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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. Since then many empirical market studies for agricultural commodities have been published. For the coffee market we mention Bacha (1968), Edwards and Parikh (1976), Gelb (1977), Parikh (1974) and Wickens and Greenfield (1969) among many others. 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 equations of the model for a number of countries. Much attention is paid to the theoretical foundation of the empirical model. 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.

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 U.S., Japan and the major coffee importing countries in Western Europe, and for Brazil, Columbia and aggregated other producing countries. The results provide evidence on the appropriateness of the theoretical model for the coffee market. In section 4, we briefly 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. Of course, they could decide to harvest only part of the crop, a point that will be briefly discussed below. 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:

$$\Pi_t = \Pi_{0t} + \delta \, \Pi_{1t} \qquad (2.1)$$

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

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

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

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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.

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

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 $\frac{\partial\ var(\Pi_t)}{\partial\ z_t} = - \frac{\partial\ var(\Pi_t)}{\partial\ f_t}$. 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,

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

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 section

2.2. 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:

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

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

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

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 maximum 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

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

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 cov $(p_{t+1}\ q_{t+1}\ ,\ r_{t+1}) =$ cov $(p_{t+1}\ ,\ r_{t+1}) = 0$. Under these additional assumptions, the optimal value for S_t immediately follows from (2.5)

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

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.

<u>Hedging on the futures market</u>

From (2.5b), we get

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

In fact, in (2.10) we get an expression for the speculation component of a producer's or inventory holder's position 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

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

with Z being aggregate inventory.
Given the probability distribution for the next period, condition (2.12) establishes a linear relationship between the 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

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

This bias is also called normal backwardation.

2.2 The supply side
Wholesale inventories and exports

Price taking producers are assumed to determine the optimal inventory level according to (2.6) possibly subject to $z_t \geq \bar{z}$.
Exports by a producing country are obtained from

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

where dis_t denotes domestic disappearance which we assume to be predetermined. Δ denotes the difference operator. The model explains how exportable production, $q_t - dis_t$, is distributed over export and wholesale inventories. [2)]

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2) The model could be extended by assuming that producers maximize the expected utility of profits with respect to the amount to be harvested q_t subject to a quadratic cost function for harvesting, $ch_t = q_t (w_t + b + c\, q_t)$ and the restriction $q_t \leq \bar{q}_t$, with w_t being the wage and $\bar{q}_t$ the total available production. This extension would yield the additional behavioral equation for producers $q_t = \frac{p_t - w_t - b}{2c}$ and $q_t \leq \bar{q}_t$. In the present version of the model, we assume that $q_t = \bar{q}_t$.
For more discussion on this point, we also refer to Wright (1969).

When a producer has a large share of the market (e.g. Brazil), the assumption of pricetaking behavior is probably not adequate anymore. Instead, we assume that the producer is a pricesetter. Formally this means that he faces a downward sloping demand curve

$$p_t = \phi_0 - \phi_1 \ exp_t \quad , \quad \phi_1 > 0 \tag{2.15}$$
$$= \phi_0 + \phi_1 \ z_t - \phi_1 \ (q_t + z_{t-1}) \ ,$$

where the coefficients ϕ_0 and ϕ_1 possibly depend on the situation on the coffee market at time t but they are not controlled by the producer.

We assume that a price-setting producer (or inventory holder) maximizes the expected utility of profits (2.2), with Π_t being given in (2.1) (S_t is ignored) subject to (2.15) and $z_t \geq \bar{z}_t$. The derivatives of the conditional moments with respect to the decision variables f_t and z_t are taken to be zero except for $\partial \ E \ p_{t+1}/\partial \ z_t$. The optimal inventory level of a price-setting producer is given by

$$z_t = \max \{ \frac{1}{2(\phi_1+c)} [2\phi_1(q_t+ z_{t-1}) - \phi_1 \ f_{t-1} + p_t^f - b - \phi_0 + $$
$$+ \delta \frac{\partial \ E \ p_{t+1}}{\partial \ z_t} (\frac{\delta \ E \ p_{t+1} - p_t^f - \gamma \ cov(p_{t+1}q_{t+1}, p_{t+1})}{\gamma \ var \ (p_{t+1})})] ; \ \bar{z}_t \}$$

(2.16)

The second order conditions for a maximum are satisfied if

$\partial \ Ep_{t+1} / \partial z_t \leq 0$ and $\partial^2 E \ p_{t+1} / \partial \ z_t^2 \leq 0$. When $\partial \ E \ p_{t+1} / \partial \ z_t = 0$, expression (2.16) specializes accordingly.

2.3 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 and that they 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, who is a price taker 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

$$z_t = \max \left(\frac{p_t^f - p_t - b}{2c} \; ; \; \bar{z}_t\right) \; . \qquad (2.17)$$

Notice finally that some of the variables have to satisfy inequality restrictions. Inventories and consumption cannot be negative, i.e. we have

$$z_t \geq 0 \quad \text{and} \quad cons_t = dis_t - z_t^r + z_{t-1}^r \geq 0 \; , \; z_t^r \geq 0 \; , \qquad (2.18)$$

where z_t^r are inventories in the retail sector and in private households.

<u>Consumption</u>

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

$$\frac{cons_t}{n_t} = \alpha_0 + \alpha_1 \frac{p_t^r}{cp_t} + \alpha_2 \ln \frac{y_t}{n_t} \; , \qquad (2.19)$$

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 .

This functional form has been chosen in order to force the income elasticity to decrease when consumption increases. The variables n_t , cp_t and y_t are exogenous.

<u>Retail inventories</u>

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

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

The solution of the problem is

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

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

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

Total imports (or negative exports) are given by

$$\begin{aligned} imp_t &= dis_t + \Delta\ z_t \\ &= -\ exp_t \end{aligned} \qquad (2.23)$$

where z_t is determined by (2.17) 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

$$p_t^r = (1 + \eta)[k_t + \beta(L)p_t] \ , \qquad (2.24)$$

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 ,

$\beta(L) = \beta_0 + \beta_1 L + \beta_2 L^2 + \ldots$, 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.

2.4 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. 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) [or (2.16) for a price setter] 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) 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)				

2.5 Solution of the model

Now we briefly outline how the solution of the model can be obtained under the following assumptions:

1) 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.
2) The conditional second moments of next period prices are constant over time.
3) Conditionally on Φ_t , q_{it+1} and p_{t+1} are independent.
4) Each country which holds inventories at the wholesale level has access to the futures market.

Under assumptions 2), 3) and 4), equation (2.12) can be written as

$$\nu_1 \, p^f_t - \nu_2 \, E \, p_{t+1} + Z_t + E \, Q_{t+1} = 0 \quad , \qquad (2.27)$$

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

Equation (2.26) can be expressed as

$$Q_t + Z_{t-1} - Dis_t - Z_t = 0 \quad , \qquad (2.28)$$

where Q_t and Z_{t-1} are predetermined. After substitution of (2.24) for p^r_t and the expected value of (2.24) for $E \, p^r_{t+1}$ in $cons_{it}$ and z^r_{it} , total disappearance, Dis_t , can be expressed as a linear function of p_t , $E \, p_{t+1}$ and $E \, p_t$ besides the predetermined variables n_{it} , y_{it}/n_{it} , cp_{it} , k_{it} and lagged values of p^r_{it} and p_t . Using (2.6) and (2.16) for respectively price-taking and price-setting inventory holders, Z_t can be expressed as a linear function of the spread $p^f_t - p_t$, p^f_t and $E \, p_{t+1}$ and some predetermined variables (assuming $\partial E \, p_{t+1}/\partial z_{it}$ to be constant). After eliminating Dis_t and Z_t from (2.28) by substitution, expression (2.28) becomes a linear relationship between p_t , p^f_t , $E \, p_t$, $E \, p_{t+1}$ and and some predetermined variables in the model.

With price expectations being rational, the complete model is linear in the endogenous variables. The two market equilibrium conditions can be solved for p_t , p^f_t , Ep_t , Ep_{t+1} using a solution method for rational expectations models along the lines of e.g. Kawai (1983). Estimates of the variable $E \, Q_{t+1}$ are available, so that it can be treated as a predetermined variable.

2.6 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 effective.
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 Other 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 CIP 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

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

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:

$$\overline{exp}_t = exp_t^{in} + \lambda \ p_{t-1}^* + v_{t-1} \ , \quad \lambda > 0 \ , \tag{2.30}$$

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

$$p_t^* = p_t - p_t^\ell \ , \text{ if } \ p_t < p_t^\ell$$
$$= 0 \ , \text{ if } \ p_t^\ell \leq p_t \leq p_t^u$$
$$= p_t - p_t^u \ , \text{ if } \ p_t > p_t^u$$

with p_t^ℓ and p_t^u being lower and upperbounds of the price range,

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

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) 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), (2.16), (2.17) 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 (first moments) 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 $Ep_{t+1}^r - p_t^r$ and we take $\delta=1$ 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 real income has been approximately constant in many countries

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				I	II	III						
1972, III-	30.53	$-.23.10^{-3}$	7.94	-.0022	-.0021	-.0021	216.23	1.09	-227.74	-.34	-.20	-.13
1980, IV	(6.39)	(1.01)	(.23)	(1.27)	(1.13)	(1.22)						
France				III								
1976, IV-	31.33	-.25	5.23	-3.81			111.43	2.68	-120.42	-.56	-.30	-.17
1981, III	(15.50)	(3.49)	(.62)	(3.53)								
Italy	20.56	-.000019	.15				71.75	2.29	-140.70	-.67	-.32	-.17
1976, III-	(19.16)	(4.63)	(1.42)									
1982, III												
Spain	52.48	-.032	.17				76.87	1.67	- 96.29	-.74	-.27	-.13
1977, II	(7.13)	(1.42)	(.52)									
1981, II												
Japan	10.88	-.0039	.088				128.80	.98	-149.05	-1.94	-.79	-.48
1976, IV-	(8.41)	(3.50)	(.44)									
1982, III												
Netherlands				III								
1972, III-	46.02	-.00090	26.34	-.0077			90.22	2.58	-199.19	-1.76	-.39	-.21
1980, IV	(9.23)	(2.33)	(2.41)	(2.98)								
Sweden				III	IV							
1976, III-	63.65	-.70	16.86	-4.63	10.66		53.28	2.21	-132.07	-1.71	-.39	-.19
1982, III	(10.88)	(3.01)	(3.40)	(1.51)	(3.11)							
U.K.												
1976, III-	12.96	-.074	7.95				115.02	1.81	-127.83	-1.48	-.56	-.29
1981, III	(5.63)	(1.90)	(2.04)									
U.S.				I	III							
1972, I-	30.52	-.059	19.65	1.36	-2.67		417.08	2.03	-243.21	-1.16	-.33	-.17
1980, I	(26.81)	(6.92)	(2.98)	(1.66)	(3.13)							
Belgium, Luxembourg, Austria, Switzerland *)				I	1976-I							
1972, III	774.76	-14.50		38.99	238.74		66.75	1.34	-188.95	-.80	-.31	-.17
1980, IV	(15.45)	(3.73)		(1.37)	(3.32)							

SER = Standard Error of Regression
DW = Durbin-Watson statistic
lnL = value of log-likelihood function
*) $n_t = 1$, p_t^r of The Netherlands

Table 3. Empirical results for other importing member countries; net imports

Countries, sample period	p_t^r of country (real)	constant term	p_t^r	seasonal	dummies	LR-test $\nabla z_t^r = 0$	SER R^2	DW	lnL	price elasticity min.	average	max.
Denmark, Finland, Norway				I	II							
1976, III - 1982, III	Sweden	826.50 (10.88)	-9.96 (3.30)	113.10 (2.64)	128.72 (3.00)	3.58	86.81 .53	1.78	-144.89	-1.18	-.40	-.23
Ireland, Australia, Canada, New Zealand, Hong Kong												
1976, III - 1981, II	U.K.	957.71 (12.35)	-6.39 (4.99)	49.12 (1.43)		.00	66.52 .62	1.42	-110.70	-1.33	-.67	-.39
Hungary, Yugoslavia				I								
1972, III 1980, IV	F.R.G.	401.49 (3.10)	-4.10 (.65)	81.38 (2.05)		.38	102.11 .13	1.56	-202.59	-.97	-.28	-.14
Portugal												
1976, III 1981, II	Spain	66.58 (4.49)	-.050 (1.11)			.02	19.69 .06	2.05	-86.81	-1.06	-.38	-.11

so 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 downward 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 Δz_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 and Spain. The coefficient of the inventory component also has the expected sign. In terms of disturbance autocorrelation (e.g. the Durbin-Watson statistic), 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 and the group Belgium, Luxembourg, Austria and Switzerland, in the third quarter for Italy, the Netherlands, Sweden and the U.S., and in the fourth quarter for Japan, Spain 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 tine 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 various countries.

In table 3, we report the empirical results for the net imports of several groups of countries. Net imports were used as data on disappearance are not always available for these countries. Also the real price variable of a neighbour country has been used as is indicated in the second column of table 3. This saves us from collecting the price series for all the countries and aggregating them into one price indicator. As net imports are equal to consumption plus the change of wholesale and retail inventories, we tested whether the change of $E\, p^r_{t+1} - p^r_t$ had a significant effect on net imports.

The likelihood ratio statistic for this hypothesis is reported in column 7 of table 3. For all the countries, we can conclude that the change of $E\, p^r_{t+1} - p^r_t$ does not significantly affect the net imports. Therefore, these variables will not be included in the equation for net imports. Notice that the price elasticities for net imports in table 3 are very similar to those for the disappearance reported in table 2.

Finally, for the remainder of total imports ($Rimp_t$) which is not modeled separately as disappearence, change of wholesale inventories or net imports, we specified the following logistic growth curve

$$Rimp_t = \frac{\pi}{1 + \beta\, e^{-\gamma t}}$$

where π denotes a constant saturation level. This growth curve has been estimated by non-linear least squares (Newton's method) from yearly data for the period 1952-1974. The results are $\hat{\pi} = 6497$ (13.72) , $\hat{\beta} = 2.99$ (13.28) , $\hat{\gamma} = .12$ (8.06) , SER = 211.04 , DW = 1.62 , lnL = -154.13, where asymptotic t-values are given between parentheses.

3.2 Retail prices

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

$$p^r_t = (1 + \eta) \quad [k_t + \beta(L)p_t] \ , \ \eta > 0 \ . \qquad (3.1)$$

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),

$$p^r_t = \alpha^* + \beta^* (L)\, p_t \ , \qquad (3.2)$$

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 corection 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 4. For France and the U.K., we use for the world market price the spot 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 4, 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 4 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.

Table 4. 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	-123.51	-.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)				
Spain													
1977, II	50.57		.59		-.086		-.58	22.72	1.92	-74.94	.71	1.88	.61
1981, II	(3.51)		(1.41)		(.28)		(5.24)	.69					.84
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		.24	.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	.82	9.27	1.49
1976, II-	(2.47)		(.30)	(1.49)	(3.85)	(1.64)	(3.35)	.82					1.38
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

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 in table 5 the first 5 coefficients of the step response for an increase and a decrease of the world market price respectively.

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. $\eta < 0$).

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 exporting countries. The main producers of coffee will be separately included in the model. Thereby, we assume that due to the importance of their production of coffee in the total world supply, Brazil and Columbia 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

Table 5. Step response of retail prices according to (3.5)

Country	change of p_t	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
Spain	+	.59	1.00	1.17	1.25	1.28
	-	-.09	.72	1.05	1.20	1.26
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

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 6, 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 OLS estimation (see column 7 of table 6). 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

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

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

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

with ε_{it} being a disturbance term. Strictly speaking, the partial adjustment assumption is not compatible with the theoretical model put forward in section 2. Ideally, one should derive the adjustment process from the behavioral model. As this approach would lead to a more complicated dynamic structure, it has not yet been pursued here. 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.

Table 6. **Wholesale inventories**

Country, sample period	Series p_t^f	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
Spain 1973m I – 1981, IV	NY	CIP	144.65 (4.23)	2.06 (2.55)	.67 (8.89)	100	76.36 .80	1.47 1.67	-182.57	2.0
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.	Other Milds	1730 (3.87)	38.6 (3.26)	.41 (2.59)		307 .61	2.17 -1.00	-155.6	.65
Belgium, Luxembourg, Austria, Switzerland* 1972, III – 1980, IV	NY	CIP	264.58 (3.58)	1306.28 (1.90)	.55 (3.97)	450	49.31 .47	1.44 2.66	-136.65	1.22

$\bar{z}$ = floor of the inventory level
NY = New York
CIP = Composite Indicator Price
h-test = Durbin's h-test
* Prices deflated by the CPI of The Netherlands

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 6 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 6 are OLS estimates. The assumption of absence of simultaneity is reasonable for small countries, which have to take the price spread as given when adjusting 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.

An alternative specification for the inventory equation derived from an intertemporal model without futures market have been analyzed for the European countries and Japan. On the whole however, the empirical results for the alternative specification are not superior to those reported in table 6. 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.

The results for the inventory equation of the producing countries are contained in table 7. Inventory formation is disaggregated into stock of the four types of coffee. For the Robusta, Other Milds, Columbian Milds in Kenya and Tanzania and of Unwashed Arabicas in Ethiopia, the specifications (3.6) - (3.7) have been estimated. A dummy variable has been included for the quarter of the harvest (second or third quarter). The findings are in accordance with the underlying theoretical model, although the impact of the spread on inventories is usually not significantly different from zero. When the dummy variable is not included, the significance of the spread increases. The spread by itself does not fully take account of the seasonality in the inventory series.

Brazil and Columbia are assumed to be price-setters facing a downward sloping demand curve.

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

$$p_t = \phi_0 - \phi_1 \, exp_{Bt} \, , \, \phi_1 > 0 \, . \qquad (3.8)$$

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. The inventory equation of a price-setter is given in (2.16).

Table 7. Producers' inventories (1973, I - 1982, I)

Coffee type or country	Series p^f_t	p_t	Constant term	spread	z_{t-1}	seasonal dummy		$\bar{z}$	SER R^2	DW h-test	lnL
Robusta	London	ROB	557.4 (.51)	12.51 (.62)	.88 (9.43)	3114.6^{II} (6.82)		0	1069.2 .77	1.51 1.81	-308.4
Other Milds	NY	OM	2115.5 (2.63)	11.33 (.64)	.61 (5.38)	2368.9^{II} (5.59)		0	1069.2 .63	1.56 1.85	-308.5
Columbian Milds											
Kenya, Tanzania	NY	CM	361.7 (4.02)	.76 (.33)	.55 (5.25)	304.9^{II} (4.66)	452.7^{81-II} (2.75)	600	152.0 .72	1.33 2.64	-197.0
Columbia	NY	CM	$z_t = \underset{(.60)}{190.53} + \underset{(4.76)}{1.06}\, z_{t-1} - \underset{(5.56)}{.72}\, z_{t-2} + \underset{(2.79)}{.41}\, x_{ct} - \underset{(1.69)}{1.68}\, Ep_{t+1} + \underset{(.14)}{.45}\, p^f_t$						SER = 332.95 R^2 = .93	DW 1.95	lnL -264.12
Unwashed Arabica Brazil	NY	UA	$z_t = \underset{(2.46)}{-14271} + \underset{(9.24)}{.85}\, x_{Bt} + \underset{(2.72)}{.35}\, x_{Ot} - \underset{(.20)}{3.50}\, (Ep_{t+1} - p^f_t) - \underset{(7.59)}{9909}\, dum^{III}_t$						SER = 3061 R^2 = .85	DW 1.59	lnL -346.8
Ethiopia	NY	UA	$z_t = 428.5 - \underset{(4.95)\ (.14)}{.12}\, (Ep_{t+1} - p^f_t) + \underset{(3.70)}{.37}\, z_{t-1} - \underset{(2.45)}{151.15}\, dum^{I}_t + \underset{(5.33)}{327.39}\, dum^{III}_t + \underset{(2.92)}{445.36}\, dum^{81-III}_t$						SER = 148.0 R^2 = .71	DW = 1.25 h = 2.87	lnL = -227.7

If the derivative, $\partial Ep_{t+1} / \partial z_t$, the second moments in (2.16) and the size of the population in the importing countries are constant, we have

$$z_{Bt} = \max\,(\psi_0 + \psi_1 x_{Bt} + \psi_2 x_{0t} - \psi_3 Ep_{t+1} + \psi_4 p_t^f + \psi_5 n_t - \psi_6 f_{t-1};\ \bar{z}_{Bt}), \quad (3.9)$$

$x_{Bt} = q_{Bt} + z_{Bt-1}$, $x_{0t} = q_{0t} + z_{0t-1}$ (with 'o' denoting the other countries (except Brazil)).

The ψ_i's are constant coefficients with $\psi_1, \psi_2, \psi_3, \psi_4, \psi_5, \psi_6 \geq 0$, when $\partial Ep_{t+1} / \partial z_t \leq 0$. The sign of ψ_0 is not a priori determined.

Equation (3.9) has been estimated by OLS for Brazil. The observed price variable p_t is substituted as a proxy for Ep_{t+1} . As no data on f_t are available, we take $\psi_6 = 0$.
The restrictions $\psi_3 = -\psi_4$ and $\psi_5 = \psi_6 = 0$ are imposed on the estimates of equation (3.9) for Brazil. The results are given in table 7. The estimates 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. The seasonal dummy for the harvest period is highly significant. When it is deleted, the t-value of the spread increases, but some seasonality appears in the residuals. Notice also that there is serial correlation left in the disturbances so that some dynamics will have to be introduced in (3.9) We have tried to imbed equation (3.9) in a partial adjustment process. 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 $\psi_3 = -\psi_4$, $\psi_5 = \psi_6 = 0$. Although according to the theoretical model (3.9), 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 (3.9).

For Columbia, we had to further restrict the inventory equation by assuming that $\psi_2 = 0$ and to imbed it into an error correction model. The results for Columbia given in table 7 can be written as an error correction model of the form

$$\Delta z_t = .72\ \Delta z_{t-1} - .66[z_{t-1} - 288.7 - .62x_{ct} - 2.55\,E\,p_{t+1}^{CM} - .68\ p_t^f\,] .$$

This model is at variance with the traditional error correction model in the sense that the error explaining Δz_t equals $z_{t-1} - z_t^*$, where z_t^* is the desired inventory level. The model fits the data for Columbia fairly well and the estimates of the coefficients have the sign predicted by theory. Therefore, the model is retained for the inventories of Columbia.

3.4 Spot and futures prices of various types of coffee

In the previous sections we have used spot prices of the four types of coffee and futures prices for Robusta coffee in London and for Other Milds in New York respectively.
As the quality of the various types of coffee differs, arbitrage will not lead to one price of coffee. The differences of the quality will be reflected in the price formation. Moreover the impact of competition and substitution on coffee prices will take some time. For this reason, we use an error correction scheme to model the adjustment of the spot prices of Robusta, Columbian Milds and Other Milds to the spot price of Unwashed Arabicas. In a similar way we relate the futures prices of Robusta in London to the futures price of the C-contract in New York. The specification (3.4) has been estimated with $\eta = 0$. The results are reported in table 8.

The adjustment of prices has been found to be reversible. It appears to be rather slow in some instances as can be seen from the coefficients of the step response. The implied longrun relationship between the various prices measured by $\alpha^* = \alpha' \phi^{-1}(1)$ fully reflects the differences in quality of the various types of coffee. Therefore, the models reported in table 8 have been included in our empirical model which is now complete.

Table 8. Relationships between the spot prices and between the futures prices respectively

Coffee type	α'	$-\phi_2$	γ_0	$-\gamma_2$	$-(1-\phi_1-\phi_2)$	SER R^2	DW	lnL	mean lag	γ_1	α^*	step response 0	1	2	3	4
<u>Spot price:</u> 1960,III - 1982,III																
Columbian Milds	.87 (.83)	.32 (3.62)	.51 (7.54)	-.13 (1.73)	-.26 (4.43)	9.68 .52	1.90	-322.1	1.16	-.38	3.35	.51	.67	.87	.89	.95
Robustas	-.44 (.29)	.18 (1.67)	.49 (6.81)	-.12 (1.51)	-.07 (1.34)	9.93 .51	2.12	-324.3	6.77	-.54	-3.68	.49	.49	.53	.55	.59
Other Milds	-.70 (.56)	.25 (2.76)	.51 (7.21)	-.10 (1.27)	-.19 (3.53)	10.47 .51	1.93	-328.9	1.76	-.42	-6.29	.51	.63	.73	.80	.86
<u>Futures prices:</u> 1973,III - 1982,II ; $\phi_2 = \gamma_2 = 0$																
London	-6.87 (2.39)		.92 (21.26)		-.38 (2.59)	7.31 .93	2.06	-121.1	.20	-.54	-18.08	.92	.95	.97	.98	.99

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 futures 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 refined and 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.

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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 composite indicator price 1976 is the quarterly average of the indicator price for Other Milds (OM) or for Robusta (ROB) on the New York Coffee, Sugar and Cocoa Exchange; the composite indicator price 1968 = $1/3\,[\frac{1}{2}(OM + CM) + ROB + UA]$, where CM and UA denote the indicator prices for Columbian Milds and Unwashed Arabicas respectively.
   We use the CIP-1968.
   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.: pence 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 1975 = 100. For the U.S., we used the wholesale price index; the base period is the first quarter of 1975.
   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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