No. 362 April 1993

Rationalizing the International Coffee Agreement Virtually

by
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ABSTRACT

Social choice theory tells us that it is difficult to ascribe to any group a collective will. Yet groups *do* decide. This paper is an attempt to make sense formally of decision-making by one such group—the International Coffee Agreement—under which world trade in coffee was governed with one or two lapses for about a quarter century. The notion of virtual implementation is used to legitimize treatment of the ICA as an optimizing entity. A particular social choice rule is specified for the ICA. This rule, though manipulable, is nonetheless virtually implementable in Nash equilibrium, a notion due to Matsushima (1988) and to Abreu and Sen (1991). The constituent parts of this rule are constructed using published data on demand and supply elasticities and traded quantities. The empirical results of the paper provide a *rationalizing* argument for the ICA, in the sense that if it sought to maximize the criterion function that I specify, we would expect it to behave precisely as it did behave. The recent demise of the ICA permits a further check of the model, which is shown to project with reasonable accuracy the performance of the world coffee market in the post-ICA period.

*I have benefited from helpful comments by Jim Andreoni, Dan Bromley, David S. Bullock, Jean-Paul Chavas, and Ian Sheldon, who are not responsible for any remaining errors. Thanks go to seminar participants at the University of Illinois and at the University of Wisconsin. I wish to thank Yang Yao for exceptionally able research assistance. Financial support in the form of a Hatch award through the University of Wisconsin College of Agricultural and Life Sciences is gratefully acknowledged.

RATIONALIZING THE INTERNATIONAL COFFEE AGREEMENT VIRTUALLY

I. Introduction

The problem of collective choice represents a conundrum for economics. At one level it seems that groups of people are adept at making joint decisions—witness a group of schoolchildren choosing sides for a playground football game. Yet the hallmark of the formal study of social choice has long been of an essentially negative nature. Since the pioneering work of Arrow (1963) the leading regularity of models of social decision problems is the impossibility of devising a well-behaved decision rule for groups. In short, groups cannot decide. If a familiar set of conditions on individual preferences and the decision rule are satisfied, then any Arrovian social *welfare* function must be dictatorial (Arrow 1963). A related set of conditions together guarantee that any nondictatorial social *choice* function must be manipulable: some member can gain by lying about his or her individual preferences (Gibbard 1973; Satterthwaite 1975).[1]

In recent years a line of research with a more positive theme has burgeoned. The literature on implementation of a social choice rule adopts the stratagem of combining game theory with social choice theory, seeking formally to legitimize the notion of collective decision-making. Implementation begins with a social choice rule or correspondence, f, which maps agents' preferences over a set of social alternatives into a subset of the alternatives. This rule operates upon agents' *preferences*, and these are known only when they are supplied by the agents themselves, at least one of whom Gibbard and Satterthwaite assure us will lie. This is the central difficulty, inherent in a social choice rule, that implementation seeks to remedy. Implementation consists in devising a game form (or *mechanism*), to be played by the same agents, with the property that the equilibrium outcome of the game form agrees with the outcome that f would produce if the true preferences were known. The idea is to harness the strategic impulse of agents, which would cause f itself to unravel, so as to produce a "correct" outcome.

A social choice rule is *implementable* if a game form can be devised whose equilibria coincide with the set of alternatives that f itself yields. A crucial requirement is that this agreement obtains

[1]The literature connected with these results is vast; a summary shall not be attempted here. Sen (1986) provides an authoritative survey.

for any possible array of preferences, for the implementing game form must be designed without knowledge of agents' preferences. Maskin (1977), in a pathbreaking paper to which much of the recent literature can be traced, used the assumption of complete information and employed the Nash equilibrium concept, showing what must be true in order for an f to be implementable in Nash equilibrium.[2] Though positive in nature, Maskin's result was soon shown to be more restrictive than first hoped.[3] However, it has now been extended in a number of directions, with the result that a wide variety of social choice rules can be implemented so long as one takes care in specifying the game form appropriately.[4]

A recent innovation is the notion of "virtual" implementation, due to Matsushima (1988) and to Abreu and Sen (1991). In contrast to "exact" implementation, a social choice rule is implemented virtually if the value of f obtains with arbitrarily high probability. The extraordinarily permissive main result of AS is that under a mild set of conditions *any* social choice rule can be implemented virtually. Virtualness, in which preferences over outcomes are extended to corresponding preferences over lotteries over outcomes, suggests that the mechanism itself has a stochastic element, an idea that has some appeal in any empirical setting. Abreu and Sen (1991) also adopt Maskin's (1977) assumption of complete information—that each agent know's everyone's preferences, though the designer of the implementing mechanism does not have this information.[5]

My purpose in this paper is to examine the decision-making problem for a particular collective body, the International Coffee Agreement (henceforth the ICA), an organization amongst states that trade on the world market in coffee either as exporters or as importers. From 1963 to 1989, with one or two lapses the ICA controlled trade by limiting exports from member exporters to member importers, assigning to each exporter a quota that was chosen anew annually. The aim of the paper is to legitimize the idea that this organization was an optimizing entity, and it is here

[2] Since Maskin a number of alternative equilibrium concepts have been examined. Among the alternatives to Nash equilibrium are implementation in dominant strategy equilibrium (this strong equilibrium notion was used by Gibbard (1973); and Satterthwaite (1975)), in undominated Nash equilibrium (Palfrey and Srivastava (1991)), and in subgame perfect equilibrium (Moore and Repullo (1988), Abreu and Sen (1990)). See Moore (1992).

[3] Maskin showed that in order for a given social choice rule f to be implementable in Nash equilibrium, it is necessary that f be *monotonic*, and sufficient that f be monotonic and satisfy no veto power. If f is a single-valued function (as is the rule employed in this paper) Muller and Satterthwaite (1977) show that f is monotone precisely when it is dictatorial.

[4] Moore (1992) succinctly emphasizes this point, as well as the drawbacks to the required assumptions. He states, "The latest developments in implementation theory have been striking. We suddenly seem capable of implementing anything, provided that we appeal to the right notion of equilibrium. This is quite a contrast with the earlier literature. ... Although I have not stressed the fact, ... these general results are obtained at a cost in terms of realism." (1992, p. 209).

[5] For a survey of the literature on implementation under incomplete information assumption, see Palfrey (1992).

that the implementation apparatus comes into play. Using data on the world coffee market for the 1984/85 crop year, I devise a social choice rule that amounts to a candidate criterion function for the ICA. This rule, which maps preferences of member countries into a vector of quota levels for member exporters, is shown to be manipulable. However, it satisfies the Abreu and Sen (1991) conditions guaranteeing that it is implementable virtually.[6] The role of implementation in this paper, then, is to rescue an optimizing framework for the ICA.[7]

The search that I undertake is for a *rationalizing* criterion function for the ICA. "Rationalize" is used here in the technical sense. I ask whether it is possible to devise a theoretically coherent and logically consistent model of collective decision-making (this will amount to an f) such that the data we observe would have been generated if agents behaved according to the model.[8] My search consists in first specifying a candidate social choice rule, which takes the form of an asymmetric Nash bargaining rule; then using demand and supply elasticity data to specify a set of preferences for members (these are profit functions for exporters and surplus measures for importers). The search can be judged successful if, when available information on the primitives of the model (preferences, agents, and alternatives) is employed, *the criterion function is maximized by the outcome that is actually observed*.

The International Coffee Agreement provides a fertile ground for my exercise for a number of reasons. First, the institution itself is intrinsically interesting in that its members include both consuming and producing countries. This distinguishes the ICA from the familiar cartel problem, and presents collective decision-making challenges all its own. Another is that data concerning the decision process and the actual decisions are available from published sources. During its yearly meeting the ICA chose a quota vector using a weighted voting scheme—the weights assigned to each country are data for this study.[9] Third, the ICA collapsed recently, thereby granting an opportunity

[6] A natural question is whether the alternative implementation schemes—implementation in subgame perfect equilibrium, for example—could have been used in the place of the virtual scheme. The answer to this question is no. The rule that I develop is actually a *function*, which is in general more difficult to implement than a social choice *correspondence*. One of its appealing features—all-important for my purposes—is that Abreu and Sen's theorem covers this case.

[7] Buchanan (1975) argues that there is no sense in attempting to claim that a group optimizes (see also Buchanan (1954)). This paper does not attempt to refute Buchanan on philosophical grounds, but it does take some small steps toward countering his claim at least in a formal, mathematical sense.

[8] This use must be distinguished from the use of "rationalizability" in game theory, as in Bernheim (1984) and Pearce (1984).

[9] I should hasten to note that though a voting scheme is at work, the social choice rule developed below does not seek to mimic the institutional framework of the ICA. My f is built up from data on the market behavior of participants.

to observe the world coffee market at work shorn of its Agreement. As we shall see, this permits a useful comparison between my results and actual performance of the market. My findings are by and large positive.[10] The search for a rationalizing criterion function is successful, and what is more it yields results that perform quite well in projecting actual behavior in the post-ICA world coffee market. It also permits welfare comparisons that measure the welfare effects, for exporters and importers, of the ICA.

Though it is strong, the perfect information assumption seems to be reasonable in this instance, in that the member countries are able to observe one another without great difficulty. Indeed, one of the prominent features of the ICA is a stringent reporting requirement, which makes available to member countries (and to analysts) a thorough dataset on the world coffee market. The story that is often used to motivate the notion of implementation under complete information is that of a club, whose bylaws were written in the past before it was known who the members would be. Once the club is formed, the members know each other quite well, and they function under the existing rules. This story appears to match the ICA nicely. The original 1963 Agreement, though amended in the ensuing years, remained largely the same for the entire 26-year period. The membership of the Agreement continually changed as time passed, and members' knowledge of one another, I submit, remained fairly complete.

In the following sections of the paper I describe the International Coffee Agreement briefly; I provide a summary of the virtual implementation argument of Abreu and Sen and develop the necessary notation; and I then devise a social choice function for the ICA and carry out an empirical investigation of its past decision-making.

II. The International Coffee Agreement

Akin in certain respects to an international cartel, the International Coffee Agreement is nevertheless almost of its own kind in international trade. It is among the class of International Commodity Agreements, of which there have been five noteworthy examples in recent history (the others are for cocoa, sugar, tin, and natural rubber). These agreements bear some resemblance

[10] My use of the word "positive" is in opposition to "negative," a word that characterizes much of the social choice literature. Despite the risk that it will suggest to the reader the normative-positive dichotomy, I use the word positive here for want of an alternative that conveys the same idea.

to export cartels, about which there is a vast literature.[11] The distinction between the two organizational forms is important for my purposes. Unlike an export cartel, a commodity agreement includes both exporting and importing countries as members.

Though this is not the place for a comprehensive overview of the International Coffee Agreement, I wish to provide a brief look at its essentials in order to motivate what is to come.[12] The history of the world coffee market before 1960 is one of widely varying prices, intermittent shortages, and, during lengthy periods, chronic oversupply. Brazil, by a good bit the world's largest producer of coffee, suffers severe frosts and droughts with sufficient frequency that other traders learned early on to fear the resulting market disruption.

Before World War II Brazil singlehandedly held the world price above equilibrium by buying coffee from its growers and destroying it.[13] This program soon became prohibitively expensive, and Brazil's share of the world export market dwindled. In 1954 Brazil suffered a disastrous frost, and prices shot upward, to as much as $1.00 per pound in the U.S. By 1960 Brazil's growers were back on their feet and another surplus loomed on the horizon. The first of a series of four ICA's was established in 1962, to come into effect in 1963. The Agreement's headquarters, located in London and dubbed the International Coffee Organization (ICO), was charged with administering the provisions of the Agreement. The U.S., the world's largest importer of coffee, played a leading role in the formation of the Agreement, and has continued to be an influential member. The Agreement was renewed, with some revisions, in 1967, 1976, and 1983. It finally broke down when the attempt to produce yet another version failed in July of 1989. Since that time the ICA has been in effect, but without economic provisions.[14]

The Agreement has two primary goals: To achieve a balance between world supply and demand;

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[11] A sampling of studies addressing the various problems facing a cartel includes papers by Stigler (1964), Green and Porter (1984), Laffont and Tirole (1986), Crampton and Palfrey (1990), and Harrison and Rustroñ (1991). See also the references cited therein.

[12] There are a number of thorough surveys, upon which my discussion draws. Fisher (1972) provides an authoritative study of the political and political economic aspects of the Agreement, though his book is by now dated somewhat. The interested reader may wish to consult more recent works by Marshall (1983) and Pieterse and Silvis (1988) on the coffee agreement, and by Gilbert (1987) and Gordon-Ashworth (1984) on commodity agreements generally. The encyclopedic textbook by Wrigley (1988) provides a remarkably broad survey of the coffee industry in every aspect; his discussion of the ICA specifically is likewise both thorough and elegant.

[13] "[A] history of controls to this date [1937] is essentially a history of national controls introduced by Brazil" (Gordon-Ashworth (1984, p. 209)).

[14] See Gilbert (1987) for an overview of the five agreements active since World War II. Gilbert's prescience is noteworthy. He states that "... [I]t is indeed ... likely that more of the existing agreements will lapse (p. 591)." Coincidentally, on April 1, 1993, governing bodies of both the ICA and the International Natural Rubber Agreement—the last two active agreements—announced that these two agreements had collapsed.

and to moderate price fluctuations. Evidently a subsidiary goal, at least of the U.S., was from early on to provide a certain level of export revenue to developing country exporters.[15]

The central mechanism of the Agreement is the setting of quotas or market shares for exporters. "From the outset, the biggest difficulty was, and remains, that of deciding the market shares. Very few countries get the share they claim" (Marshall 1983, p. 108). There are a great many additional features and details, including a provision that scales the quotas up or down by formula within a year in response to extreme movements in a global indicator price. Exporters are required to export one quarter of their yearly quota amount in each three-month quarter of the calendar year. The ICA, unlike the cocoa and rubber agreements, was never a buffer stock agreement.

These quotas are revised annually, at a September meeting in London. This meeting is called by the ICO, and is attended by the Coffee Council, the regulatory body of the Agreement. The Council consists of all members, both importers and exporters, of which there are 25 and 40, respectively. With the exception of rules changes (which require a two-thirds majority) their decisions are produced by simple majority rule. A total of 2000 votes are distributed among the member countries, 1000 to exporters and 1000 to consumers. This distribution depends upon historical quota sizes (for exporters) and import volumes (for importers). The collective will of the Agreement is compiled into a final annual decision—the selection of quota levels for member exporters—at this meeting, where a draft proposal is produced by a handful of the larger members, and then submitted to a final vote by the entire council.

At least three puzzles present themselves in connection with the ICA. First, why and how did the agreement come into being? Second, how did the agreement work while it was in effect? Third, why did the agreement finally disintegrate in 1989? Of these three, the first and last lie outside the purview of the present paper, which emphasizes rationalizing observed behavior under the agreement. Gilbert (1987) and Gordon-Ashworth (1984) provide insights into the question of why the agreement arose in 1963. Evidently the demise of the ICA can be attributed largely to the dissatisfaction among the smaller exporters with their quotas. It seems that some of the importing members also grew increasingly unhappy with the artificially high world coffee prices that obtained

[15] According to Gordon-Ashworth (1984, p. 64), the U.S. displayed little support for international commodity agreements until about 1960, when its adherence to the ICA "resulted from its new perception that Western hemispheric security would be improved by the stability of coffee trade and prices."

under the Agreement (Canada and Australia, for example, withdrew from the ICA in 1987). In the concluding section I revisit this question briefly.

III. Virtual Implementation[16]

A general collective decision problem of the kind I consider includes four primitive elements. These are, first, a set of (feasible) outcomes; second, a collection of decision-makers; third, these decision-makers' preferences over outcomes; and fourth, a social choice correspondence f. Let the group of agents—the *council*—be $I = \{1, \ldots, N\}$, where $N \geq 3$. The current element of I is denoted i. The council's task is to select an *outcome vector* $\mathbf{q} = (q_1, \ldots q_N)$ from amongst the set of feasible outcomes the set of feasible outcomes $\mathcal{Q} \subset R_+^N$. Let $\mathcal{Q}^* = (\mathbf{q}^1, \mathbf{q}^2, \ldots)$ denote a countable dense subset of $\mathcal{Q}$, and let $\mathcal{L}$ denote the set of (discrete) lotteries on $\mathcal{Q}^*$. An element of $\mathcal{L}$, denoted x, assigns nonnegative probabilities to elements of $\mathcal{Q}^*$.

Member i has a preference ordering over $\mathcal{Q}$, $R_i(\theta) \subset \mathcal{Q} \times \mathcal{Q}$, where $\theta = (\theta_1, \ldots \theta_N) \in \Theta$ indexes a profile of admissible preferences, and where θ_i indexes i's preferences over $\mathcal{Q}$. The vector θ summarizes the state of the world. Let Γ denote a profile of preferences over $\mathcal{L}$ consistent with θ. Given any two elements $\mathbf{q}, \mathbf{r} \in \mathcal{Q}$, $\mathbf{q} R_i(\theta) \mathbf{r}$ is read, "i prefers $\mathbf{q}$ to $\mathbf{r}$." It is assumed that each member of the council has complete information about the preferences of all members.

Preferences $\theta \in \Theta$ are assumed to satisfy a pair of assumptions. First, (A1) for any pair $\theta, \psi \in \Theta$, there is a member whose ordering over some pair $\mathbf{q}, \mathbf{r} \in \mathcal{Q}^*$ is reversed between the two profiles. Second, (A2) for any pair $\theta, \psi \in \Theta$, there are two members i, j and two alternatives $\mathbf{q}, \mathbf{r}$ such that when comparing these alternatives, i strictly prefers $\mathbf{q}$ and j strictly prefers $\mathbf{r}$. Two assumptions are also placed upon preferences over lotteries. First, (A3) to each element of Γ there corresponds a unique element θ of Θ consistent with γ, in the sense that for every member i the restriction of preferences γ to elements of $\mathcal{Q}$ matches $R_i(\theta)$. Second, (A4) preferences over lotteries are monotone. That is, any lottery that moves probability to a more preferred alternative is preferred by a member to the original lottery.

A *social choice correspondence* (SCC) is a rule $f : \Theta \Longrightarrow \mathcal{Q}$ that associates with each profile a non-empty subset of $\mathcal{Q}$. A *mechanism* G assigns to each agent a strategy set S_i, and provides a

[16]This section draws upon Abreu and Sen (1991). Because the application in this paper has a continuum outcome space, the development here looks to their Theorem 6 in Section 6.

rule for associating to each vector of strategies an outcome (payoff) vector. G is also called a *game form*. A game form is distinguished from a game in that a game form must provide the rules for strategic interaction conditional on a (possibly unknown) θ. Let $S = \times_{i=1}^{N} S_i$, and let $g : S \longrightarrow \mathcal{Q}$ be a *payoff function* that maps the strategies of players into elements of $\mathcal{Q}$. We write $G = (S, g)$. Let $s_{-i} = (s_1, \ldots, s_{i-1}, s_{i+1}, \ldots, s_N)$ be the $(N-1)$-dimensional vector obtained by deleting the ith element of s. In this paper the equilibrium concept under study is the Nash equilibrium. A Nash equilibrium in G is a vector of strategies at which no agent can gain by unilaterally adopting a different strategy. A *Nash equilibrium* for G is a strategy vector $s^* \in S$, denoted $N(G, \theta)$, such that for each $i \in I$, for each $\theta \in \Theta$, $g(s_i^*, s_{-i}^*) R_i(\theta) g(s_i, s_{-i}^*)$ for each $s_i \in S_i$.

The problem of implementation concerns the logical relationship between f and a given game form G. Say that G *implements* f if whenever a council with profile θ plays the game G, the equilibrium of the game and the outcome of $f(\theta)$ coincide. In either case, whether using f or G, the problem is to map preferences into outcomes. The social choice correspondence relies entirely upon the rules embedded in $f(\theta)$ when selecting an outcome. Under a general set of conditions, members participating in a collective decision process that incorporates f face incentives to misrepresent their preferences. The game form G, on the other hand, invites members to behave strategically, and if successful the equilibrium mapping from preferences to lotteries should coincide with the outcome $f(\theta)$. The social choice correspondence f is *implementable* in Nash equilibrium if there is a game form G such that for every $\theta \in \Theta$, $N(G, \theta) = f(\theta)$.

The conditions necessary for an SCC to be implementable are stringent. The innovation of virtual implementation is in insisting only that the mechanism yield the value of f with probability close to one. Following Abreu and Sen (1991), say that two SCC's f and $\tilde{f}$ are *ϵ-close* if for every profile $\theta \in \Theta$, the Euclidean distance between $f(\theta)$ and $\tilde{f}(\theta)$ is no greater than ϵ. Then the SCC f is *virtually implementable* in Nash equilibrium if for every $\epsilon > 0$, there is an $\tilde{f}$ that is implementable and that is ϵ-close to f. Abreu and Sen's (1991) remarkable result is that any f can be implemented virtually.

THEOREM (ABREU AND SEN). *Let $N \geq 3$. Then any SCC $f : \Theta \Longrightarrow \mathcal{Q}$ is virtually implementable in Nash equilibrium.*

The canonical game form that Abreu and Sen employ in the proof of their theorem shall not be constructed here. At an equilibrium of G, member i will announce the true profile θ, a lottery

$x \in f(\theta)$, and two nonnegative integers, n_i and k_i. For arbitrary $\epsilon > 0$, the outcome of the game form yields the lottery[17]

$$L(x,\theta) = (1-\epsilon)x + \epsilon\frac{1-\beta}{\beta}\sum_{j=1}^{\infty}\beta^j \mathbf{q}_j,$$

where $\beta \in (0,1)$. The $\sum \beta^j \mathbf{q}_j$ term in L captures the "virtualness" of the equilibrium of G. Though members agree on the equilibrium lottery x, and employ it as part of their strategy, the game form contains some noise that produces a different (possibly non-equilibrium) lottery. Of course, x is itself a lottery, so that there is in general no guarantee that any one pure outcome will obtain even if ϵ is allowed to go to zero.

Given this setup, the model is complete upon specification of a suitable social choice correspondence. This correspondence, it will be recalled, maps a vector of preferences into an outcome vector $\mathbf{q} \in \mathcal{Q}$. I now turn to a development of the virtual implementation scheme for an international commodity agreement.

IV. Implementing a Commodity Agreement Virtually

As in the general case, the implementing game form for the ICA requires specifying a set of agents, a set of outcomes, each agent's preferences over these outcomes, and a social choice correspondence. The set of agents consists of all exporting and importing members of the Agreement. Let I denote the council, with $I = I_1 \cup I_2$, where $\# \mid I_k \mid = n_k$. That is, there are n_1 exporters and n_2 importers. Let i denote the current element of I_1, an exporter, and let j denote the current element of I_2, an importer. The set of outcomes $\mathcal{Q}$ is a subset of $R_+^{n_1}$. An element of this outcome space is $\mathbf{q} = (q_1, \ldots, q_{n_1})$, specifying the export quota for each exporting member.

Clearly the preferences of importers and exporters, which both depend upon the coffee price, are interrelated. The general formulation of these preferences is presented here. In the following section, I offer a specific set of preference relations that, if the true preferences, would yield the quota values that were actually observed under the ICA in the late 1980's.

Importer j possesses a linear import demand function given by $Q_j = (a_j - P)/b_j$.[18] World import demand is the piecewise linear function given by the horizontal summation of the Q_j.

[17]If $\epsilon > 1$, the proof will work if ϵ is replaced throughout by the number 1/2.

[18]Throughout the remainder of the paper q_i denotes a quota amount (or, equivalently, exports) for exporter i and Q_j denotes imports by importer j. By definition it will always be true that $\sum_i q_i = \sum_j Q_j$. The symbol Q denotes this sum.

Denote the inverse world import demand by $\hat{P}(Q_1, \dots Q_{n_2})$. In the relevant range this function, given that $\sum_i q_i = \sum_j Q_j$, can be denoted $P(\mathbf{q})$. The parameters a_j and b_j index j's preferences: $\theta_j = (a_j, b_j)$. It is assumed that importer j's preferences are determined from its consumer's surplus at a given price P:

$$\text{(1)} \qquad \mathrm{CS}_j(P(\mathbf{q}); a_j, b_j) = \frac{1}{b_j} \int_{P(\mathbf{q})}^{a_j} (a_j - z)\, dz = \frac{(a_j - P(\mathbf{q}))^2}{2b_j}.$$

For two outcome (quota) vectors $\mathbf{q}$ and $\mathbf{r}$ we write

$$\mathbf{q} R_j(\theta_j) \mathbf{r} \iff \mathrm{CS}_j(P(\mathbf{q}), a_j, b_j) \geq \mathrm{CS}_j(P(\mathbf{r}), a_j, b_j).$$

Exporter i exports q_i, and achieves profits

$$\text{(2)} \qquad \pi_i(q_i; \mathbf{q}_{-i}, c_i, d_i) = q_i \cdot P(\mathbf{q}) - C(q_i; \mathbf{q}_{-i}, c_i, d_i),$$

where $P(\mathbf{q})$ is the world coffee price depending upon the entire quota vector (via aggregate import demand), and where C_i is i's cost function, with parameter vector (c_i, d_i). The cost function is assumed to be quadratic in q_i:

$$C_i(q_i; q_{-i}, \delta_i) = c_i q_i + d_i q_i^2.$$

An exporter's preferences coincide with its profit function, which is a complete ordering of all elements $\mathbf{q} \in \mathcal{Q}$. The parameters c_i and d_i index i's preferences: $\theta_i = (c_i, d_i)$. For two outcome (quota) vectors $\mathbf{q}$ and $\mathbf{r}$ we write

$$\mathbf{q} R_i(\theta_i) \mathbf{r} \iff \pi_i(\mathbf{q}; c_i, d_i) \geq \pi_i(\mathbf{r}; c_i, d_i).$$

Note that exporter i has a linear marginal cost function, given by $\mathrm{MC}_i(q_i; c_i, d_i) = c_i + 2d_i q_i$. A profile of preferences over $\mathcal{Q}$—one preference ordering for each exporter and each importer—is given by $\theta = (c_1, d_1 \dots c_{n_1}, d_{n_1}; a_1, b_1, \dots, a_{n_2}, b_{n_2})$.

Three of four elements of the implementing scheme are now in place. All that remains is to specify a rule for combining preferences into a quota outcome. It is assumed that the objective of the Agreement is to maximize the weighted sum of logged consumer's surplus and profits across all members. Each exporting and each importing member is assigned a weight, perhaps based upon the member's past performance in the Agreement. These weights are such that $\sum_i \alpha_i = 1$ and $\sum_j \beta_j = 1$.[19] Specifically, the social choice correspondence $f(\theta)$ is given by

$$(3) \qquad f(\theta) = \arg\max_{\mathbf{q}\in\mathcal{Q}} \left(\sum_i \alpha_i \ln \pi_i(q_i; \mathbf{q}_{-i}, c_i, d_i) + \sum_j \beta_j \ln \mathrm{CS}_j(P(\mathbf{q}), a_j, b_j) \right).$$

The maximand in (3), consisting of the weighted sum of logged profits and surpluses, will sometimes be denoted $W(\mathbf{q};\theta)$. This function is well-defined only on the subset of $R_+^{n_1}$ where the profits and surplus measures are strictly positive. In particular, because $\pi_i(0; \mathbf{q}_{-i}, c_i, d_i) = 0$, $\mathcal{Q}$ must be a subset of the interior of $R_+^{n_1}$.[20]

With the scheme now complete, two questions naturally arise. These are, first, can this scheme make use of the Abreu and Sen result; and second, does it need the result? In the remainder of this section I demonstrate that the answer to both questions is yes. Assumptions (A1)–(A4) have been adopted throughout, so it is immediate that their theorem applies. Assumptions (A3) and (A4) are placed upon preferences over lotteries; these are needed for the result, but do little to restrict the interpretation of preferences over quota outcomes. The interpretation of assumptions (A1) and (A2) is straightforward. The first requires that there is an agent whose preferences over a pair of alternatives are reversed for any pair of distinct profiles, θ and ψ. This is easily seen to hold for any exporter, whose most preferred quota vector will always move in response to a change in the profile of cost function parameters. The second—that not all agents have the same preferences—is automatically satisfied in that importers' wishes and exporters' wishes concerning the aggregate level of exports are diametrically opposed.

The fact that this f can be implemented virtually is now seen to be a forceful result, for as I now demonstrate it is single-valued. My f is obviously not dictatorial, and the virtual approach appears to be the only way to implement an f with these two properties. To make this point, a result due to Barberà and Peleg (1990) is now marshalled to demonstrate that the f of this paper is manipulable. Barberà and Peleg (1990) extend the Gibbard-Satterthwaite theorem to the case with continuous preferences and a single-valued social choice rule.

[19]This construction is lifted directly from the ICA, under which importing members are given 1000 votes and exporting members are given 1000 votes.

[20]The maximand in (3) may also be written $\Pi_i \pi_i^{\alpha_i} \Pi_j \mathrm{CS}_j^{\beta_j}$, which is the criterion function for an asymmetric Nash bargaining game with zero threat point. In this form, it would be possible to define W on the entire non-negative n_1-dimensional orthant.

To show that the value of f is unique, it is sufficient to show that $W(\mathbf{q};\theta)$ achieves a unique maximum on Q. The following proposition, proved in the Appendix, formalizes the claim that $f(\theta)$ is single-valued.

PROPOSITION 1. *Given the specifications for π_i and CS_j in equations (1) and (2), $f(\theta)$ in (3) is single-valued.*

The Barberà and Peleg (1990) result applies to a social choice scheme in which the set of alternatives is a metric space, and preferences are continuous.

THEOREM (BARBERÀ AND PELEG). *Any non-manipulable, single-valued social choice rule whose range contains at least three alternatives is dictatorial.*

In the model of this paper preferences, being polynomial functions of the $\mathbf{q}$, are continuous. Together with the fact that the f in (3) is nondictatorial, the Theorem leads immediately to the following result, whose obvious proof is omitted.

PROPOSITION 2. *The social choice rule $f(\theta)$ given in (3) is manipulable.*

The value of f, the optimal vector of quota levels, will henceforth be denoted $\mathbf{q}^*$.

V. Rationalizing the Behavior of the ICA

I now turn to an examination of the observed behavior of the International Coffee Agreement during the last years before its collapse. The ICA is complicated. In 1985, there were 40 exporting countries and 25 importing countries with voting rights. Each of these exporters held a quota, however small, to export coffee to importing members. Quality of coffee varies a great deal, and the Agreement places exporting members in one of four categories according to the primary variety of their exports.[21] Coffee prices vary across the categories, and they vary for a great many other reasons as well. The actual quota selection mechanism is complex; for example, it includes provisions for adjusting quotas during the crop year if prices move out of a band established in the Agreement (see, for example, Gilbert 1987).

In short, my analysis cannot cover all features of the ICA, and so some simplifying assumptions will of necessity be maintained. To keep the number of members to a manageable size, exporting

[21] The four are "Colombian milds," produced in Colombia predominantly; "Other milds," produced in most of the rest of Latin America; "Brazilian and other arabicas," produced in Brazil and Ethiopia; and "Robustas," produced mostly in Africa. See the footnotes to Table 1.

countries will be divided into four groups, according to the variety of coffee produced in the country. Importing countries will be placed into three groups according to geographical region. Importing regions include "Europe," "North America," and "Asia and the Pacific." Thus, we have $n_1 = 4$ and $n_2 = 3$. I also assume that there is a single coffee price, which applies across all four varieties. This assumption is strong—in part because quality differs across varieties. The complications introduced when one allows prices to differ by variety (which would require information on the demand for each variety by every importer) are deferred to a later study.

Summary of the available data

The data are for the 1984/85 crop year, which was a relatively normal year for the Agreement—safely ahead of the 1989 collapse—though the coffee price was high. The following data are available: actual quotas held by exporters; quantities imported by members; voting weights as set out in the Agreement itself; the coffee price; and estimates of supply (demand) elasticities for exporting (importing) groups. Table 1a summarizes the information known for exporters. Actual quota figures for each group, hereafter denoted q_i^*, were decided upon under the provisions of the Agreement.[22] Exporter vote figures are sums for countries belonging to the respective groups, out of a total of 1000 for exporters. The coffee price per 60kg bag, $P = 172.04$, is the average composite New York price from October 1984 to September 1985.

Supply elasticities, denoted η_i, are calculated using results from Akiyama and Varangis (1990). The numbers used here are weighted averages of the two-year country supply elasticities.[23] The supply elasticity figures, together with the functional form for marginal cost, may be used to express c_i in terms of d_i for each exporter, thereby reducing the number of free parameters for each exporter to one. Recall the expression for marginal cost,

$$\mathrm{MC}_i(q_i; c_i, d_i) = c_i + 2d_iq_i,$$

which may be combined with the elasticity expression to obtain, after rearranging,

$$c_i = 2d_iq_i(\eta_i - 1). \tag{4}$$

[22]During the 1984/85 crop year, the quotas that were established initially were later revised upward because of an intrayear price rise.

[23]Akiyama and Varangis (1990) do not estimate supply elasticities for every country that is a member of the Agreement. My figures for each group are weighted averages of the group members whose country elasticities are given in Akiyama and Varangis.

Knowing q_i and η_i, if one can discover d_i then one knows fully the marginal cost function and, hence, the cost function for i.

Table 1b summarizes the information known for importers. Import quantities are imports by members from exporting members. These figures are approximate and sum to the total of export quotas. Available information on imports by country includes inventory changes; imports from exporting members are 5.1% below the total quota figure. Imported quantities are scaled upward proportionally in order to ensure that $\sum_j Q_j = \sum_i q_i$. Importer vote figures are sums for countries belonging to the respective groups, out of a total of 1000 for importers.

Import demand elasticities, denoted ϵ_j, are taken from Akiyama and Varangis (1990); like the supply elasticities these numbers are weighted averages of member countries. Knowledge of elasticities and of import quantities and the price allows the direct calculation of the demand function parameters a_j and b_j by group. The derivation follows the lines of that for c_i above; the difference is that in the case of the importers a point on the demand curve is known. This permits one to specify the demand function exactly.[24]

Table 1 about here.

Now, given equation (4) all that is unknown in the system is one of the parameters for each cost function. But these can be got from the criterion function f. *The calculation that yields them is the key derivation of the paper*. Recall what we know about f. Having asserted it, we know, and this is most important, that it is a weighted sum of logged profits (for exporters) and logged consumer's surpluses (for importers). From the data we also know almost all of the parameters in f, we know P, and we know the quota vector $\mathbf{q}^*$ that it is to yield at a solution. The search for the d_i amounts to a search for the f that, if the ICA is behaving so as to maximize *this* f, then the actual $\mathbf{q}^*$ would result.

As before, let $\mathbf{q}^*$ denote the observed vector of quota amounts for the four exporters. We have

$$W(\mathbf{q};\theta) = \textstyle\sum_i \alpha_i \ln\big(\pi_i(\mathbf{q};c_i,d_i)\big) + \sum_j \beta_j \ln\big(\mathrm{CS}_j(\mathbf{q};a_j,b_j)\big).$$

If it is assumed that P is less than the smallest a_j (this assumption must be satisfied so long as

[24]This point is important, and perhaps bears some elaboration. It is true that exporters receive the same price for their product that importers pay. However, while this price lies on an importer's demand curve (at the corresponding quantity) it needn't lie on an exporter's supply curve.

each j imports a positive amount of coffee), then in the relevant range world demand is

$$P(\mathbf{q}) = \left(\frac{1}{\sum_j (1/b_j)}\right) \cdot \left(\sum_j \frac{a_j}{b_j} - \sum_i q_i\right).$$

Exporting member i has profit function $\pi_i(q_i; \mathbf{q}_{-i}, c_i, d_i) = P(\mathbf{q})q_i - c_i q_i - d_i q_i^2$. Importing member j has import demand $Q_j = (a_j - P)/b_j$, which yields $\text{CS}_j = (a_j - P)^2/2b_j$. The criterion function is found by inserting the CS_j from (1) and the π_i from (2) into $W(\mathbf{q}; \theta)$. At an optimum, the four first partial derivatives of W must be zero. These derivatives are given by

$$(5) \quad \frac{\partial W}{\partial q_i} = \frac{\alpha_i}{\pi_i}\left[(P - c_i)\sum_{j=1}^{3}(1/b_j) - q_i\left(1 + 2d_i \sum_{j=1}^{3}(1/b_j)\right)\right] - \sum_{k \neq i} \frac{\alpha_k q_k}{\pi_k} + \sum_{j=1}^{3} \frac{\beta_j Q_j}{\text{CS}_j} = 0, \qquad i = 1, \ldots 4.$$

It is important to bear in mind that though the derivatives in (5) are with respect to the q_i, the *values* q_i^* are known from the data. If the expression for c_i is inserted, the only unknowns in equations (5) are the d_i. Thus, these equations constitute a four-equation system in four unknowns, the d_i. The solution to this system yields the remaining unknowns in θ, the vector of preference parameters. I now turn to the solution to equations (5) and the empirical results of the study.

Empirical Results

The solution of equations (5) was carried out using a non-linear equation system solver in the GAUSS programming language. The results are presented in Table 2, where the d_i^* denote the solution, and where the c_i^* are calculated from them using equation (4). The marginal cost values appearing in the table are calculated from the derivatives of each exporter's cost function, $\text{MC}_i(q_i^*; c_i^*, d_i^*) = c_i^* + 2d_i^* q_i^*$. Note that there is no need for the marginal costs for exporters to equal the actual coffee price. They do not. Recall that the actual coffee price is $P = 172.04$. The Brazilian arabicas group has the lowest export elasticity, and also has the *flattest* marginal cost.[25] Brazil enjoys a low marginal cost at its output level, but as we shall see their profits do not appear to be unusually high. Marginal cost is relatively high for the Robustas group, whose export elasticity is also quite high.

[25] This may seem paradoxical—we usually think of low elasticity corresponding to relatively steep supply or demand curves. But with linear supply our intuition is not a safe guide: along any linear demand function elasticity covers the entire range from zero to negative infinity. The fact that the marginal costs differ across exporters may be unexpected (these would be equalized in a cartel), but there are no side payments available, either monetary or through trading quotas. The chosen quota levels are the law.

Table 2 about here.

The leading question of the paper—whether an observed quota decision can be *rationalized*—may now be answered affirmatively. All of the required information (the θ vector of c_i, d_i, a_j, and b_j representing preferences) is now available. For convenience I record here the entire set of cost and demand functions.

$$C_1(q_1; c_1, d_1) = -267.95q_1 + 0.00001382q_1^2 \qquad Q_1(P; a_1, b_1) = (969.54 - P)/0.0000240$$

$$C_2(q_2; c_2, d_2) = -358.08q_2 + 0.00001400q_2^2 \qquad Q_2(P; a_2, b_2) = (720.79 - P)/0.0001093$$

$$C_3(q_3; c_3, d_3) = -321.69q_3 + 0.00000882q_3^2 \qquad Q_3(P; a_3, b_3) = (782.52 - P)/0.0000286$$

$$C_4(q_4; c_4, d_4) = -202.62q_4 + 0.00000933q_4^2$$

Testing whether the q_i^* are rationalized by the cost and demand functions derived here requires plugging the parameter vector into equation (5) and locating the maximum to $W(\mathbf{q}; \theta)$. This calculation was performed numerically, and the vector $\mathbf{q}^*$ was indeed found to provide a maximum to the welfare function in (5), from which we conclude that on this count the exercise has been successful.

There is no need to stop here, however. The cost and demand function information that has been obtained yield answers to further questions. In particular, we may make welfare comparisons between the ICA outcome and others that would obtain under different behavioral criteria. Table 3 contains the results of performing three comparisons, which are directly analogous to the cases presented in the earlier example. As before, $SW(\mathbf{q})$ denotes the weighted sum of unlogged profits and consumer surpluses.

Table 3 about here.

The cartel outcome $\mathbf{q}^c$ is the solution to the problem

$$\max_{\mathbf{q}} \sum_{i=1}^{4} \pi_i(q_i; c_i, d_i).$$

At $\mathbf{q}^c$ the coffee price would be \$401.46 per bag—more than double the ICA (observed) price. This outcome is unstable in the usual way: it is not internally self-sustaining. This is unfortunate for the exporters. They would enjoy profits above \$23 billion at the cartel outcome, against \$17.6 billion at the ICA outcome. Importers would be harmed severely if the cartel were successful, as can be seen in the figures for $\sum_j \text{CS}_j$. It is not surprising that social welfare, the weighted sum of (unlogged) profits and consumer surpluses, is low at the cartel result.

The Nash outcome $\mathbf{q}^N$ is the joint solution to the four problems (one for each exporter)

$$\max_{q_i} \ \pi_i(q_i; \mathbf{q}_{-i}, c_i, d_i),$$

where each exporter takes the exports of others as fixed. Total exports under the Nash outcome are smaller than those at the ICA result, consistent with the earlier example. Importers prefer the ICA outcome to the Nash outcome.

The third comparison is between the ICA outcome and the market outcome, denoted $\mathbf{q}^M$. The market outcome is obtained by setting aggregate supply equal to aggregate demand. This market equilibrium is achieved for $\sum_i q_i = 67.08$ million bags, and the price per bag is \$85.04. Exporters each take this *price* as given (in the Nash outcome they take other exporters' *quantities* as given), and maximize profits by choosing the export level q_i^M at which $\text{MC}_i = P$. As expected, of the four outcomes under consideration this outcome yields the lowest profits to exporters and the highest surplus to importers. It also yields the greatest level of social welfare.

There is a sense in which the figures appearing in the "Market Outcome" column in Table 3 constitute a set of projections. They tell what would happen, given that the cost and demand functions I have presented are the true ones, in the absence of a coffee agreement. If these results are correct then the world coffee industry should move toward them if competitive forces were unleashed. History has smiled on us in this connection, and has performed a fortuitous experiment. As I have said, in July of 1989 the Agreement broke down, and it has operated without economic provisions since that date. The world market has had more than three years to reach for a competitive equilibrium. In short, it is possible to test the projections of my model against current facts. Let us turn now to a cursory version of such a test.

The 1990/91 and 1991/92 world coffee market

The December 1992 issue of the USDA-FAS publication "World Coffee Situation" (USDA 1992, p. 9) reports 1990/91 exports by member exporting countries. As a final exercise I compare the export quantities that my model projects to the 1990/91 and 1991/92 actual figures. This comparison is a useful one, though an important caveat should be mentioned. My model is static;

the world coffee market is not. The model can say only what would happen at a competitive equilibrium if the supply and demand functions that I have derived are the correct ones. There is nothing special about the 1991/92 marketing year in this regard—it is only the most recent year for which actual import, export, and price information is available. Even if the "market" outcomes are correct the model is silent on when they should obtain.

Table 4 contains the numbers that permit comparison between the "projected" and actual quantity and price figures, for the marketing years 1990/91 and 1990/92. To evaluate the information in this table one should perhaps think of the world coffee market as being in motion—headed toward a market equilibrium without the ICA quota restraints. The last column in the table, for the 1991/92 marketing year, gives actual export quantities. The discrepancy between the projected total exports (67.08m bags) and actual exports (64.99m bags) is 3.11 percent, while the descrepency between projected and 1984/85 levels was 11.14 percent. The error fell by 72.07 percent. Prices agree less closely, with the actual price falling below the projected level by about 32 percent.

When looked at across exporting groups, one sees that three of the exporting groups are quite close to those the model projects. The most notable exception is Brazil, whose actual exports fell short of my projections. The discrepancy for Brazil might stem from changes in the domestic credit program that has encouraged farmers to hold stocks in the hope that prices will rise. Colombia, whose exports have risen more than expected according to my results, depends heavily upon coffee exports for foreign exchange earnings (of which coffee's share is presently about 25%). Thus, Colombia's generous subsidy program has continued. Columbia's growers are largely shielded from low world prices by the National Coffee Fund, and without the quota restriction that held exports in check under the ICA Colombia's exports have risen dramatically. The robustas group fell below the projection, though if one includes the exports of Vietnam, who joined the ICA after the 1984/85 crop year, the robustas figure rises to 15.16m bags in 1991/92, and the overall total rises to 66.50m bags. This last figure is less than one percent below the market projection. The other milds group also exported more than the model projected.

The 1990/91 composite indicator New York market price, deflated by the GDP deflator to constant 1985 dollars, was $74.20 per bag, 13% below the model's projected price of $85.04. The 1991/92 composite price, again deflated, fell to 32% below the model's projection. Though the agreement between these numbers is not perfect one should bear in mind that the basis for my projections is 1984/85, a single marketing year six years past.

Table 4 about here.

VI. Conclusions

In this paper I have constructed a model of the decision-making process that during its active existence might have guided the quota allocation decisions of the International Coffee Agreement. Behavior by the ICA was rationalized in the sense that my objective criterion, if true, would have produced the decisions that were actually observed for the 1984/85 crop year. The objective function was itself created from the data, using price and quantity information and demand and supply elasticities for member countries.

Evidently this model covers, without straining too much, the essential facts concerning the operation of the ICA. What is more, it yields as a solution the explicit cost functions for member exporting groups. These cost functions permit welfare comparisons between the ICA outcome and the (ideal) cartel outcome and the competitive outcome that one would expect if there were no ICA. Fortunately for my purposes the recent performance of the world coffee market, which has been for almost four years shorn of its international Agreement, constitutes an experiment that makes possible a comparison between the projection of my model and actual market outcomes. On this measure the model has been shown to perform quite well.

In closing I want to return to three questions that have been hinted at previously. First, why were member exporters willing to admit importers into their circle? Why did they not simply form an export cartel made up exclusively of exporting countries? The reasons for this seem clear enough. The primary one, I conjecture, is that the exporters saw in their importing companions a natural enforcement mechanism. An exporter cannot defect away from the Agreement, exceeding its quota, without help from an importer who must choose to be a co-conspirator.

Second, why were importers willing to join the Agreement? It seems from my results—and indeed from common sense—that their interests were harmed by the ICA, and that they are now better off without it. Of course, my model does not address one of the defining characteristics of the coffee market, namely, production uncertainty and interperiod price variability. It is this price variability that the ICA was formed to moderate, and in future we can expect to see weather disasters that will send the coffee price skyward once again. Importers and exporters alike may then regret having allowed the Agreement to lapse.

Third, and finally, why did the Agreement fail in 1989? My hypothesis, and this will not be surprising, is that the great majority of countries view the world coffee price—not the export volume of other exporters—as parametric. If Nicaragua, for example, believes that its production choice has no effect upon the world price, then it doubtless chafes under the quota limit imposed on it by the Agreement. If all or almost all exporters take this view then we might expect the natural state of things to settle at the competitive outcome, however unstable prices may be there.

My model is silent on much of what is interesting in the International Coffee Agreement. The large puzzle (why it was formed and why it held together for so long) and the smaller puzzle (why it eventually collapsed) are each connected to the dynamic and stochastic aspects of the world coffee market. Formal consideration along the lines I have pursued of either or both of these central elements must await further study.

APPENDIX

PROOF OF PROPOSTION 1: The proof proceeds in two steps. In the first, $W(\mathbf{q};\theta)$ is shown to be strictly concave in $\mathbf{q}$. In the second, it is shown that in any direction from a given $\mathbf{q}$, $W(\mathbf{q};\theta)$ cannot increase monotonically. Taken together, these results establish that W achieves a unique maximum on $\mathcal{Q}$.

Step 1: To show that W is strictly concave in $\mathbf{q}$, it is enough to show that each of the elements of the sum is strictly concave. Note that the log of any non-negative and non-constant linear function is strictly concave. (If $s(x)$ is a linear function of x and $t(x) = \ln(s(x))$, then $t'' = -(s')^2/s^2 < 0$. The extension of this argument to the multi-dimensional case is straightforward.)

Take first the profit function of exporter i, and rewrite $\ln \pi_i$ as

$$\ln \pi_i(q_i; \mathbf{q}_{-i}, c_i, d_i) = \ln q_i + \ln\big(P(\mathbf{q}) - c_i - d_i q_i\Big).$$

Because $P(\mathbf{q})$ is a linear function, each of the terms on the right side of this expression is the log of a non-constant linear function of $\mathbf{q}$, and is therefore strictly concave. Take now the surplus function of importer j, and rewrite $\ln \mathrm{CS}_j$ as

$$\ln \mathrm{CS}_j(P(\mathbf{q}); a_j, b_j) = 2\ln\big(a_j - P(\mathbf{q})\big) - \ln 2b_j.$$

The first term on the right side of this expression is once again a linear function of $\mathbf{q}$, and is therefore strictly concave. Thus, $W(\mathbf{q};\theta)$, the sum of strictly concave terms, is strictly concave.

Step 2: To show that W cannot be monotone increasing, for a given $\theta \in \Theta$ take a $\mathbf{q}$ at which W is well-defined; that is, at which each $\pi_i > 0$ and each $\mathrm{CS}_j > 0$. I claim that in any direction from $\mathbf{q}$ there must be a $\hat{\mathbf{q}}$ such that $W(\hat{\mathbf{q}};\theta) < W(\mathbf{q};\theta)$. Let $\mathbf{d} \in R^{n_1}$ denote a direction vector emanating from $\mathbf{q}$, and let $\mathbf{q}(t) = \mathbf{q} + t\mathbf{d}$, $t \geq 0$, parameterize the ray from $\mathbf{q}$ in the $\mathbf{d}$ direction. If $\mathbf{d} \geq 0$, then because $P(\mathbf{q})$ is linear with strictly negative first derivatives, there is a t' such that $P(\mathbf{q}(t')) = 0$. At this price $\pi_i < 0$ for each $i \in I_{n_1}$. By the continuity of the π_i, there must therefore be a t'' such that min $_{i \in I_1} \pi_i(\mu\mathbf{q}(t''; c_i, d_i) = 0$. Let k denote this exporter, and let $\hat{\mathbf{q}} = \mathbf{q}(t'' - \epsilon)$, where $\epsilon > 0$. Then for a sufficiently small $\epsilon > 0$, it is possible to make $\mid \pi_k(\hat{q}_k; \hat{\mathbf{q}}_{-k}, c_k, d_k) \mid$ sufficiently large that $W(\hat{\mathbf{q}};\theta) < W(\mathbf{q};\theta)$.

If $d_i < 0$ for some $i \in I_1$, then there is a t' such that $q_i(t') = 0$, at which once again $\pi_i = 0$. (If there are multiple $d_i < 0$, we can again select the i for which $q_i(t)$ reaches zero at the smallest value for t.) As before let $\hat{\mathbf{q}} = \mathbf{q}(t' - \epsilon)$, and the last step goes through as before.

This argument establishes that W cannot increase monotonically. But then by the continuity of $W(\mathbf{q};\theta)$ it must achieve a maximum on $\mathcal{Q}$, and by strict concavity this maximum must be unique. This completes the proof of the proposition. ∎

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Table 1. Export and Import Data by Group.

(a)
Exporting Groups
(Quantity figures in millions of 60kg bags)

	Colombian Milds[a] ($i=1$)	Other Milds[b] ($i=2$)	Brazilian Arabicas[c] ($i=3$)	Robustas[d] ($i=4$)
η_i	0.1441	0.1066	0.0324	0.2818
Actual q_i [e]	11.33	14.31	18.86	15.11
Votes[e]	183	264	277	276

(b)
Importing Groups
(Quantity figures in millions of 60kg bags)

	Europe[f] ($j=1$)	Asia and Pacific[g] ($j=2$)	North America[h] ($j=3$)
ϵ_j	-0.2157	-0.3135	-0.4305
a_j	969.54	720.79	782.52
b_j	-2.397×10^{-5}	-10.930×10^{-5}	-2.864×10^{-5}
Q_j [i]	33.273	5.02	21.32
Votes	599	101	300
Coffee Price	P=172.04/bag		

[a] **Colombian Milds—(Votes in parenthesis)**: Colombia (142); Kenya (25); Tanzania (16)

[b] **Other Milds**: Bolivia (6); Burundi (6); Costa Rica (23); Cuba (6); Dominican Republic (0); Ecuador (21); El Salvador (40); Guatemala (34); Honduras (18); India (16); Jamaica (4); Malawi (4); Mexico (35); Nicaragua (14); Panama (4); Papua New Guinea (14); Paraguay (6); Peru (0); Venezuala (4); Zimbabwe (4)

[c] **Brazilian and Other Arabicas**: Brazil (252); Ethiopia (25)

[d] **Robustas**: Angola (9); Ghana (4); Indonesia (45); Liberia (6); OAMCAF (includes: Cameroon (23), Central African Republic (4), Ivory Coast (56), Madagascar (12), Togo (5)); Phillipines (11); Rwanda (11); Sierra Leone (8); Sri Lanka (4); Thailand (6); Uganda (42); Zaire (22); Zambia (4)

[e] Source: USDA (January, 1985)

[f] **Europe**: Austria (20); Belgium/Luxenbourg (32); Cyprus (6); Denmark (20); Finland (20); France (87); FR Germany (134); Greece (11); Ireland (6); Italy (62); The Netherlands (43); Norway (15); Portugal (9); Spain (31); Sweden (29); Switzerland (20); United Kingdom (42); Yugoslavia (12)

[g] **Asia and the Pacific**: Australia (15); Fiji (5); Japan (58); New Zealand (7); Singapore (16)

[h] **North America**: Canada (32); United States (268)

[i] Source: USDA (February, 1987)

Table 2. Cost Function Parameters: Empirical Results.

	Colombian Milds	Other Milds	Brazilian Arabicas	Robustas
d_i^*	13.8192×10^{-6}	14.0020×10^{-6}	8.8153×10^{-6}	9.3324×10^{-6}
$c_i^* = 2d_i^* q_i(\eta_i - 1)$	-267.952	-358.076	-321.688	-202.617
MC_i^*	45.120	42.735	10.768	79.500

Table 3. Comparison of four quota outcomes—International Coffee Agreement.

	Cartel Outcome	Nash Outcome	ICA Outcome	Market Outcome
q_1 [a]	7.38	11.93	11.33	12.77
q_2 [a]	10.50	14.09	14.31	15.82
q_3 [a]	14.62	17.84	18.86	23.07
q_4 [a]	7.43	13.30	15.11	15.41
$\sum_i q_i$ [a]	39.93	57.15	59.61	67.08
$P(Q)$ [b]	401.46	200.69	172.04	85.04
$\sum_i \pi_i$ [c]	23,280	18,943	17,636	12,668
$\sum_j CS_j$ [c]	9,733	19,479	21,152	26,663
$SW(\mathbf{q})$ [c]	10,795	14,114	14,557	15,754

[a] Million bags.
[b] $US.
[c] Million $US.

Table 4. A Comparison Between Actual and Projected Market Outcomes

	Market Outcome	1990/91 Actual[a]	1991/92 Actual[a]
Colombian Milds	12.77	12.724	15.045
Other Milds	15.82	16.720	17.209
Brazilian/Arabicas	23.07	17.384	18.568
Robustas	15.41	15.692	13.664
Member totals	67.08	62.520[b]	64.987[b]
Price per bag ($US)[c]	85.04	74.20	57.90

[a] Source: International Coffee Organization Certificates of Origin, compiled by the Horticultural and Tropical Products Division, USDA Foreign Agricultural Service.

[b] Equals exports by ICO exporting members to all destinations, multiplied by the fraction of all imports accounted for by member importers.

[c] 1990/91 and 1991/92 figures are averages for October–September, deflated by the GDP deflator.