f(\tilde{\alpha})\tilde{\alpha} - C(\tilde{\alpha}) + \tilde{p}\tilde{\alpha} / (1 - \beta) + \tilde{p}l \}^R, \]

\[ \hat{B}_i = \tilde{\alpha} l^R, \]

\[ \hat{Q}_i = \tilde{\alpha}, \]

\[ \hat{\psi}_i = \tilde{p}, \]

\[ \hat{\beta}_i(S) = \tilde{\alpha}; \]

for all i.

The functions \( \Lambda \) describe a constant price of \( \tilde{p} \), with some planters growing corn and others coffee, replanting the trees every year, to give a permanent harvest equal to the monopolist's profit maximizing quantity choice given the price \( \tilde{p} \). The roaster buys and roasts the resulting crop every year. Now we see:

**Proposition 4.** \( \Lambda \) is an equilibrium under the international treaty. It is not an equilibrium without the treaty.

**Proof:** The planters' behaviour is optimal by construction. (4.3) always holds, so the spot market
clears under the intervention. Further, by the definition of $\alpha$, the roaster cannot do better at the input price $p$ than to roast and sell $\alpha$ every period; $\bar{R}(\alpha-i^*)$ is the input cost of doing so. Finally, $\Lambda$ is not an equilibrium without the treaty because $\bar{V}_i$ and $\bar{U}_i$ are continuous and $\bar{p}_i$ is not identically equal to zero, while Proposition 2 applies. Q.E.D.

Now we have something quite different from what we had before: a continuous equilibrium with permanent coffee production and no weakly dominated strategies being played. Further, this is achieved without any actual storage by the governments involved. They have merely to commit themselves to storage should the need arise, and that defuses the threat of roaster opportunism. Since there is then no incentive for opportunism, the governments never are called into action.

One might wonder about the credibility of the treaty. Specifically, if the roaster did leave some stocks on the open market at the end of the period, would ICA members really be willing to absorb them, given that they would necessarily have to do so at a loss? The answer is that in the real world, political pressure for the ICA was sufficient that consuming and producing governments alike were willing to take a considerable loss in order to keep it going. In the evolution of the ICA, at times large quantities of beans were stored by producer countries to keep exports below their quota in face of high production levels. In doing so, those governments incurred huge financial costs (Gordon-Ashworth, 1984, p. 217), but they calculated that shirking their agreed role and thus endangering the agreement would simply make them even worse off.

Note a paradox: in this equilibrium and in the pessimistic one $\Lambda^*$, the roaster faces what must be called a flat input supply curve. In the case of equilibrium $\Lambda$, this is perhaps understandable, because what the treaty does is in effect to rob the roaster of its monopsony
power, but in the case of $\Delta^*$, it is the roaster's unfettered monopsony power that brings about the flat $\psi$ function. The point is that in that case, no matter what happens and no matter what the roaster does, the market expects it to indulge in opportunism at the next possible moment, and this always brings the price to a natural floor.

8. Discussion.

What has been established here is that the structure of the coffee market gave rise to a time-consistency problem and that the ICA can be interpreted as a solution to it. This, of course, in no way implies that it is the only possible solution. Futures markets, forward contracts and vertical integration are well-known alternatives. The point is that each device will have its own costs and limitations, so that which one is desired in a given case will depend on their relative drawbacks in each case. Futures contracts, for example, typically trade no more than a year or two in advance of maturity, much shorter than the horizon of a coffee planter. Legally binding forward contracts with individual planters may be feasible but would be very costly given the millions of small farmers who would be signatories. Vertical integration would mean in this case roaster purchases of huge tracts of land in producer countries, which could run up against nationalist politics in those countries and also the risk of future expropriation.

The purpose here has not been to remove any of these devices from the theoretical inventory, but to add a new one, one that in this case seems to have been preferred by the firms
involved.

The argument that the ICA may have served as a commitment device seems to be, in all of the long literature on commodity price stabilization schemes, quite unprecedented. It points out that in some important cases there can be a role for "stabilization" schemes that has nothing to do with stabilization. It suggests a policy rule of thumb: if a commodity is perennial and if large processing firms lobby alongside of producers for a stabilization scheme for it, there is a good chance that it is a socially efficient scheme. This is not because managers of large processing firms are especially big-hearted or brilliant, but simply because it appears to be only in the conditions outlined here that it would be in their incentives to press such a case. Stabilization schemes encroach on the large firms' freedom of movement, and tend to increase their input prices, so one must suppose that when they ask for such a scheme, there must be something going on beneath the surface.

It is instructive to contrast the historical episode discussed in this paper with related situations in which different outcomes were observed. Roasters made no concerted effort to agitate for an ICA in the first half of the century, for example, and that is consistent with the view that Brazil was able to extract monopoly rents during that period. The argument of this paper requires a diffuse sector of planters, unable to organize effectively without outside help, and this was not a reasonable description of the green side of the market until after the Second World War and the entry of many new producers. On the other hand, the roasters have not been supportive of ICA's now for several years. Their support waned in the 1970's, and in February 1980 the National Coffee Association (recall section 2.B) voted at its annual meeting in Boca Raton, Florida to withhold political support from legislation required to implement the ICA then
being negotiated (Economist Intelligence Unit, 1989, pp. 23-4). Part of the reason was apparently resentment over certain maneuvers of the Latin American governments, but it is also significant that the structure of the market had again changed dramatically since the early 1960's. In the late 1960's Procter and Gamble had decided to purchase an independent West Coast brand named Folger's; it spent the 1970's and 1980's building it into a major national U.S. brand. This destroyed the dominant position of General Foods on the roasting side of the market, and led to very bitter competition between the two firms. It is easy to see how the commitment role of the ICA would be obviated by a highly competitive roaster sector; the argument in this paper requires a highly concentrated or collusive roasting sector which is able to extract monopsony rents from farmers, and that would be destroyed by, say, two Bertrand roasters bidding against each other.

As a final example, it is arguable that the argument made here for coffee would not work if applied to cocoa, because the largest cocoa producers (at the time of the first cocoa agreement, all in West Africa) were countries in which producer prices were set by the government.

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10This competition is interestingly documented and analyzed in Hilke and Nelson (1989). They argue that there is considerable evidence that General Foods tried to force Procter and Gamble out through predatory pricing. One consultant to General Foods apparently compared that firm's response to Folger's expansion to the bombing of Hanoi (footnote 43). In other words, this was not a terribly collusive duopoly. The consensus in the business press even now seems to be that the industry is not very profitable because it is too competitive; see Fortune, May 21, 1990.

11A related point is that with an oligopsony instead of a monopsony there are more ways in which to build a folk-theorem type result. For example, the firms can agree to have a price war if any deviates, so that the punishment phase is worse than in the case of a monopolist. This is essentially the point of Gul (1987) and Ausubel and Deneckere (1987) in the context of durable goods producers. However, given the history of roaster interaction after the entry of Procter and Gamble, this is certainly not the right way to analyze this particular market.
Commitment on the part of the large chocolate firms was essentially irrelevant to the decisions of planters. Thus, there was less of a case for a commodity agreement. In this case, the large processing firms mostly lobbied against the proposed agreement\textsuperscript{12} -- including General Foods.

\textsuperscript{12}This is dealt with extensively in Short (1987).
<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
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<tr>
<td>Q,R</td>
<td>Quantity roasted and purchased by roaster.</td>
</tr>
<tr>
<td>f(Q)</td>
<td>Demand curve for roasted coffee.</td>
</tr>
<tr>
<td>C(Q)</td>
<td>Cost of roasting.</td>
</tr>
<tr>
<td>k</td>
<td>Marginal cost of storage.</td>
</tr>
<tr>
<td>δ</td>
<td>Rate of depreciation in storage.</td>
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<tr>
<td>K</td>
<td>Cost of planting coffee tree.</td>
</tr>
<tr>
<td>I^R, I^T</td>
<td>Beginning of period inventories of roaster and of traders.</td>
</tr>
<tr>
<td>α</td>
<td>Fraction of plots allocated to coffee as of start of period; hence, size of coffee harvest within period.</td>
</tr>
<tr>
<td>x = I^R + I^T + α</td>
<td>Total availability.</td>
</tr>
<tr>
<td>S = (I^R, I^T, α)</td>
<td>State of the market.</td>
</tr>
<tr>
<td>H</td>
<td>History. (H_{t+1} = (B_t, Q_t, H_t).)</td>
</tr>
<tr>
<td>ψ(S_t, H_t, B_t, Q_t)</td>
<td>Equilibrium price function.</td>
</tr>
<tr>
<td>ψ(S_t, H_t) = ψ(S_t, H_t, B_t(S_t, H_t), Q(S_t, H_t))</td>
<td>Same, with equilibrium roaster behaviour substituted in.</td>
</tr>
<tr>
<td>ρ_t(S_t, H_t)</td>
<td>Fraction of planters who replant their coffee trees at time t.</td>
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<tr>
<td>V^R_t</td>
<td>Roaster's value function.</td>
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Bibliography


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