AN ECONOMETRIC ANALYSIS OF THE SHORT-RUN DEMAND FOR COFFEE

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E. Vogelvang

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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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expected utility of the present value of profits over periods to and a transfer asset with a random return. In order to maximize the
future market and to decide on an alternative use of this mean, e.g. the
leverage to choose the level of inventories, to take a position on the
level of the future price, a producer is assumed to supply coffee (or equivalent-
The following expected utility of net revenue

2.1 Producers and Inventory Holders

Assume to choose their decisions on prices expressed in domestic
expressed in the same currency, in the empirical model, agents are
inventories. In the empirical model, all prices are
assumed to be the same currency, the cost function is quadratic and strictly convex in the
inventories. The cost function is quadratic and strictly convex in the
inventories. An agent is a stochastic commodity, agents can hold
future market, an agent is a stochastic commodity, agents can hold
forward contracts which are fixed price contracts entered into in the
forward contracts which are fixed price contracts entered into in the
agents can and will coffee at the going price on the spot market.
agents can and will coffee at the going price on the spot market.
Prices and the resulting trade flows of coffee between countries.
the major importing countries, the inventories at the demand and sup-
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Formally, the profit (net revenue) function is given by:
\[ \Pi_t = \Pi_{0t} + \delta \Pi_{1t} \] (2.1)
with
\[ \Pi_{0t} = p_t q_t + p_t z_{t-1} - (p_t + b + c z_t) z_t + f_t p_t - S_t \]
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
\[ \delta \] is the discount factor, \( \delta \leq 1 \).

We assume that a producer has the following utility function with constant absolute risk aversion,
\[ U(\Pi_t) = - \exp - Y^* \Pi_t \], (2.2)
where \( Y^* \) is the Arrow-Pratt coefficient of absolute risk aversion. When \( \Pi_t \) is normally distributed\(^1\), the maximization of expected utility \( E(U(\Pi_t)) \) is equivalent to the maximization of
\[ E \Pi_t - \frac{Y^*}{2} \text{var}(\Pi_t) \], (2.3)

---

1) Notice that the normality of \( \Pi_t \) is implied by the joint normality of \( p_{t+1}, q_{t+1} \) and \( r_{t+1} \). The normal distribution of \( \Pi_t \) 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 \( \Pi_t \), would be to assume a quadratic utility function instead of (2.2). However, then the quadratic terms of current period revenue \( \Pi_{0t} \) enter into the expected utility function and make the subsequent analysis more complicate.
where $E$ and $\text{var}$ denote respectively the (subjective) expectation and variance of profits conditional on information available at period $t$. These moments are

$$E(\Pi_t) = \Pi_{0t} + \delta \left[ z_t Ep_{t+1} z + z_t Ep_{t+1} f_t Ep_{t+1} + S_t (1+ Er_{t+1}) \right]$$

and $\text{var}(\Pi_t) = \delta^2 \left[ \text{var}(p_{t+1}, q_{t+1}) + (z_t - f_t)^2 \text{var}(p_{t+1}) + S_t^2 \text{var}(r_{t+1}) + 2 (z_t - f_t) S_t \text{cov}(p_{t+1}, r_{t+1}) + \text{cov}(p_{t+1}, q_{t+1}) + 2 S_t \text{cov}(p_{t+1}, q_{t+1}) \right]$. 

(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

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

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

$$\frac{\partial E(U)}{\partial f_t} = p_t - \delta E p_{t+1} + \gamma ((z_t - f_t) \text{var}(p_{t+1}) + S_t \text{cov}(p_{t+1}, r_{t+1}) + \text{cov}(p_{t+1}, q_{t+1}, p_{t+1})] = 0 \quad (2.5b)$$

$$\frac{\partial E(U)}{\partial S_t} = -1 + \delta (1 + Er_{t+1}) - \gamma [S_t \text{var}(r_{t+1}) + (z_t - f_t) \text{cov}(p_{t+1}, r_{t+1}) + \text{cov}(p_{t+1}, q_{t+1}, r_{t+1})] = 0 \quad (2.5c)$$

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

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

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

$$-2c \left\{ \gamma^2 \text{var}(p_{t+1}) \text{var}(r_{t+1}) - \gamma^2 \text{cov}^2(p_{t+1}, r_{t+1}) \right\}$$

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:

\[-(p_t + b + 2c z_t) + p^f_t \leq 0 \]

or alternatively:

\[ z_t = \max \left( \frac{p^f_t - p_t - b}{2c} ; 0 \right) \quad (2.6) \]

Assuming that the first term between brackets is positive, we get the so-called "supply of storage" equation (see Working (1994))

\[ z_t = \frac{p^f_t - p_t}{2c} - \frac{b}{2c} \quad (2.7) \]

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 \( z \), 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

\[ z_t \geq z \geq 0 \]

The solution for \( z_t \) is then the maximum of (2.7) and \( z \).

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

\[ x_t = q_t + z_{t-1} - z_t \quad (2.8) \]
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 $q_{t+1}$, so that $\text{cov}(p_{t+1}, q_{t+1}, r_{t+1}) = 0$. Under these additional assumptions, the optimal value for $S^*_t$ immediately follows from (2.5)

$$S^*_t = \frac{-1 + \delta(1 + E_r t+1)}{\gamma \text{var}(r_{t+1})}.$$  \hfill (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

$$f^*_t - z^*_t = \frac{p^*_t - \delta E_p p_{t+1}}{\gamma \text{var}(p_{t+1})} + \frac{\text{cov}(p_{t+1}, q_{t+1}, p_{t+1})}{\text{var}(p_{t+1})}.$$  \hfill (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:

$$\sum_i f^*_{it} = 0,$$  \hfill (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

\[ 0 = \sum_i \left[ \frac{p_t^f - \delta E \ p_{t+1}}{\gamma_i \ var_i (p_{t+1})} \right] + Z_t + \sum_i \left[ \frac{\text{cov}_i (p_{t+1}, q_{it+1}, p_{t+1})}{\gamma_i (p_{t+1})} \right] \]

(2.12)

with \( Z_t \) 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

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

(2.13)

Exports

Finally, exports by a producing country are obtained from

\[ \exp_t = q_t - \Delta z_t - \text{dist}_t \]  

(2.14)

where \( z_t \) is determined by (2.6) and \( \text{dist}_t \) denotes domestic disappearance which we assume to be predetermined. \( \Delta \) denotes the difference operator. In the model, exportable production, \( q_t - \text{dist}_t \), 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 $z_t$ will be required to assure a smooth roasting process and to quickly satisfy the demand of roasted coffee. The optimal inventory level corresponds to

$$z_t = \max \left( \frac{p^f_t - p^r_t - b}{2c} ; z_t \right) .$$  \hspace{1cm} (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 expected utility of profits (2.2) is maximized with profits being given as in (2.1) but with

$$\pi_{0t} = p^r_t \text{dis}_t - p^r_t \text{a}_t - (b + c z_t) z_t + f_t p^f_t \hspace{1cm} (2.16)$$

and

$$\pi_{1t} = p^r_{t+1} z_t - f_t p^r_{t+1} . \hspace{1cm} (2.17)$$

The notation and the assumptions are as follows:

1) $p^r_t = p^r_t - k_t$, with $p^r_t$ 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 $a_t = \text{dis}_t + \Delta z_t$.

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
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 $p_t$ 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

$$z_t \geq 0 \quad \text{and} \quad \text{cons}_t = \text{dis}_t - z_t^r + z_{t-1}^r \geq 0 \, , \, z_t^r \geq 0 \, ,$$

where $z_t^r$ 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

$$\frac{\text{cons}_t}{n_t} = a_0 + a_1 \frac{p_t^r}{\text{cpt}} + a_2 \ln \frac{y_t}{n_t} \, , \quad (2.19)$$

where $\text{cons}_t$ = the total consumption,

$n_t$ = the size of the population,

$cpt$ = the consumer price index,

$y_t$ = the total disposable income deflated by $cpt$.

The variables $n_t$, $cpt$ 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
assumed to hold stocks $z^r_t$ larger than a normal level $\bar{z}^r_t$ 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

$$n_t = -z^r_t (p^r_t + b + c z^r_t) + \delta p^r_{t+1} z^r_t.$$  \hspace{1cm} (2.20)

The solution of the problem is

$$z^r_t = \max \left( \frac{\delta E p^r_{t+1} - p^r_t - b}{2c + \gamma \text{var}(p^r_{t+1})}, \bar{z}^r_t \right). \hspace{1cm} (2.21)$$

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

$$\text{dis}_t = \text{cons}_t + \Delta z^r_t$$

$$= a_0 n_t + a_1 \frac{n_t p^r_t}{cp_t} + a_2 n_t \ln \frac{y_t}{n_t} + \Delta \left[ \frac{\delta E p^r_{t+1} - p^r_t - b}{2c + \gamma \text{var}(p^r_{t+1})} \right].$$  \hspace{1cm} (2.22)

Total imports (or negative exports) are given by

$$\text{imp}_t = \text{dist}_t + \Delta z_t$$

$$= - \text{expt}_t$$  \hspace{1cm} (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

$$p^r_t = (1 + \eta)(k_t + \beta(L)p_t),$$  \hspace{1cm} (2.24)

where $k_t$ is the unit costs (labor, capital...) of roasting coffee, assumed to be proportional to the general price level,
\( n \) = the profit margin, assumed to be constant and \( \geq 0 \),
\( \beta(L) = \beta_0 + \beta_1 L + \ldots + \beta_L \), 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 condition (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)

\[
\sum_{t} \text{Exp}_t = 0 , \tag{2.25}
\]
with exports being given in (2.14) and (2.23) respectively.
Condition (2.25) can also be written as

\[
Q_t + Z_{t-1} + Z^r_{t-1} = \text{Cons}_t + Z_t + Z^r_t , \tag{2.26}
\]
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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Production</th>
<th>Consumption: cons.</th>
<th>Disappearance: dis.</th>
<th>Inventory</th>
<th>Export exp.</th>
<th>Retail price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country i</td>
<td>q_{it}</td>
<td>cons.</td>
<td>dis.</td>
<td>z_{it}</td>
<td>exp_{it}</td>
<td>p_{it}</td>
</tr>
<tr>
<td>Producer (Exporting country)</td>
<td>predetermined</td>
<td>consumption</td>
<td>predetermined</td>
<td>wholesale</td>
<td>exp_{it} = q_{it} - dis_{it} - \Delta z_{it}</td>
<td></td>
</tr>
<tr>
<td>Importing country</td>
<td>q_{it} = 0</td>
<td>cons. = a_{it} \cdot i_{it} + + a_{2i} \cdot \ln \left( \frac{y_{it}}{n_{it}} \right) + + \Delta z_{it}^F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spot market</td>
<td>f_{it} = 0</td>
<td>\sum_{i} \exp_{it} = 0 \iff \sum_{i} \left( q_{it} - \text{cons.} - \Delta z_{it} - \Delta z_{it}^F \right) = 0</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Futures market</td>
<td>f_{it} = 0</td>
<td>\sum_{i} \left( \frac{p_{t}^F - \delta_i \cdot E_i \cdot p_{t+1}^F}{Y_{i} \cdot \text{var}(p_{t+1})} + \left( \frac{\text{cov}<em>{i}(p</em>{t+1}, q_{it+1}) \cdot p_{t+1}}{\text{var}<em>i(p</em>{t+1})} \right) \right) = 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

\[
Q_t - \text{Const}_t + Z_{t-1} - \mu_1 (\rho^f - \rho_t) + \mu_2 = 0 \quad (2.27)
\]

where \( Q_t \), \( \text{Const}_t \) and \( Z_{t-1} \) are predetermined,

\[
\mu_1 = \frac{1}{\Sigma_1} (2\Sigma_1)^{-1} \quad \text{and} \quad \mu_2 = \frac{1}{\Sigma_1} b_1 (2\Sigma_1)^{-1}. \]

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. \( E_t(p_{t+1}) = E_t(p_{t+1} | \Phi_t, \text{model}) \), where \( \Phi_t \) denotes the information available at time \( t \).
5) The conditional second moments of next period prices are constant over time.
6) Conditionally on \( \Phi_t \), \( q_{t+1} \) and \( p_{t+1} \) are independent.

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

\[
v_1 p_t^f - v_2 E_t p_{t+1} + Z_t + E_t Q_{t+1} = 0 \quad (2.28)
\]

with \( v_1 = [\Sigma_1^{-1} \var_1^{-1}(p_{t+1})]^{-1} \), \( v_2 = [\Sigma_1^{-1} \var_1^{-1}(p_{t+1})]^{-1} \).

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

\[
p_t - \frac{v_2}{v_1} E_t p_{t+1} + \left( \frac{1}{\mu_1} + \frac{1}{v_1} \right) Z_t + \frac{\mu_2}{\mu_1} + \frac{1}{v_1} E_t Q_{t+1} = 0 \quad (2.29)
\]

With price expectations being rational, equation (2.29) can be solved
for $E_{Pt+1}$ along the lines of e.g. Kawai (1983). The solution for $E_{Pt+1}$ can be substituted back into (2.29) to give $pt$. 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 occurred 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 \( z_t < z_t^\ast \), where

\[
\bar{z}_t = q_t + z_{t-1} - \text{const}_t - \exp_t,
\]

(2.29)

with \( \exp_t \) being the export quota. For the sample period, the value of \( \exp_t \) is known. For postsample simulations, \( \exp_t \) is assumed to be determined as

\[
\bar{\exp}_t = \exp_{t-1}^\ast + \lambda \, p_{t-1} + x_{t-1}, \quad \lambda > 0,
\]

(2.30)

where \( \exp_{t-1}^\ast \) = the predetermined initial quota as described above,

\[
p_t^\ast = p_t - p_t^l, \quad \text{if} \quad p_t < p_t^l
\]

= 0, \quad \text{if} \quad p_t^l \leq p_t \leq p_t^u
\]

= \( p_t - p_t^u \), \quad \text{if} \quad p_t^u < p_t
\]

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

\[
x_t = \bar{\exp}_t - \exp_t.
\]

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 behavioral 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 \( \Pi_{0t} \) and \( \Pi_{1t} \) in (2.1), (2.16), (2.17) and (2.20) by \( \rho_t \). The coefficients \( \delta \) and \( \gamma \) 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 \( \rho_t \) 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, \( \Delta p_t \), at time \( t \), as a proxy for \( \Delta p_{t+1} \) 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 \( \alpha_2 \) 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 \( \alpha_2 \) 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), $a_2 = 0$

<table>
<thead>
<tr>
<th>Country, sample period</th>
<th>$n_t$</th>
<th>$\frac{p_t^{r} n_t}{c_{pt}}$</th>
<th>$\frac{\Delta p_{t+1}^{r}}{c_{pt}}$</th>
<th>Seasonal dummies</th>
<th>SER</th>
<th>DW</th>
<th>lnL</th>
<th>price elasticity min. average max.</th>
</tr>
</thead>
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<tr>
<td><strong>F.R. Germany</strong>&lt;br&gt;1972, III-</td>
<td>30.53</td>
<td>-0.23</td>
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<td>-0.0022</td>
<td>216.23</td>
<td>1.09</td>
<td>-227.74</td>
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<td>(1.01)</td>
<td>(2.23)</td>
<td>(1.27)</td>
<td>(1.13)</td>
<td>(1.22)</td>
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<td>31.33</td>
<td>-0.25</td>
<td>5.23</td>
<td>3.81</td>
<td>111.43</td>
<td>2.68</td>
<td>-120.42</td>
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<td>(6.12)</td>
<td>(3.53)</td>
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<td></td>
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</tr>
<tr>
<td><strong>Italy</strong>&lt;br&gt;1976, III-</td>
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<td>0.15</td>
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<td>2.29</td>
<td>-140.70</td>
<td>-0.67</td>
<td>-0.32</td>
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<td>(4.63)</td>
<td>(1.42)</td>
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<tr>
<td><strong>Japan</strong>&lt;br&gt;1976, IV-</td>
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<td>-0.0039</td>
<td>0.088</td>
<td>128.80</td>
<td>0.98</td>
<td>-149.05</td>
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<td>90.22</td>
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<td><strong>Sweden</strong>&lt;br&gt;1976, III-</td>
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<td>53.28</td>
<td>2.21</td>
<td>-132.07</td>
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<td>(3.01)</td>
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<td>(1.51)</td>
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<td><strong>U.K.</strong>&lt;br&gt;1976, III-</td>
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<tr>
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<td>397.07</td>
<td>2.23</td>
<td>-241.59</td>
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<td>1980, I</td>
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<td>(7.47)</td>
<td>(3.19)</td>
<td>(1.75)</td>
<td>(3.29)</td>
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</tbody>
</table>

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., $\alpha_2$ 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 $\alpha_1$ and of the coefficient of $\Delta z_t^r$ are almost insensitive to the deletion of $\alpha_2$. As expected, $\hat{\alpha}_1$ is negative and $\alpha_1$ 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 $-0.5$ to $-0.2$ 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.
\[ p_t^r = (1 + \eta) \left( k_t + \beta(L)p_t \right), \quad \eta > 0. \] (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 \( c_{pt} \), i.e. \( k_t = \alpha c_{pt} \), 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),

\[ p_t^r = \alpha^* + \beta^*(L)p_t, \] (3.2)

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

\[ \beta^*(L) = \frac{\gamma(L)}{\phi(L)} = \frac{\gamma_0 + \gamma_1L + \gamma_2L^2}{1 - \phi_1L - \phi_2L^2} \] (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 \( \eta \).

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

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

\[ \Delta p_t^r = \alpha' - \phi_2\Delta p_{t-1}^r + \gamma_0^+\Delta p_t - \gamma_2^+\Delta p_{t-1} + \gamma_0^-\Delta p_t - \gamma_2^-\Delta p_{t-1} - (1 - \phi_1 - \phi_2) \] (3.5)

where a normally distributed white noise disturbance term \( \epsilon_t \) has been added and \( \Delta^r p_t \) 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>
<thead>
<tr>
<th>Country, sample period</th>
<th>( \alpha' )</th>
<th>( \phi_2 )</th>
<th>( Y_0^+ )</th>
<th>( Y_2^+ )</th>
<th>( Y_0^- )</th>
<th>( Y_2^- )</th>
<th>((1-\phi_1-\phi_2)^{-1})</th>
<th>SER ( R^2 )</th>
<th>DW</th>
<th>lnL</th>
<th>mean lag+</th>
<th>mean lag-</th>
<th>( Y_1^+ )</th>
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<tr>
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<td>.10</td>
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<td>1.49</td>
<td>1.38</td>
<td>.82</td>
<td>9.27</td>
</tr>
<tr>
<td>1981, III</td>
<td>(2.47)</td>
<td>(3.0)</td>
<td>(1.49)</td>
<td>(3.85)</td>
<td>(1.64)</td>
<td>(3.35)</td>
<td>.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1960, IV</td>
<td>4.02</td>
<td>.15</td>
<td>.19</td>
<td>.60</td>
<td>.41</td>
<td>.28</td>
<td>-.15</td>
<td>2.02</td>
<td>1.70</td>
<td>-166.24</td>
<td>.41</td>
<td>1.13</td>
<td>.61</td>
</tr>
<tr>
<td>1980, III</td>
<td>(2.78)</td>
<td>(3.02)</td>
<td>(4.44)</td>
<td>(8.78)</td>
<td>(7.08)</td>
<td>(4.48)</td>
<td>(3.21)</td>
<td>.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.06</td>
</tr>
</tbody>
</table>
market price of Robusta, whereas for the remaining countries, we use the composite indicator price for $p_t$. The restriction $\eta = 0.3$ has been imposed a priori. For some countries, the estimate of $\eta$ was very close to $0.3$. For most countries, the most plausible results were obtained, when $\eta$ is set equal to $0.3$. 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 $\gamma^+$ and $\gamma^-$ 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 $p_t^-$ 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 $p_t^-$ and $p_t$ is then smaller than one (i.e. $\eta < 0$).
Table 4 Price adjustment (3.5)

<table>
<thead>
<tr>
<th>Country</th>
<th>$\delta^+(L)$, $\delta^-(L)$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.R. Germany</td>
<td>+</td>
<td>0.10</td>
<td>0.57</td>
<td>0.79</td>
<td>0.93</td>
<td>1.02</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-0.32</td>
<td>0.91</td>
<td>1.22</td>
<td>1.32</td>
<td>1.34</td>
</tr>
<tr>
<td>France</td>
<td>+</td>
<td>0.19</td>
<td>1.42</td>
<td>1.35</td>
<td>1.32</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.07</td>
<td>0.63</td>
<td>1.01</td>
<td>1.17</td>
<td>1.25</td>
</tr>
<tr>
<td>Italy</td>
<td>+</td>
<td>0.48</td>
<td>1.11</td>
<td>1.28</td>
<td>1.37</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.04</td>
<td>0.51</td>
<td>0.73</td>
<td>0.89</td>
<td>0.98</td>
</tr>
<tr>
<td>Japan</td>
<td>+</td>
<td>-0.13</td>
<td>0.40</td>
<td>0.73</td>
<td>0.94</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.80</td>
<td>0.99</td>
<td>1.11</td>
<td>1.17</td>
<td>1.22</td>
</tr>
<tr>
<td>Netherlands</td>
<td>+</td>
<td>-0.006</td>
<td>1.12</td>
<td>1.17</td>
<td>1.20</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.52</td>
<td>1.19</td>
<td>1.22</td>
<td>1.24</td>
<td>1.25</td>
</tr>
<tr>
<td>Sweden</td>
<td>+</td>
<td>0.24</td>
<td>1.36</td>
<td>1.33</td>
<td>1.32</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.21</td>
<td>0.82</td>
<td>1.03</td>
<td>1.15</td>
<td>1.22</td>
</tr>
<tr>
<td>U.K.</td>
<td>+</td>
<td>-1.15</td>
<td>1.25</td>
<td>1.27</td>
<td>1.28</td>
<td>1.29</td>
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<tr>
<td></td>
<td>-</td>
<td>-1.81</td>
<td>-1.50</td>
<td>-0.36</td>
<td>0.31</td>
<td>0.71</td>
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<tr>
<td>U.S.</td>
<td>+</td>
<td>0.19</td>
<td>0.98</td>
<td>1.15</td>
<td>1.19</td>
<td>1.22</td>
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<td></td>
<td>-</td>
<td>0.41</td>
<td>0.88</td>
<td>1.01</td>
<td>1.07</td>
<td>1.11</td>
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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 (1956) 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 $p_t^c - p_t$, 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 $z_i$ is imposed in which case, observed values of $z_{it}$ smaller than $z_i$ 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

<table>
<thead>
<tr>
<th>Country, sample period</th>
<th>Series</th>
<th>constant term</th>
<th>spread</th>
<th>( z_{t-1} )</th>
<th>( z )</th>
<th>SER ( R^2 )</th>
<th>DW</th>
<th>lnL</th>
<th>mean lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.R. Germany 1973, I - 1982, II</td>
<td>NY CIP</td>
<td>172. (4.50)</td>
<td>.51</td>
<td>(4.85)</td>
<td>58.9</td>
<td>.68</td>
<td>1.95</td>
<td>-189.60</td>
<td>1.04</td>
</tr>
<tr>
<td>France 1972, I - 1982, II</td>
<td>London Robusta London</td>
<td>310.8 (9.78)</td>
<td>52.4 (2.62)</td>
<td>.23 (3.16)</td>
<td>285</td>
<td>46.5</td>
<td>.72</td>
<td>1.62</td>
<td>-149.13</td>
</tr>
<tr>
<td>Japan 1973, I - 1982, II</td>
<td>NY CIP</td>
<td>376.3 (4.19)</td>
<td>.64 (4.27)</td>
<td>(7.24)</td>
<td>640</td>
<td>113.5</td>
<td>.81</td>
<td>.98</td>
<td>-182.93</td>
</tr>
<tr>
<td>The Netherlands 1973, I - 1982, II</td>
<td>NY CIP</td>
<td>48.4 (4.76)</td>
<td>18.1 (2.20)</td>
<td>.43 (4.27)</td>
<td>19.7</td>
<td>1.33</td>
<td>196.85</td>
<td>.75</td>
<td></td>
</tr>
<tr>
<td>Finland 1973, I - 1982, II</td>
<td>NY Other Milds</td>
<td>151. (3.79)</td>
<td>53.89 (2.95)</td>
<td>(.43)</td>
<td>74</td>
<td>1.83</td>
<td>-210.22</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>U.K. 1975, I - 1982, II</td>
<td>London Robusta</td>
<td>131. (4.58)</td>
<td>.42 (3.57)</td>
<td>160</td>
<td>41.1</td>
<td>1.91</td>
<td>-106.60</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>U.S. 1975, II 1980, IV</td>
<td>N.Y. CIP</td>
<td>1730 (3.87)</td>
<td>38.6 (3.26)</td>
<td>(2.59)</td>
<td>307</td>
<td>2.17</td>
<td>-155.6</td>
<td>.65</td>
<td></td>
</tr>
</tbody>
</table>

\( z \) = floor of the inventory level  
NY = New York  
CIP = Composite Indicator Price  
h-test = Durbin's h-test
where the desired inventory level, $z^*_t$, is explained by equation

$$z^*_t = \frac{1}{2c_1} [p^r_t - p_t] - \frac{b_1}{2c_1} + \varepsilon_{it},$$

with $\varepsilon_{it}$ being a disturbance term. Substitution of (3.7) into (3.6) yields the equation which has been estimated. The spread, $p^r_t - p_t$, 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 \( a_{ii} \) 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

\[
\begin{align*}
\rho_t &= \phi_0 - \phi_1 \exp_{Bt} , \quad \phi_1 > 0 .
\end{align*}
\]

If variations of the inventories at the retail level are negligible, \( \phi_0 \) increases linearly with the size of the population in all importing countries and with \( E_{t+1} \). 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 \( \Pi_t \) (2.2) with \( \Pi_t \) 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 \( 3E_{t+1}/3z_t \), the solution of this programming problem for the inventory level is

\[
\begin{align*}
\dot{z}_{Bt} &= \max \left\{ \frac{1}{2(\phi_1 + c)} \left[ 2\phi_1 x_{Bt} - \phi_0 + p_t^f - b \right. \right. \\
&\left. \left. + \frac{3E_{t+1}}{3z_t} \left[ \frac{6E_{t+1} - p_t^f - \gamma \cov (p_{t+1}, q_{Bt+1} , p_{t+1})}{\gamma \var (p_{t+1})} \right] \right\} \right\} \geq 0 ,
\end{align*}
\]

where the subscript 'B' denotes Brazil, \( x_{Bt} = q_{Bt} + z_{Bt-1} \) and \( \dot{z}_{Bt} \) is some minimum inventory level.
The second order conditions for a maximum are satisfied if \( \partial E_{t+1} / \partial z_t \leq 0 \) and \( \partial^2 E_{t+1} / \partial z_t^2 \leq 0 \).

When \( \partial E_{t+1} / \partial z_t = 0 \), 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

\[
z_t = \max (\psi_0 + \psi_1 x_{Bt} + \psi_2 x_{Qt} - \psi_3 E_{t+1} + \psi_4 p_t + \psi_5 n_t ; z_t),
\]

\( (3.10) \)

\( x_{0t} = x_{0t}^0 + z_{0t-1} \) (with '0' denoting the other countries (except Brazil)).

The \( \psi_i \)'s are constant coefficients with \( \psi_1 \), \( \psi_2 \), \( \psi_4 \), \( \psi_5 \geq 0 \), \( \psi_3 \leq 0 \) when \( \partial E_{t+1} / \partial z_t \leq 0 \). The sign of \( \psi_0 \) 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 \( E_{t+1} \). When the restrictions \( \psi_3 = -\psi_4 \) and \( \psi_5 = 0 \) are imposed the estimates of equation (3.10) are

\[
z_{Bt} = -15272.6 + .58 x_{Bt} + .48 x_{Qt} - 29.18 [ E_{t+1} - p_t^f ]
\]

\( (1.80) \) \( (4.68) \) \( (2.68) \) \( (1.14) \)

(with \( z = 10,000 \), 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 \( x_{Qt} \) 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 embed 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 \( \psi_3 \) and \( \psi_4 \) 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 behavioral 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
the international coffee agreement under various production and market conditions. However, possible scenarios for the interaction of coffee and commodity markets are also discussed. In the second part, we examine the implications of this interaction for the behavior of market makers, the future price, and the spillover effects on the coffee market. In the third part, we conclude with a discussion of the implications for the future price of coffee and the market makers' behavior.
References


Appendix: Description of the data

The series are:


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,

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

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<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Title</th>
</tr>
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<tr>
<td>1981-2</td>
<td>H.P. Smit</td>
<td>Demand and Supply of Natural Rubber, Part I</td>
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<td>R. Vos</td>
<td>The political Economy of the Republic of Korea; A proposal for a model framework of an open economy in the ESCAP-region, with emphasis on the Role of the State</td>
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<td>P. Nijkamp in co-op. with H.v. Handenhoven and R. Janssen</td>
<td>Urban Impact Analysis in a Spatial Context: Methodology and Case Study</td>
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<td>R. Ruben</td>
<td>Primaire exporten en ekonomiese ontwikkeling</td>
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<td>P. van Dijck and H. Verbruggen</td>
<td>A Constant-Market-Shares Analysis of ASEAN Manufactured Exports to the European Community</td>
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<td>1981-10</td>
<td>P. Nijkamp, H.de Graaff and E. Sigar</td>
<td>A Multidimensional Analysis of Regional Infrastructure and Economic Development</td>
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<td>1981-11</td>
<td>P. Nijkamp</td>
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<td>1981-12</td>
<td>A.J. Mathot</td>
<td>L'Utilisation du Crédit lors de l'Achat d'une Voiture</td>
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<td>1981-13</td>
<td>S.P. van Duin en P.A. Cornelis</td>
<td>Onderzoek naar levensomstandigheden en opvattingen over arbeid bij mensen zonder werk, deel I</td>
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<td>1981-14</td>
<td>W. van Lierop and P. Nijkamp</td>
<td>Disaggregate Models of Choice in a Spatial Context</td>
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<td>Hidde P. Smit</td>
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<td>1981-17</td>
<td>F.C. Palm and Th.E. Nijman</td>
<td>Linear Regression Using Both Temporally Aggregated and Temporally Disaggregated Data</td>
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<td>1981-18</td>
<td>F.C. Palm and J.M. Sneek</td>
<td>Some econometric Applications of the exact Distribution of the ratio of Two Quadratic Forms in Normal Variates</td>
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