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AN ECONOMETRIC ANALYSIS OF THE
SHORT-RUN DEMAND FOR COFFEE

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Abstract

We develop a short-run econometric model for the world coffee market and we give empirical evidence on the behavioral equations of the model for the major coffee importing and exporting countries. The behavioral relationships for producers, inventory holders, speculators and consumers are derived from optimizing considerations in an uncertain environment. Spot and futures prices adjust to clear the spot and futures markets at each period. International trade flows of coffee are determined by the optimizing behavior of the agents (countries) in the model. The empirical evidence confirms our hypothesis of a highly structured model which is consistent with profit maximizing behavior under uncertainty.

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1. Introduction

Modelbuilding for markets of agricultural products has a long tradition in econometrics. In fact, in the nineteen-fifties, outstanding contributions have been made to modeling demand, supply and market interaction for agricultural crops. Moreover, several innovations in econometrics itself originated from agricultural economics.
More recently, important progress has been made in the field of commodity modeling. One impulse came from outside, from the implementation of theoretical results for economic decisions under uncertainty in the analysis of commodity markets. We mention the book by Newbery and Stiglitz (1981) which brings together theoretical results and applies them to the problem of commodity price stabilization. Using a theoretical model, Kawai (1983) and Turnovsky (1983) study the effect of the presence of a futures market on the spot price variation.

In this paper, we shall develop a short-run econometric model for the world coffee market and give empirical evidence for the demand side of the model for a number of countries. To derive the model, we assume that producers, dealers and speculators have access to the spot and futures market and that, given a two-period time horizon, they maximize the expected value of the utility of profit from activities such as inventory holdings, buying or selling on spot or futures markets. In this short-term model, we assume that production is predetermined. Consumption per capita is explained by the relative price for coffee and the real income per capita. The spot and futures markets clear at each period. The model is aggregated in the sense that coffee is treated as one homogeneous commodity. Demand however is disaggregated into the demand by the major coffee importing countries.

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After the presentation of the model, we give empirical results for the demand side. At a disaggregate level, the endogenous variables are the disappearance, which equals consumption plus changes in inventories at the retail level, wholesale inventory holding and retail prices. These variables are assumed to respond to changes of the spot and futures prices and of the expectations concerning next period market conditions. Whenever possible, the same functional form of the equations is used for different countries.

The paper is organized as follows. In section 2, we present the theoretical model. Section 3 contains the estimation results for the demand and retail price equations of coffee for the U.S., Japan and the major coffee importing countries in Western Europe. The results provide evidence on the appropriateness of the theoretical model for the coffee market. In section 4, we briefly describe work that is in progress and we draw some conclusions.

2. Agents' Behavior

As the area used for growing coffee is fixed in the short-run and newly planted trees have zero yield during a period of 4 to 6 years, we assume that the area of the coffee plantation is exogenous and that production depends on stochastic factors such as weather conditions but not on producers' decisions. Our aim is then to model the price formation on spot and futures markets, the consumption of coffee in the major importing countries, the inventories at the demand and supply side and the resulting trade flows of coffee between countries.
Agents can buy and sell coffee at the going price on the spot market. Forward contracts which mature next period are exchanged on the futures market. As coffee is a storable commodity, agents can hold inventories. The cost function is quadratic and strictly convex in the level of inventories. In the theoretical model, all prices are expressed in the same currency. In the empirical model, agents are assumed to base their decisions on prices expressed in domestic currency.

2.1 Producers and inventory holders
Maximizing expected utility of net revenue

At the time t, a producer is assumed to supply coffee (or equivalently to choose the level of inventories), to take a position on the futures market and to decide on an alternative use of his means, e.g. a financial asset with a random return r, in order to maximize the expected utility of the present value of profits over periods t and $t + 1$.

Formally, the profit (net revenue) function is given by:

$$\Pi_t = \Pi_{0t} + \delta\, \Pi_{1t} \tag{2.1}$$

with $\Pi_{0t} = p_t\, q_t + p_t\, z_{t-1} - (p_t + b + cz_t)z_t + f_t\, p_t^f - S_t$

being current period revenue and

$$\Pi_{1t} = p_{t+1}\, q_{t+1} + p_{t+1}\, z_t - f_t\, p_{t+1} + (1 + r_{t+1})\, S_t$$

being next period revenue,

where p_t is the spot market price,

q_t is the volume of production,

z_t is the level of inventories,

f_t is the position on the futures market (short and long positions correspond to $f_t > 0$ and $f_t < 0$ respectively),

p_t^f is the futures price

S_t is the amount of an alternative asset,

r_{t+1} is the random return on S_t,

b and c are parameters of the cost function for inventories ($c > 0$), and

δ is the discount factor, $\delta \leq 1$.

We assume that a producer has the following utility function with constant absolute risk aversion,

$$U(\Pi_t) = -\exp - \gamma^* \Pi_t \quad , \tag{2.2}$$

where γ^* is the Arrow-Pratt coefficient of absolute risk aversion. When Π_t is normally distributed[1], the maximization of expected utility $E(U(\Pi_t))$ is equivalent to the maximization of

$$E\,\Pi_t - \frac{\gamma^*}{2} \operatorname{var}(\Pi_t) \quad , \tag{2.3}$$

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1) Notice that the normality of Π_t is implied by the joint normality of $p_{t+1}\, q_{t+1}$ and r_{t+1}. The normal distribution of Π_t is consistent with a normally distributed spot price when q_{t+1} is nonstochastic or (almost) exactly known at period t. An alternative, which does not require a normal distribution of Π_t would be to assume a quadratic utility function instead of (2.2). However, then the quadratic terms of current period revenue Π_{0t} enter into the expected utility function and make the subsequent analysis more complicate.

where E and var denote respectively the (subjective) expectation and variance of profits conditional on information available at period t . These moments are

$$E(\Pi_t) = \Pi_{0t} + \delta[E\, p_{t+1}\, q_{t+1} + z_t E p_{t+1} - f_t E p_{t+1} + S_t(1+Er_{t+1})]$$

and

$$\begin{aligned} var\,(\Pi_t) = \delta^2\, [&var(p_{t+1}\, q_{t+1}) + (z_t - f_t)^2\, var\,(p_{t+1}) + \\ &+ S_t^2\, var\,(r_{t+1}) + 2\,(z_t - f_t)\{S_t cov\,(p_{t+1}, r_{t+1}) + \\ &+ cov\,(p_{t+1} q_{t+1}, p_{t+1})\} + 2S_t\, cov\,(p_{t+1} q_{t+1}, r_{t+1})]\ . \end{aligned} \tag{2.4}$$

Taking prices, quantities and the moments as given, the first order conditions for the maximization of (2.3) with respect to z_t , f_t and S_t , subject to $z_t \geq 0$, are

$$\begin{aligned} \frac{\partial\, E(U)}{\partial\, z_t} = &- (p_t + b + 2cz_t) + \delta\, E\, p_{t+1} - \gamma[(z_t - f_t)\, var\,(p_{t+1}) + \\ &+ S_t\, cov\,(p_{t+1}, r_{t+1}) + cov\,(p_{t+1} q_{t+1}, p_{t+1})] \leq 0 \end{aligned}$$

$$\frac{\partial\, E(U)}{\partial\, z_t} z_t = 0\ , \qquad z_t \geq 0 \tag{2.5a}$$

$$\begin{aligned} \frac{\partial\, E(U)}{\partial\, f_t} = &\, p_t^f - \delta\, E\, p_{t+1} + \gamma\, [(z_t - f_t)\, var\,(p_{t+1}) + \\ &+ S_t\, cov(p_{t+1}, r_{t+1}) + cov(p_{t+1} q_{t+1}, p_{t+1})] = 0 \end{aligned} \tag{2.5b}$$

$$\begin{aligned} \frac{\partial\, E(U)}{\partial\, S_t} = &-1 + \delta\,(1 + E\, r_{t+1}) - \gamma\, [S_t\, var\,(r_{t+1}) + \\ &+ (z_t - f_t)\, cov\,(p_{t+1}\, , r_{t+1}) + \\ &+ cov\,(p_{t+1}\, q_{t+1}\, , r_{t+1})\,] = 0\ , \end{aligned} \tag{2.5c}$$

where the argument Π_t has been deleted for the sake of simplicity of the notation and $\gamma = \gamma^* \delta^2$.

Notice also that $\dfrac{\partial\, var(\Pi_t)}{\partial\, z_t} = - \dfrac{\partial\, var(\Pi_t)}{\partial\, f_t}$. The second order conditions are satisfied as the Hessian matrix of E(U) is negative definite for $c > 0$. In particular, the determinant of the Hessian matrix,

$$-2c\, [\gamma^2\, var\,(p_{t+1})\, var\,(r_{t+1}) - \gamma^2\, cov^2\,(p_{t+1}\, , r_{t+1})]$$

is negative.

In its present version, the model is not suited for describing the behavior of a large producer (and inventory holders) who can influence the price formation. For instance, Brazil, the World's major coffee producer, probably ought to be modeled as a price-setter rather than as a price-taker. This point will receive more attention in a refined version of the model. Also, for a nonproducing inventory holder, we have that $q_t = q_{t+1} = 0$.

Wholesale inventories

The sum of (2.5a) and (2.5b) gives:

$$-(p_t + b + 2c\, z_t) + p_t^f \leq 0 \quad ,$$

or alternatively:

$$z_t = \max\left(\frac{p_t^f - p_t - b}{2c} \;;\; 0\right) \quad . \qquad (2.6)$$

Assuming that the first term between brackets is positive, we get the so called "supply of storage" equation (see Working (1949))

$$z_t = \frac{p_t^f - p_t}{2c} - \frac{b}{2c} \quad , \qquad (2.7)$$

which states that the optimal inventory level depends on the price spread, i.e. the difference between the futures price and the current spot price, and on the parameters of the cost function for inventories. Given the price spread, the optimal level of z_t is independent of the market conditions in the next period. It is also independent of the values of f_t and S_t . This is a first separation result.

A minimum inventory level $\bar{z}$, reflecting for instance infinite convenience yield associated with a low inventory level (e.g. a minimum inventory required for a smooth roasting process) or being due to the existence of a quota system, as we will see below, can easily be allowed for by maximizing expected utility subject to

$$z_t \geq \bar{z} \geq 0 \quad .$$

The solution for z_t is then the maximumum of (2.7) and $\bar{z}$.

Similarly, by taking $b < 0$, one can allow for a convenience yield of low inventory levels.

Sales (or purchases) by producers and inventory holders are equal to

$$x_t = q_t + z_{t-1} - z_t \quad . \qquad (2.8)$$

Alternative assets

We can now solve the system (2.5) for f_t and S_t. However, it is plausible to assume that the return on S_t is not correlated with the next period spot price p_{t+1} or the revenue from next period production $p_{t+1}\, q_{t+1}$, so that $\text{cov}\,(p_{t+1}\, q_{t+1}, r_{t+1}) = = \text{cov}\,(p_{t+1}, r_{t+1}) = 0$. Under these additional assumptions, the optimal value for S_t immediately follows from (2.5)

$$S_t = \frac{-1 + \delta(1 + E\, r_{t+1})}{\gamma\ \text{var}\ (r_{t+1})} \quad . \tag{2.9}$$

In fact, S_t does not depend on the characteristics of the probability distribution of the coffee market. We get a second separation between the decision concerning S_t and that concerning the variables f_t and z_t. In the sequel, we shall make these additional assumptions.

The futures market

From (2.5b), we get

$$f_t - z_t = \frac{p_t^f - \delta\ E\ p_{t+1}}{\gamma\ \text{var}\ (p_{t+1})} + \frac{\text{cov}\ (p_{t+1}\ q_{t+1}, p_{t+1})}{\text{var}\ (p_{t+1})} \ . \tag{2.10}$$

In fact, in (2.10) we get an expression for the speculation component of a producer or inventory holder on the futures market. An inventory holder who completely hedges against price risk has to sell a quantity z_t on the futures market. To the extent that the right-hand side of (2.10) is positive, he sells more than required for complete hedging and therefore takes a price risk. The optimal f_t is obtained by substituting (2.7) into (2.10), provided $z_t \geq 0$.
The equilibrium condition for the futures market reads as follows:

$$\sum_i f_{it} = 0 \quad , \tag{2.11}$$

where the subscript i refers to agent i on the futures market.

Adding a subscript i in expression (2.10) and summing over i, assuming the agents on the futures market are (potential) inventory holders, we get the aggregate 'supply of storage' equation

$$0 = \sum_i \left[\frac{p_t^f - \delta_i E_i p_{t+1}}{\gamma_i \, var_i \, (p_{t+1})}\right] + Z_t + \sum_i \frac{cov_i \, (p_{t+1} \, q_{it+1}, p_{t+1})}{var_i \, (p_{t+1})} \qquad (2.12)$$

with Z_t being aggregate inventory.
Given the probability distribution for the next period, condition (2.12) establishes a linear relationship between teh futures price and the aggregate level of inventories. If all agents have the same price expectation $\delta \; E \; p_{t+1}$ and if q_{it+1} and p_{t+1} are independent, which is likely to be the case under perfect competition, the futures price is a downward biased predictor of the future spot price. This can be seen from equation (2.12) which then becomes

$$p_t^f - \delta \, E \, p_{t+1} = - \left[\sum_i \gamma_i \, var_i \, (p_{t+1})\right] Z_t - \sum_i E \, q_{it+1} \, . \qquad (2.13)$$

Exports

Finally, exports by a producing country are obtained from

$$exp_t = q_t - \Delta z_t - dis_t \qquad (2.14)$$

where z_t is determined by (2.6) and dis_t denotes domestic disappearance which we assume to be predetermined. Δ denotes the difference operator. In the model, exportable production, $q_t - dis_t$, is distributed over export and wholesale inventories.

2.2 The demand side

Wholesale inventories

At the wholesale level of the importing side, coffee is demanded by roasters to be prepared for consumption or to be held as inventory. We assume that coffee roasters only hold green coffee in their inventories.
For countries with a spot and futures market for coffee, like the U.S. and several Western European countries, we assume that roasters have access to the spot market and that the transportation costs from the spot market to the warehouse are negligible, so that roasters can buy and sell the green coffee at the spot market price. Moreover, they can hedge on the futures market against price risk. The behavior of a

roaster can then be modeled like that of an nonproducing inventory holder (see (2.6)) with a nonzero minimum level of inventories. A strictly positive minimum inventory level $\bar{z}_t$ will be required to assure a smooth roasting process and to quickly satisfy the demand of roasted coffee. The optimal inventory level corresponds to

$$z_t = \max\left(\frac{p_t^f - p_t - b}{2c}\ ;\ \bar{z}_t\right) \quad . \tag{2.15}$$

For countries without a spot exchange for coffee, we assume that coffee roasters buy more than the amount required for a smooth roasting process if they expect the retail coffee price to increase such that it becomes profitable to buy green coffee now and to sell to the retail sector in the next period. More formally, we assume that the espected utility of profits (2.2) is maximized with profits being given as in (2.1) but with

$$\Pi_{0t} = \bar{p}_t^r \, dis_t - p_t a_t - (b + cz_t)z_t + f_t \, p_t^f \tag{2.16}$$

and

$$\Pi_{1t} = \bar{p}_{t+1}^r \, z_t - f_t \, p_{t+1} \quad . \tag{2.17}$$

The notation and the assumptions are as follows:

1) $\bar{p}_t^r = p_t^r - k_t$, with p_t^r being the retail price of coffee and k_t being the unit cost of roasting, assumed to be exogenous. The retail price is assumed to be fixed (in the short-run).
2) Disappearance, dis_t , equals the consumption of coffee plus the change of inventories.
3) The purchase of green coffee by roasters equals $a_t = dis_t + \Delta z_t$.
4) The cost of holding inventories increases quadratically with z_t .
5) The total amount of inventories z_t can be sold next period without affecting the retail price. This assumption could be relaxed by introducing a downward sloping demand curve for roasted coffee.
6) Roasters have access to the futures market. They choose the level of z_t and the amount f_t which maximize the expected utility of profits.

The optimal amount of z_t is given by

$$z_t = \frac{\text{var }(p_{t+1})[\delta E\ \bar{p}^r_{t+1} - p_t - b] + \text{cov}(p_{t+1},\bar{p}^r_{t+1})[\delta E\ p_{t+1} - p^f_t]}{\text{var }(p_{t+1})[\gamma\ \text{var}(\bar{p}^r_{t+1}) + 2c] - \gamma\ \text{cov}^2\ (p_{t+1},\ \bar{p}^r_{t+1})}$$

$$\geq 0\ . \tag{2.18}$$

The optimal inventory level in (2.18) is a weighted average of the expected gain from selling on the retail market and from taking a short position on the futures market.

If the (conditional) covariance between p_{t+1} and $\bar{p}^r_{t+1}$ equals zero, equation (2.18) specializes accordingly. This assumption might be plausible when the transmission of the impact of a change of the spot price on the retail price occurs with a lag of at least one period. Notice finally that some of the variables have to satisfy inequality restrictions. Inventories and consumption cannot be negative, i.e. we have

$$z_t \geq 0 \quad \text{and} \quad cons_t = dis_t - z^r_t + z^r_{t-1} \geq 0\ ,\ z^r_t \geq 0\ ,\ \text{where} \quad z^r_t$$

are inventories in the retail sector and in private households.

Consumption

At the retail level, roasted coffee is demanded for consumption and for inventory holding. In a utility maximization framework, per capita consumption is determined by relative prices and by the real per capita income. The following semi-logarithmic-linear specification for per capita consumption has been used in the empirical analysis

$$\frac{cons_t}{n_t} = \alpha_0 + \alpha_1 \frac{p^r_t}{cp_t} + \alpha_2 \ln \frac{y_t}{n_t}\ , \tag{2.19}$$

where $cons_t$ = the total consumption,
n_t = the size of the population,
cp_t = the consumer price index,
y_t = the total disposable income deflated by cp_t .

The variables n_t , cp_t and y_t are exogenous.

Retail inventories

Inventories at the retail level or held by private households are also derived from a two-period profit optimization problem. Consumers are asssumed to hold stocks z_t^r larger than a normal level $\bar{z}_t^r$ if the expected next period retail price exceeds the current retail price plus the costs of holding inventories. Formally, they are assumed to maximize the expected utility of profits (2.3) with

$$\Pi_t = - z_t^r \, (p_t^r + b + c \, z_t^r) + \delta \, p_{t+1}^r \, z_t^r \quad . \tag{2.20}$$

The solution of the problem is

$$z_t^r = \max \left(\frac{\delta \; E \; p_{t+1}^r - p_t^r - b}{2c + \gamma \; var(p_{t+1}^r)} \; , \; \bar{z}_t^r \right) . \tag{2.21}$$

For a retail seller, the criterion function (2.20) has to be slightly modified by replacing p_t^r by the cost price of roasted coffee. Assuming that the first term on the r.h.s. of (2.21) is larger than $\bar{z}_t^r$, total disappearance becomes

$$\begin{aligned} dis_t &= cons_t + \Delta \; r_t^r \\ &= \alpha_0 n_t + \alpha_1 \frac{n_t p_t^r}{cp_t} + \alpha_2 n_t \ln \frac{y_t}{n_t} + \Delta \left[\frac{\delta \; E \; p_{t+1}^r - p_t^r - b}{2c + \gamma \; var \; (p_{t+1})} \right] . \end{aligned} \tag{2.22}$$

Total imports (or negative exports) are given by

$$\begin{aligned} imp_t &= dis_t + \Delta \; z_t \\ &= - \; exp_t \end{aligned} \tag{2.23}$$

where z_t is determined by (2.15) or by (2.18) assuming that reexports are zero. For notational convenience, imports will be defined as negative exports.

Retail price

The retail price is linked to the spot market price through a cost function

$$p_t^r = (1 + \eta)[k_t + \beta(L)p_t] \quad , \tag{2.24}$$

where k_t = the unit costs (labor, capital...) of roasting coffee, assumed to be proportional to the general price level,

η = the profit margin, assumed to be constant and ≥ 0 ,

$\beta(L) = \beta_0 + \beta_1 L + \dots \beta^s L^s$, with L being the lag operator and $\beta(1) = 1$.

The lag polynomial $\beta(L)$ is introduced to take account of the fact that part of the coffee which is roasted and sold in period t has been bought in the past. Also, in some countries, price regulations prohibit an instantaneous adjustment of prices to changes in production cost.

2.3 Market equilibrium

In section 2.1, we briefly discussed the futures market equilibrium, which corresponds to the conditon (2.11) where the positions of all agents (or countries) add up to zero. When an agent does not have access to the futures market, his position equals identically zero. These agents can be divided into two categories. Agents who operate on the spot and futures markets are assumed to determine their position on the futures market according to (2.7) and (2.10), with q_t being zero for nonproducing speculators. Agents who have access to a futures market only (for reasons of transportation costs), determine their position by maximizing the expected utility of profits as given in (2.16) and (2.17).

The clearing condition for the spot market corresponds to the equality of total exports to zero (with imports being negative exports)

$$\sum_i \exp_{it} = 0 \quad , \tag{2.25}$$

with exports being given in (2.14) and (2.23) respectively.

Condition (2.25) can also be written as

$$Q_t + Z_{t-1} + Z^r_{t-1} = Cons_t + Z_t + Z^r_t \quad , \tag{2.26}$$

where capital letters denote the aggregate value of the corresponding variable. The spot and futures prices are jointly determined by (2.11) and (2.25).

Except for the equations explaining the first and second moments of price variables, the model is complete. For the convenience of the reader, we summarize the model in table 1.

Table 1 A summary of the theoretical model

Variable / Country i	Production q_{it}	Consumption: $cons_{it}$ Disappearance: dis_{it}	Inventory z_{it}	Export exp_{it}	Retail price p^r_{it}
Producer (Exporting country)	predetermined	Consumption predetermined disappearance: $dis_{it} = cons_{it} + \Delta z^r_{it}$	wholesale $z_{it} = \max\left(\frac{p^f_t - p_t - b_i}{2c_i};\ \bar{z}_{it}\right)$ (2.6) retail z^r_{it} = predetermined	$exp_{it} = q_{it} - dis_{it} - \Delta z_{it}$ (2.14)	-
Importing country	$q_{it} = 0$	consumption $cons_{it} = \alpha_{oi} n_{it} + \alpha_{1i}\left(\frac{n_{it}\, p^r_{it}}{cp_{it}}\right) + \alpha_{2i}\, n_{it} \ln\left(\frac{y_{it}}{n_{it}}\right)$ (2.19) disappearance $dis_{it} = cons_{it} + \Delta z^r_{it}$	wholesale $z_{it} = \max\left(\frac{p^f_t - p_t - b_i}{2c_i};\ \bar{z}_{it}\right)$ (2.6) [or (2.18)] retail $z^r_{it} = \max\left(\frac{\delta_i E_i p^r_{it+1} - p^r_{it} - b_i}{2c_i + \gamma_i\, var_i(p^r_{it+1})};\ \bar{z}^r_{it}\right)$ (2.21)	$exp_{it} = -imp_{it} = -dis_{it} - \Delta z_{it}$ (2.23)	$p^r_{it} = (1 + \eta_i)[k_{it} + \beta_i(L) p_t]$ (2.24)
Market clearing	Spot market $\sum_i exp_{it} = 0 \iff \sum_i (q_{it} - cons_{it} - \Delta z_{it} - \Delta z^r_{it}) = 0$ (2.26) Futures market $\sum_i f_{it} = 0 \iff \sum_i \left\{\left[\frac{p^f_t - \delta_i E_i p_{t+1}}{\gamma_i\, var_i(p_{t+1})}\right] + z_{it} + \frac{cov_i(p_{t+1}\, q_{it+1},\ p_{t+1})}{var_i\, (p_{t+1})}\right\} = 0$ (2.12)				

2.4 Solution of the model

Now we discuss the solution of the model under the following assumptions:

1) Retail inventories are zero.
2) The wholesale sector of each country has access to spot and futures markets.
3) $\beta(0) = 0$.

Assumptions 1) and 2) imply that inventory formation depends on the price spread only. As $\beta(0) = 0$, consumption is predetermined. The price spread is determined by equation (2.26) which, after substitution of (2.7), can be written as

$$Q_t' - Cons_t + Z_{t-1} - \mu_1(p_t^f - p_t) + \mu_2 = 0 \qquad (2.27)$$

where Q_t , $Cons_t$ and Z_{t-1} are predetermined,

$\mu_1 = \sum_i (2c_i)^{-1}$ and $\mu_2 = \sum_i b_i\ (2c_i)^{-1}$. With the price spread being determined, the optimal wholesale inventory level can be obtained for each country. To determine the trade of coffee between countries, the futures market clearing condition (2.12), does not have to be taken into account nor do we have to make assumptions on the moments of next period price and quantity distribution.

Of course, if we are interested in the level of spot and futures prices, additional assumptions have to be made to solve equation (2.12).

We assume that:

4) Price expectations are rational, i.e. $E_i(p_{t+1}) = E(p_{t+1}|\Phi_t,$ model), where Φ_t denotes the information available at time t.
5) The conditional second moments of next period prices are constant over time.
6) Conditionally on Φ_t , q_{t+1} and p_{t+1} are independent.

Under assumptions 5) and 6), equation (2.12) can be written as

$$\nu_1\ p_t^f - \nu_2\ E\ p_{t+1} + Z_t + E\ Q_{t+1} = 0 \ , \qquad (2.28)$$

with $\nu_1 = [\sum_i \gamma_i^{-1} var_i^{-1}(p_{t+1})]^{-1}$, $\nu_2 = [\sum_i \delta_i\ \gamma_i^{-1}\ var_i^{-1}(p_{t+1})]^{-1}$.

Using $Z_t = \mu_1\ (p_t^f - p_t) - \mu_2$ to eliminate p_t^f from (2.28) yields

$$p_t - \frac{\nu_2}{\nu_1} E\ p_{t+1} + (\frac{1}{\mu_1} + \frac{1}{\nu_1})\ Z_t + \frac{\mu_2}{\mu_1} + \frac{1}{\nu_1} E\ Q_{t+1} = 0 \qquad (2.29)$$

With price expectations being rational, equation (2.29) can be solved for $E\ p_{t+1}$ along the lines of e.g. Kawai (1983). The solution for $E\ p_{t+1}$ can be substituted back into (2.29) to give p_t. As the price spread is already known, the value for the futures price is immediately obtained and the model is completely solved. Finally notice that without some simplifying assumptions, the presence of retail inventories complicates the solution of the model, a point that we do not discuss here any further.

2.5 Institutional aspects

Until now, we have not taken into account the International Coffee Agreement (ICA), which has been in existence since 1962 with periods of interruption. The aim of the ICA has been to achieve adequate supply of coffee at equitable, stable prices. The data used in the empirical analysis cover the period 1973-1982. During the subperiod 1973-1980 IV, no export quotas or price stabilization mechanism were operational.
However, 'special deals', which are sales contracts between producers and large coffee roasters, came into existence. In 1975, as a result of the destruction of a major part of Brazil's coffee production, coffee prices dramatically increased. In December 1975, the third ICA between 62 producer and consumer members of the International Coffee Organization (ICO) was approved to become effective on October 1, 1976 for a period of 6 years. It aimed at achieving stable prices through a system of export quotas.
In short, the third agreement which is the only agreement in the sample period that we analyze here works as follows:

Initial export quotas become effective when the Composite Indicator Price (CIP), which is the mean of the indicator prices for Others Milds and Robustas, remains on average for 20 consecutive market days at or below the ceiling of the price range fixed by the ICO. They are suspended if the CIP remains on average for 20 consecutive market days above the ceiling price. The initial export quotas are revised when the CPI drops below the floor of the price range fixed by the ICO. Quotas are allocated in fixed and variable parts to exporting members. The fixed part equals 70% of the annual quota, the variable part amounts to 30%. The fixed part is calculated on the basis of exports in the years 1968-1972. The variable part is proportional to the fraction of the country's inventories in total inventories of all exporting members of the ICO. Members are not allowed to exceed their annual and quarterly quotas. The upper limit is respectively 30, 60 and 80% of the annual quota for the first three quarters.
Initial quotas are revised according to the development of the coffee

price. When a member's export is smaller than the quota in a given quarter, the difference is added to his quota in the next quarter. For more details on the agreement and some minor changes which occured during the period of the agreement we refer to International Coffee Organization (1976). Since 1984, the fourth ICA is effective.

In our model, the quotas are introduced as additional restrictions faced by exporters. When the quotas are effective, exporting members are assumed to maximize (2.3) with profits given in (2.4) subject to the restriction $z_t \geq \bar{z}_t$, where

$$\bar{z}_t = q_t + z_{t-1} - cons_t - \overline{exp}_t \ , \qquad (2.29)$$

with $\overline{exp}_t$ being the export quota. For the sample period, the value of $\overline{exp}_t$ is known. For postsample simulations, $\overline{exp}_t$ is assumed to be determined as

$$\overline{exp}_t = exp_t^{in} + \lambda \, p^*_{t-1} + x_{t-1} \ , \quad \lambda > 0 \ , \qquad (2.30)$$

where exp_t^{in} = the predetermined initial quota as described above,

$$\begin{aligned} p^*_t &= p_t - p^\ell_t \ , \text{ if } p_t < p^\ell_t \\ &= 0 \ , \text{ if } p^\ell_t \leq p_t \leq p^u_t \\ &= p_t - p^u_t \ , \text{ if } p_t > p^u_t \end{aligned}$$

with p^ℓ_t and p^u_t being lower and upperbounds of the price range,

$x_t = \overline{exp}_t - exp_t$.

With the specification for the export quota system, the theoretical model is complete. In the next section, we shall present empirical results for the main coffee importing countries.

3. Empirical results

In this section, we give the empirical results for the disappearance, the retail price and the supply of storage for a number of countries. Before we can estimate the behavorial equations, additional assumptions have to be made. We assume that the parameters b_i and c_i of the cost function are expressed in nominal terms and are proportional to the general price level, in country i. Moreover, we assume that agents'utility depends on profits in real terms, which means that we deflate Π_{0t} and Π_{1t} in (2.1), (2.16), (2.17) and (2.20) by cp_t. The coefficients δ and γ are assumed to be constant over time. The implications of these assumptions are that the model is expressed in terms of relative prices and that after deflating, the coefficients b_i and c_i in the equations (2.6), (2.12), (2.18) and (2.21) are constant over time. Finally, we assume that agents make their decisions in terms of prices expressed in domestic currency, that expectations are rational and that agents take second moments of the prices deflated by cp_t as constant over time. Whenever possible, we use the same specification for all countries. A description of the data is given in the appendix. Now we present the empirical results.

3.1. Disappearance

Data on the two components of the disappearance, consumption and changes in retail inventories, are not available. However, equation (2.22) for the disappearance can be estimated. We add a disturbance term to (2.22) which is assumed to be normally distributed, white noise and independent of the explanatory variables.

We use the observed change of the retail price, Δp_t^r, at time t, as a proxy for $Ep_{t+1}^r - p_t$ and we take δ=1 to estimate equation (2.22). by OLS. Although OLS estimates are not consistent, they do not differ very much from two-stage least squares (2 SLS) estimates, which are consistent in the present case.

Notice that under the assumptions made above, equation (2.22) is a homogeneous regression equation. For some countries, we include seasonal dummy variables in (2.22) to account for seasonal fluctuations in the consumption of coffee.

The coefficient α_2 was not significant for any of the countries. Therefore, we delete the variable $n_t \ln (y_t/n_t)$ from the specification. The insignificance of α_2 might be the result of multicollinearity between y_t and n_t. During the period we analyzed, per capita income has been approximately constant in many countries so

Table 2. Empirical results for the disappearance (2.22), $\alpha_2 = 0$

Country, sample period	n_t	$\frac{p_t^r n_t}{cp_t}$	$\Delta\frac{Ep_{t+1}^r - p_t^r}{cp_t}$	Seasonal dummies			SER	DW	lnL	price elasticity min.	average	max.
F.R. Germany 1972,III-1980, IV	30.53 (6.39)	-.23 (1.01)	7.94 (.23)	I: -.0022 (1.27)	II: -.0021 (1.13)	III: -.0021 (1.22)	216.23	1.09	-227.74	-.34	-.20	-.13
France 1976, IV-1981, III	31.33 (15.50)	-.25 (3.49)	5.23 (.62)	III: 3.81 (3.53)			111.43	2.68	-120.42	-.56	-.30	-.17
Italy 1976, III-1982, III	20.56 (19.16)	-.000019 (4.63)	.15 (1.42)				71.75	2.29	-140.70	-.67	-.32	-.17
Japan 1976, IV-1982, III	10.88 (8.41)	-.0039 (3.50)	.088 (.44)				128.80	.98	-149.05	-1.94	-.79	-.48
Netherlands 1972, III-1980, IV	46.02 (9.23)	-.00090 (2.33)	26.34 (2.41)	III: -.0077 (2.98)			90.22	2.58	-199.19	-1.76	-.39	-.21
Sweden 1976, III-1982, III	63.65 (10.88)	-.70 (3.01)	16.86 (3.40)	III: -4.63 (1.51)	IV: 10.66 (3.11)		53.28	2.21	-132.07	-1.71	-.39	-.19
U.K. 1976, III-1981, III	12.78 (6.71)	-.067 (2.22)	6.32 (1.88)				112.96	1.95	-127.45	-1.53	-.54	-.30
U.S. 1972, I-1980, I	30.40 (29.06)	-.053 (7.47)	17.81 (3.19)	I: 1.36 (1.75)	III: -2.67 (3.29)		397.07	2.23	-241.59	-1.15	-.32	-.16

SER = Standard error of regression
DW = Durbin-Watson statistic
lnL = value of log-likelihood function

that the term $\alpha_2 \, n_t \ln(y_t/n_t)$ gets confounded with $\alpha_0 \, n_t$. It is also plausible that in developed countries, the effect of income on the consumption of coffee is negligible. For the U.S., $\hat{\alpha}_2$ is negative. This is the result of a downwards trend in the consumption of coffee over a period in which income increased.
The results for the model with $\alpha_2 = 0$ are given in table 2. Roman numerals indicate the quarter in which the dummy variable takes the value 1. The estimates of α_1 and of the coefficient of $\Delta \, z_t^r$ are almost insensitive to the deletion of α_2 . As expected, $\hat{\alpha}_1$ is negative and α_1 is highly significant, except for Germany. The coefficient of the inventory component also has the expected sign. In terms of disturbance autocorrelation (e.g. the Durbin-Watson statistics), the results are satisfactory too. Notice that our findings are at variance with the results of a study of the World Bank (1982), in which the price effect is found to be insignificant, whereas the income elasticity is large and significant.

To give the reader an indication of the value of the price elasticity of the disappearance, we also report the lowest value, the average and the highest value of the price elasticity over the sample period. The lowest value is observed in 1977 in the second quarter for France, in the third quarter for Italy, the Netherlands, Sweden and the U.S., and in the fourth quarter for Japan and the U.K. The highest value occurs at the beginning of the sample period for the U.K. and the U.S., in the second quarter of 1976 for the Netherlands and at the end of the sample period for the remaining countries. It is interesting to notice that for all countries the pattern of the change of the price elasticity over time is very similar. More importantly, the average price elasticity is almost the same for a number of countries. Japan appears to be an outlier in this respect. The large absolute price elasticity may be partly explained by the fact that coffee did penetrate into the Japanese market in a period of stable or slowly decreasing prices. To conclude, there is substantial empirical evidence that the price elasticity is in the range -.5 to -.2 for a number of countries. The result is found by using the same specification for the 8 countries that we have analyzed.

3.2. Retail prices

This section is devoted to the empirical analysis of equation (2.24) for the retail price.

$$p_t^r = (1 + \eta)\ [k_t + \beta(L)p_t]\quad , \eta > 0\quad . \tag{3.1}$$

The subscript i has been deleted for reasons of convenience. Prices in (3.1) are expressed in domestic currency. The fixed and remaining variable costs per unit of roasting, k_t, are assumed to be proportional to cp_t, i.e. $k_t = \alpha\ cp_t$, possibly with a random disturbance. This assumption has resulted from a detailed analysis of various specifications for k_t and yields, after substitution into (3.1),

$$p_t^r = \alpha^* + \beta^*(L)\ p_t\ , \tag{3.2}$$

with $\alpha^* = (1 + \eta)\alpha$, $\beta^*(L) = (1 + \eta)\ \beta(L)$ and prices being deflated by cp_t. We assume that $\beta^*(L)$ is a rational polynomial

$$\beta^*(L) = \frac{\gamma(L)}{\phi(L)} = \frac{\gamma_0 + \gamma_1 L + \gamma_2 L^2}{1 - \phi_1 L - \phi_2 L^2} \tag{3.3}$$

with the restriction $\beta^*(1) = 1 + \eta$. This latter assumption means that in the long-run the retail price fully adjusts to the spot price, with a mark-up equal to η.

Equation (3.2) can now be expressed as an error correction model (ECM).

$$\Delta p_t^r = \alpha' - \phi_2 \Delta p_{t-1}^r + \gamma_0 \Delta p_t - \gamma_2 \Delta p_{t-1} - (1 - \phi_1 - \phi_2)$$

$$[p_{t-1}^r - (1 + \eta)p_{t-1}] \tag{3.4}$$

with $\alpha' = \alpha^*\phi(1)$. The model (3.4) can be further generalized by allowing for the irreversibility in the reaction of p_t^r to changes in p_t . We assume that the response of p_t^r to an increase or a decrease of p_t is respectively $\beta^+(L)$ and $\beta^-(L)$ subject to the restriction that $\phi^+(L) = \phi^-(L)$ and $\beta^+(1) = \beta^-(1)$. The ECM with irreversibility is given by

$$\Delta p_t^r = \alpha' - \phi_2 \Delta p_{t-1}^r + \gamma_0^+ \Delta^+ p_t - \gamma_2^+ \Delta^+ p_{t-1} + \gamma_0^- \Delta^- p_t - \gamma_2^- \Delta^- p_{t-1}$$

$$- (1 - \phi_1 - \phi_2)[p_{t-1}^r - (1 + \eta)\ p_{t-1}] + \varepsilon_t\ , \tag{3.5}$$

where a normally distributed white noise disturbance term ε_t has been added and $\Delta^+ p_t$ equals the change of p_t whenever the change is positive and zero otherwise. $\Delta^- p_t$ is defined in a similar way for negative changes. Models with various lag length have been estimated. The models which have been finally chosen are reported in table 3. For France and the U.K., we use for the world market price the spot

Table 3. Empirical results for the retail price formation (3.5), $\eta = .3$

Country, sample period	α'	$-\phi_2$	γ_0^+	$-\gamma_2^+$	γ_0^-	$-\gamma_2^-$	$-(1-\phi_1-\phi_2)$	SER R^2	DW ρ	lnL	mean lag$^+$	mean lag$^-$	γ_1^+ γ_1^-
F.R. Germany													
1972,III-	2.22	.20	.10	.24	-.32	1.01	-.17	.56	2.04	-24.87	2.63	.62	.37
1980, IV	(2.14)	(2.18)	(.69)	(1.24)	(1.63)	(5.45)	(2.29)	.84					1.55
France													
1976, II-	5.82		.19	.60	.07	-.14	-.57	.75	2.44	-21.32	.37	1.89	1.15
1981,III	(3.50)		(1.70)	(2.97)	(.68)	(.75)	(4.24)	.96					.52
Italy	87.3	.24	.48	.40	.04	.28	-.14	49.15	1.56	-123.5	-.82	3.14	.10
1976, IV-	(1.08)	(2.51)	(6.35)	(4.18)	(.45)	(2.25)	(1.71)	.93	ρ=.46				.42
1982, III									(2.54)				
Japan	123.8		-.13		.80		-.37	108.3	2.31	-156.54	3.07	.54	.61
1976, II-	(2.81)		(.54)		(2.65)		(3.53)	.40					-.32
1982, III													
Netherlands	1.14		-.006	.79	.52	.47	-.26	.49	2.44	-21.37	.82	.05	1.13
1972, II-	(2.10)		(.05)	(3.96)	(3.38)	(2.82)	(2.42)	.89					.29
1980, IV													
Sweden													
1976, II-	3.06		.23	.66	.21	.13	-.44	.70	2.34	-24.23	.25	1.50	.99
1982, III	(2.83)		(2.10)	(3.33)	(1.45)	(.58)	(3.12)	.94					.50
U.K.	13.48		-.15	-.81	-1.81	-.96	-.41	3.02	2.06	-52.01	1.49	1.38	.82
1976, II-	(2.47)		(.30)	(1.49)	(3.85)	(1.64)	(3.35)	.82					9.27
1981, III													
U.S.													
1960, IV-	4.02	.15	.19	.60	.41	.28	-.15	2.02	1.70	-166.24	.41	1.13	.61
1980, III	(2.78)	(3.02)	(4.44)	(8.78)	(7.08)	(4.48)	(3.21)	.95					.06

market price of Robusta, whereas for the remaining countries, we use the composite indicator price for p_t. The restriction $\eta = .3$ has been imposed a priori. For some countries, the estimate of η was very close to .3. For most countries, the most plausible results were obtained, when η is set equal to .3. By mean lag$^+$ and mean lag$^-$, we denote the mean lag implied by $\beta^+(L)$ and $\beta^-(L)$ respectively. In the last column of table 3, we report the estimate of γ_1^+ and γ_1^- obtained from the estimates of the coefficients of (3.5). When no estimate is reported for a coefficient, its value equals zero. The results in table 3 indicate that the adjustment of p_t^r to changes in p_t is asymmetric. This conclusion follows from the point estimates of the parameters and the mean lag for $\beta^+(L)$ and $\beta^-(L)$ respectively. The results vary across countries, a finding which is not surprising given the differences of the institutional arrangements for the price adjustment.

Some care is also required with the interpretation of the results, as the sample is dominated by a period of rapid price increase, caused by the loss of a major part of the coffee harvest in Brazil in 1975, followed by a period in which the coffee price steadily decreased to reach its "normal" level. To give more insight in the properties of the adjustment process, we report the first 5 coefficients of $\beta^+(L)$ and $\beta^-(L)$ in table 4. The adjustment to an increase of p_t is reasonably quick except for Germany and Japan. When p_t decreases, the adjustment of the retail price is rather slow, except for Germany and the Netherlands.

For Germany, France, Italy, the Netherlands and Sweden, the ECM with irreversibility gives the best results. However notice that for Germany the reaction to a decrease of p_t is faster than that to an increase of p_t. For Italy, we had to allow for a first order autoregressive disturbance process. The model has been estimated by the Cochrane-Orcutt method. The disturbance serial correlation can be the result of serial correlation in the component k_t. For Japan and the U.K., the results are not very satisfactory. In particular, the adjustment to a decrease of p_t is very slow. The distributed lag model (3.2) with $\beta^*(L)$ given in (3.3) yields a good fit for Japan. However, the implied long-run relationship between p_t^r and p_t is then smaller than one (i.e. $\eta < 0$).

Table 4 Price adjustment (3.5)

Country	$\beta^+(L)$, $\beta^-(L)$	0	1	2	3	4
F.R. Germany	+	.10	.57	.79	.93	1.02
	−	−.32	.91	1.22	1.32	1.34
France	+	.19	1.42	1.35	1.32	1.31
	−	.07	.63	1.01	1.17	1.25
Italy	+	.48	1.11	1.28	1.37	1.37
	−	.04	.51	.73	.89	.98
Japan	+	−.13	.40	.73	.94	1.07
	−	.80	.99	1.11	1.17	1.22
Netherlands	+	−.006	1.12	1.17	1.20	1.23
	−	.52	1.19	1.22	1.24	1.25
Sweden	+	.24	1.36	1.33	1.32	1.31
	−	.21	.82	1.03	1.15	1.22
U.K.	+	−.15	1.25	1.27	1.28	1.29
	−	−1.81	−1.50	−.36	.31	.71
U.S.	+	.19	.98	1.15	1.19	1.22
	−	.41	.88	1.01	1.07	1.11

3.3. Wholesale inventories

To model the formation of wholesale inventories, we have to take into account the characteristics of the various countries. First, we shall model the inventory holdings of green coffee in the major importing countries. Second, we shall analyze the inventory formation in the main exporting country Brazil. Thereby, we assume that due to the importance of the production of coffee by Brazil in the total world supply, Brazil can influence world market prices.

In a first instance, we assume that importing countries have access to both spot and futures markets, so that from a theoretical point of view, the specification (2.6) is appropriate for explaining the wholesale inventories. This assumption of access to spot and futures exchanges is reasonable as there is a coffee exchange in several countries in Europe and in the U.S. Prices in (2.6) are expressed in domestic currency. To account for inflation, the coefficients b_i and c_i in (2.6) are assumed to be proportional to the consumer price index of the country i. For the U.S., we have first assumed that b_i varies linearly with the wholesale price index and with the spot market price times a shortrun interest rate (see Telser (1958) for a similar approach). This second explanatory variable ought to account for the increase in the costs of holding inventories caused by an increase in interest charges. When the coefficient of the interest rate is estimated, it is not significantly different from zero. The estimates of the remaining coefficients are not sensitive to the inclusion of this additional variable in the equation for inventories. For these reasons, the interest rate has finally been deleted from the analysis. For z_{it}, the end of the quarter value is used. For the price spread $p_t^f - p_t$, we use the price series of the main part of the imports. The series are indicated in columns 2 and 3 of table 5, where the empirical results for the wholesale inventory equation are reported.

For some countries, a minimum inventory level denoted by $\bar{z}_i$ is imposed in which case, observed values of z_{it} smaller than $\bar{z}_i$ are disregarded from the estimation (see column 7 of table 5). The residuals from OLS estimation of equation (2.6) are strongly autocorrelated. To account for the dynamics in the series, the model (2.6) was extended by means of a partial adjustment equation

Table 5 Wholesale inventories

Country, sample period	Series p_t^f	Series p_t	constant term	spread	z_{t-1}	$\bar{z}$	SER R^2	DW h-test	lnL	mean lag
F.R. Germany 1973, I – 1982, II	NY	CIP	172. (4.50)		.51 (4.85)		58.9 .68	1.95 .20	−189.60	1.04
France 1972, I – 1982, II	London	Robusta London	310.8 (9.78)	52.4 (2.62)	.23 (3.16)	285	46.5 .72	1.62 1.40	−149.13	.31
Japan 1973, I – 1982, II	NY	CIP	376.3 (4.19)	2.05 (4.27)	.64 (7.24)	640	113.5 .81	1.98 .07	−182.93	1.8
The Netherlands 1973, I – 1982, II	NY	CIP	48.4 (4.76)	18.1 (2.20)	.43 (4.25)		19.7 .79	1.33 2.64	−146.85	.75
Finland 1973, I – 1982, II	NY	Other Milds	151. (3.79)	53.89 (2.95)	.52 (4.13)		74 .50	1.83 .83	−210.22	1.08
Norway 1973, I – 1982, II	NY	Other Milds	75.4 (3.86)		.40 (2.62)		26.1 .16	2.19 −1.73	−176.79	.67
U.K. 1975, I – 1982, II	London	Robusta	131. (4.58)		.42 (3.57)	160	41.1 .40	1.91 .32	−106.80	72
U.S. 1975, II 1980, IV	N.Y.	CIP	1730 (3.87)	38.6 (3.26)	.41 (2.59)		307 .61	2.17 −1.00	−155.6	.65

$\bar{z}$ = floor of the inventory level

NY = New York

CIP = Composite Indicator Price

h-test = Durbin's h-test

$$z_{it} - z_{it-1} = \beta[z_{it}^{*} - z_{it-1}], \tag{3.6}$$

where the desired inventory level, z_{it}^{*}, is explained by equation

$$z_{it}^{*} = \frac{1}{2c_i}[p_t^f - p_t] - \frac{b_i}{2c_i} + \varepsilon_{it}, \tag{3.7}$$

with ε_{it} being a disturbance term.
Substitution of (3.7) into (3.6) yields the equation which has been estimated. The spread, $p_t^f - p_t$, is an average over the quarter. In this way, additional lags in the reaction to variations in the spread are introduced.
For Italy, no quarterly data on the wholesale inventories are available. For Sweden, the quarterly data are equal to one fourth of the annual observation. These two countries have not been analyzed. Instead of Sweden, we give results for Finland and Norway. For all countries, except the U.K., Norway and Finland exceptional values for z_{it} are observed in 1977 after the period of a rapid increase in world coffee prices. These outliers for 1977 have been modeled by means of dummy variables.

The partial adjustment model accounts for most of the residual autocorrelation for the European importing countries. For Germany, Norway and the U.K., the coefficient of the spread was very small and not significantly different from zero. The spread has therefore been deleted as an explanatory variable from the specification for these countries. The results for these countries in table 5 can be interpreted as a partial adjustment to a constant inventory level, which corresponds to approximately three weeks of disappearance, an amount which is probably required for a smooth roasting process and distribution to the customers. Similar conclusions were obtained when the end of the quarter value of the spread is used instead of the average spread. Also, the data contain little evidence in favor of a partial adjustment model in which the desired inventory level varies proportionally to the volume of the disappearance. One can of course question the appropriateness of the assumption of a symmetric partial adjustment in this context. Again, there is little evidence in the data suggesting an asymmetric adjustment scheme, so that we decided to choose the specification (3.6)-(3.7). The results in table 5 are OLS estimates. The assumption of absence of simultaneity is reasonable for small countries, which have to take the price spread as given to adjust their inventory level. For a large coffee trader like the U.S. or Brazil, simultaneity between inventory levels and the price spread is likely to occur. For the U.S., a Hausman test of the exogeneity of the spread was not significant.

For the European countries and Japan, equation (2.18) has also been estimated. For some countries, the fit and the significance of the coefficients of equation (2.18) are slightly more satisfactory than for equations (3.6) and (3.7). On the whole however, the empirical results for (2.18) are not superior to those reported in table 5. Spot and futures markets are located in the countries considered or in their vicinity, so that the specification (3.6) - (3.7) is a priori plausible. Therefore, we retain the equations (3.6) - (3.7) to explain the inventory formation on the wholesale level.

In order to model the inventory formation in Brazil (or the amount of exports), we notice that conditionally on the moments of next period prices and quantities, the model in table 1 implies a downward sloping relationship between the export of some country say j and the spot market price p_t. To obtain this result, it is sufficient to assume that α_{1i} in (2.19) is negative and to substitute equations (2.6), (2.12), (2.19) for all countries except the j-th one and equation (2.21) into the market clearing condition (2.26). An unexpected increase of the export of Brazil therefore implies a decrease of p_t. More formally, the relationship between p_t and the export by Brazil, exp_{Bt}, can be expressed as a demand curve

$$p_t = \phi_0 - \phi_1 \, exp_{Bt} \, , \; \phi_1 > 0 \quad . \tag{3.8}$$

If variations of the inventories at the retail level are negligible, ϕ_0 increases linearly with the size of the population in all importing countries and with Ep_{t+1}. It decreases linearly with the total of production and wholesale inventories in respectively Brazil and the rest of the world.

We assume that Brazil maximizes the expected utility of profits Π_t (2.2) with Π_t being given in (2.1) (S_t is ignored), subject to (3.8). If the derivatives of the moments with respect to the decision variables f_t and z_t are taken to be zero except for $\partial Ep_{t+1}/\partial z_t$, the solution of this programming problem for the inventory level is

$$z_{Bt} = \max \Big\{ \frac{1}{2(\phi_1 + c)} \Big[2\phi_1 x_{Bt} - \phi_0 + p_t^f - b + \delta \frac{\partial Ep_{t+1}}{\partial z_t} \Big[\frac{\delta Ep_{t+1} - p_t^f - \gamma \operatorname{cov}(p_{t+1} q_{Bt+1}, p_{t+1})}{\gamma \operatorname{var}(p_{t+1})} \Big] \Big], \bar{z}_{Bt} \Big\}, \tag{3.9}$$

where the subscript 'B' denotes Brazil, $x_{Bt} = q_{Bt} + z_{Bt-1}$ and $\bar{z}_{Bt}$ is some minimum inventory level.

The second order conditions for a maximum are satisfied if $\partial Ep_{t+1} / \partial z_t \leq 0$ and $\partial^2 Ep_{t+1} / \partial z^2_t \leq 0$.
When $\partial Ep_{t+1} / \partial z_t = 0$, expression (3.9) specializes accordingly. If this derivative, the second moments in (3.9) and the size of the population in the importing countries are constant, we have

$$z_{Bt} = \max (\psi_0 + \psi_1 x_{Bt} + \psi_2 x_{0t} - \psi_3 Ep_{t+1} + \psi_4 p^f_t + \psi_5 n_t \; ; \; \bar{z}_{Bt}) \; , \quad (3.10)$$

, $x_{0t} = q_{0t} + z_{0t-1}$ (with '0' denoting the other countries (except Brazil)).
The ψ_i's are constant coefficients with $\psi_1, \psi_2, \psi_4, \psi_5 \geq 0$, $\psi_3 \leq 0$ when $\partial Ep_{t+1} / \partial z_t \leq 0$. The sign of ψ_0 is not a priori determined.

Equation (3.10) has been estimated by OLS for Brazil for the period 1973, I - 1982, II. The observed price variable p_t is substituted as a proxy for $E\, p_{t+1}$. When the restrictions $\psi_3 = -\psi_4$ and $\psi_5 = 0$ are imposed the estimates of equation (3.10) are

$$\underset{}{z_{Bt}} = \underset{(1.80)}{-15272.6} + \underset{(4.68)}{.58}\; x_{Bt} + \underset{(2.68)}{.48}\; x_{0t} - \underset{(1.14)}{29.18}\; [\,E\, p_{t+1} - p^f_t\,]$$

(with $\bar{z}$ = 10,000 , SER = 4579. , R^2 = .64 , DW = 1.52 , lnL = -352.4). They differ only slightly from the estimates of the unrestricted equation (3.10). The estimates for Brazil have the expected sign. The coefficients of the variables x_{Bt} and x_{0t} are significant. The price variable is not significantly different from zero. Notice also that there is serial correlation left in the disturbances so that some dynamics will have to be introduced in (3.10). We have tried to imbed equation (3.10) in a partial adjustment framework. The improvement of the empirical results however appeared to be small. At present, we select the static specification reported above which is subject to the restriction $\psi_3 = -\psi_4$. Although according to the theoretical model (3.10), this restriction should not hold exactly, the difference between ψ_3 and ψ_4 could be small, so that in this respect too the empirical finding is in agreement with the specification (3.10).

4. Concluding remarks

In this paper, we first presented a short-run model for the demand and international trade of coffee and for the price formation on world spot and future markets of coffee. We derived the behavorial relationships for producers, inventory holders and speculators from underlying optimizing considerations along the lines similar to those followed by Bray (1981), Danthine (1978), Kawai (1983), Newbery and Stiglitz (1981) and Turnovsky (1983) among others. (For a more exhaustive

treatment of futures markets, the interested reader is directed to the collections of readings available, such as Peck (1977)]. Agents (countries) are assumed to choose the inventory level and to take a position on the futures market such that the expected utility of the present value of profits over a two period decision horizon is maximized. The volume of the trade flows between countries is determined by the consumption (production) of coffee and by the variation of inventory levels. Spot and futures prices adjust to clear the spot and futures markets at each period.
In the second part, we gave empirical results for the behavorial equations of the disappearance of coffee, the inventory formation at the wholesale level and we modeled the relationship between the retail price of coffee in the main importing countries and the world spot market price. Whenever possible, we used the same functional form and the same lag structure for the behavorial equations of the various countries.

In general, our results are fairly well in agreement with the theoretical model based on optimizing considerations. Also, the value of some coefficients is surprisingly stable across countries. For instance, with the exception of Japan, the average price elasticity of the disappearance of coffee is found to be in the range of -.54 to -.20.
In conclusion, the empirical evidence confirms our initial hypothesis of a highly structured model which is consistent with profit maximizing behavior in an uncertain environment. The model will be further extended by including other coffee producing and coffee importing countries. The second largest coffee producer of the world, Columbia, will be assumed to be a price setter similar to Brazil. The remaining producers in Midden and South America and in Africa will be assumed to be price takers. On the demand side, the rest of Western Europe, Eastern Europe, Asia, Australia and Canada will be modeled along the lines of the analysis in section 3. Finally, the model will be used to simulate the impact of large shocks in the production on prices and on international trade of coffee and to study the effects of changes in the international coffee agreement under various production strategies.

References

Bray, M. (1981): "Futures trading, rational expectations, and the efficient market hypothesis", Econometrica, 49, 575-596.

Danthine, J.P. (1978): "Information, futures prices and stabilizing speculation", Journal of Economic Theory, 17, 79-98.

International Coffee Organization (1976): International Coffee Agreement, London.

Kawai, M. (1983): "Price volatility of storable commodities under rational expectations in spot and futures markets", International Economic Review, 24, 435-460.

Newbery, D.M.G., and J.E. Stiglitz (1981): The Theory of Commodity Price Stabilization, Oxford, Clarendon Press.

Peck, A.E. (ed.) (1977): Selected Writings on Futures Markets, Vol. II, Chicago, Chicago Board of Trade.

Telser, L.G. (1958): "Futures trading and the storage of cotton and wheat", Journal of Political Economy, 66, 233-255.

Turnovsky, S.J. (1983): "The determination of spot and futures prices with storable commodities", Econometrica, 51, 1363-1388.

Working, H. (1949): "The theory of the price of storage, American Economic Review, 31, 1254-1262.

World Bank (1982): Analysis of the World Coffee Market; Washington D.C., World Bank Staff Commodity Paper No. 7.

Appendix: Description of the data

The series are:

1. The wholesale inventory: the end of the quarter level in thousands of bags of 60 kg, all sorts of coffee, green and roasted; published in International Coffee Organisation: (I.C.O), *Quarterly Statistical Bulletin on Coffee*. For Brazil: U.S.D.A, *Foreign Agricultural Circular, Coffee.*

2. The disappearance has been computed as imports minus reexports minus changes in wholesale inventories, measured in the same units as the wholesale inventory level. Source: I.C.O., op. cit.

3. The world spot market price is the quarterly average of the indicator price for Other Milds (OM) or for Robusta (ROB) on the New York Commodity Exchange or the composite indicator price =

   $= \frac{1}{3}\left[\frac{1}{2}(OM + CM) + ROB + UA\right]$, where CM and UA denote the indicator prices for Columbian Milds and Unwashed Arabicas respectively.
   Source: I.C.O., op. cit.;
   Pan-American Coffee Bureau, *Annual Coffee Statistics*

4. The futures market price is the quarterly average of the average of the second and third "C-contract" (Other Milds) in New York or of the second and third contract (Robusta) in London.
   Source: I.C.O., op. cit., completed by information from La Fédération Nationale du Commerce des Cafés Verts: *Le Café*, Revue Mensuelle
   George Gordon Paton, *Coffee Annual*
   Pan-American Coffee Bureau, *Annual Coffee Statistics*

5. The retail price of coffee: quarterly average in domestic currency per kg.
   For the U.K.: price per 100 gr.
   For the U.S.: ¢ per lb,
   Source: I.C.O., op. cit.; *Bureau of Labor Statistics*

6. The price deflator is the consumer price index, all items, base period: June 1970=100. For the U.S., we used the wholesale price index; the base period is the first quarter of 1970.
   Source: *Monthly Bulletin of Statistics*
   I.M.F., *International Financial Statistics*

7. The exchange rate: quarterly average of the exchange rate for U.S. $
   Source: I.M.F., op cit.

8. The size of the population: annual data in millions of persons
   Source: Monthly Bulletin of Statistics, Quarterly figures have been derived using the interpolation method of: Doornbos, R., and J.H.C. Lisman (1968): "Afleiding van kwartaalcijfers uit jaartotalen", Statistica Neerlandica, 22, 199-205.

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