SERIE RESEARCH MEMORANDA

HYPOTHESES TESTING CONCERNING
RELATIONSHIPS BETWEEN SPOT PRICES
OF VARIOUS TYPES OF COFFEE

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A M S T E R D A M

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A B S T R A C T

In this paper hypotheses are tested concerning long-run relationships between the four indicator prices of coffee. These relationships had been assumed to exist in an earlier study on the coffee market by the same author. The tests which are performed, are the tests for co-integration as developed by Johansen. Possible specifications of these relationships are detected, which confirm earlier assumptions to some extent, although they are found to be a little more ample specified than earlier had been assumed.

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1. INTRODUCTION

In an earlier econometric study concerning the world coffee market, we analysed the price formation of coffee on the world market by establishing behavioural relationships for a quarterly model of the coffee market [see Palm and Vogelvang (1986) and Vogelvang (1988)]. The prices which have been modelled concern the four main types of coffee: Unwashed Arabica (mainly Brazil), Colombian Milds (mainly Colombia), Other Milds (Latin American countries) an Robusta (mainly Africa). The International Coffee Organization in London computes indicator prices for these coffee types, according to the regulations of the International Coffee Agreement, which are based on the daily spot prices of various coffee types as traded in the New York market. In the previously mentioned model the Composite Indicator Price '68, which is computed as an average of these four indicator prices, was determined by demand and supply factors on the spot market. The individual indicator prices are determined in the model by linking the prices of Colombian Milds (CM), Other Milds (OM) and Robusta (ROB) to the price of Unwashed Arabicas (UA), and by using the definition of the Composite Indicator Price '68 (CIP'68). The price of UA had been chosen as Brazil is a rather dominant producing country in the world market, which has been modelled as a price setter. Although the same has been done with Colombia, Brazil is considered as more influential on establishing coffee prices. The prices have been related to each other by means of simple error-correction models (ECM) for the levels of the coffee prices, as it seems to be straightforward to assume that the prices will move together in time, while they may deviate in the short run, due to individual circumstances of coffee types. These relationships have been written as:

$$\varphi_i(L)p_t^i = c_i + \gamma_i(L)p_t^{UA},$$
(1.1)

with p_t^i denoting the spot prices for $i = $ CM, OM, ROB;

p_t^{UA} the spot price of UA;

and $\varphi_i(L)$ and $\gamma_i(L)$ denoting polynomials in the lag operator.

Equation (1.1) can be rewritten as:

$$p_t^i = \frac{c_i}{\varphi_i(L)} + \frac{\gamma_i(L)}{\varphi_i(L)} p_t^{UA}.$$

Both the polynomials are assumed to be of the second degree, and $\beta^*(L)$ is

defined as the quotient $\frac{\gamma_i(L)}{\varphi_i(L)}$. When the long-run restriction is imposed $\beta^*(1) = 1 \ \forall i$, equation (1.1) can be written as:

$$p_t^i = \frac{c_i}{1 - \varphi_{1i} - \varphi_{2i}} + p_t^{UA}. \tag{1.2}$$

The constant terms in equation (1.2) represent the values of the quality differences of the CM, OM, ROB with respect to UA. The obtained results were quite realistic, which are once more given below for reasons of completeness of these introductory remarks. After the error-correction models have been estimated, the long-run equilibrium equations are computed as:

$$
\begin{aligned}
p^{CM} &= .91 + p^{UA} \\
p^{OM} &= 11.39 + p^{UA} \\
p^{ROB} &= -21.47 + p^{UA}.
\end{aligned}
$$

The prices are measured in dollar cents per pound.

In this paper we will consider these relationships among the coffee prices in more detail by using recent developed techniques which test for possible long-run relationships between variables. This present analysis is not identical to the research of e.g. the PPP (purchasing power parity) -hypothesis, or the LOP (law of one price) -hypothesis, which is frequently encountered in the empirical literature. Although the prices concern all coffee, these coffee types are different as they have tastes which are not equally appreciated. It is well-known that co-integrated variables have an ECM-specification [Engle and Granger (1987)]. Because we estimated ECM's of the coffee prices, we assumed in fact implicitly that these prices are co-integrated. In this paper we will test formally for the existence of co-integrating relationships by using the methods of Johansen (1988), who tests first for the number of co-integrating relationships after which hypotheses concerning the form of these relationships are tested. The rather obvious outcome that these prices will be co-integrated, will not be surprising (the opposite result should be very surprising). But in this paper we are interested to detect in which way the prices are related to each other. The tests of Johansen are very appropriate to test hypotheses

about the specifications of these relationships, in stead of the often used (augmented) Dickey-Fuller tests for unit roots in the residuals of pair-wise regressions concerning bi-variate relationships. It is obvious that we expect to find three relationships among the coffee prices.

This paper proceeds as follows. For reasons of completeness we give in section 2 once more a brief description of the tests of Johansen, after which in section 3, these tests are applied on the coffee prices to test for several hypotheses concerning the way they might be related. Lastly in section 4, some conclusions are formulated.

2. BRIEF DESCRIPTION OF JOHANSEN'S TESTS FOR CO-INTEGRATION

This section describes shortly the theoretical approach of Johansen (1988). The procedure consists of the following stages. The first step is to test for the number of co-integrating vectors in a multivariate system. This is done with a likelihood-ratio test, that has an asymptotic distribution which can be approximated by a χ^2 distribution. Johansen computed also fractiles of the distribution by simulation. In following steps the co-integrating space is estimated, which has a dimension equal to the number of co-integrating vectors, after which hypotheses about possible restrictions on the co-integration vectors are tested concerning economic interpretations of the results.

Johansen considers first the unrestricted vector-autoregressive (VAR) process of p variables which is integrated of order 1:

$$X_t = \Pi_1 X_{t-1} + \ldots + \Pi_k X_{t-k} + \varepsilon_t, \tag{2.1}$$

with ε_t being a sequence of i.i.d. p-dimensional Gaussian random vectors, distributed as $N(0, \Lambda)$. This specification can be rewritten as:

$$\nabla X_t = \Gamma_1 \nabla X_{t-1} + \ldots + \Gamma_{k-1} \nabla X_{t-k+1} - \Pi X_{t-k} + \varepsilon_t, \tag{2.2}$$

where $\Gamma_i = -I + \Pi_1 + \ldots + \Pi_i$,

and $\Pi = I - \Pi_1 - \ldots - \Pi_i$.

Then the research concentrates on the matrix Π, because of the long-run information that can be obtained from knowledge of this matrix, which is often called the impact matrix. The following situations may occur concerning the matrix Π:

$rg(\Pi) = p$, The matrix has full rank, implying a stationary process X_t;

$rg(\Pi) = 0$, The matrix Π is zero, implying an integrated vector process X_t;

$rg(\Pi) = r$, $0 < r < p$, implying the existence of $p \times r$ matrices α and β of rank r, giving a non-linear constraint on the coefficients $\Pi_1, .., \Pi_k$: $\Pi = \alpha\beta'$, with β being the matrix with co-integrating vectors; $\beta'X_t$ is stationary.

With reference to Johansen we memorize that the parameters α and β cannot be estimated, as they are not uniquely determined, but the space spanned by β can be estimated. First two matrices of residuals are computed, originating from the regression of ∇X_t on $\nabla X_{t-1}, ..., \nabla X_{t-k+1}$, and X_{t-k} on the same set of regressors $\nabla X_{t-1}, ..., \nabla X_{t-k+1}$. Denote these residuals by R_{0t} and R_{kt}, then the moment matrices S_{00}, S_{kk} and S_{k0} are computed. Johansen proposes the next procedure to test for the number of co-integration relationships. Solve the equation

$$|\lambda S_{kk} - S_{k0}S_{00}^{-1}S_{0k}| = 0,$$

giving the p eigenvalues λ_i and determine the corresponding eigenvectors. Let E be the matrix with eigenvectors, then E is normalized such that $E'S_{kk}E = I$. The number of co-integrating vectors r is determined by means of the likelihood-ratio test statistic:

$$-2\ln(Q) = -T \sum_{i=r+1}^{p} \ln(1 - \hat{\lambda}_i), \tag{2.3}$$

for H_0: there are at most r co-integrating vectors, where $\hat{\lambda}_{r+1}, ..., \hat{\lambda}_p$ are the $p - r$ smallest eigenvalues.

The next step concerns the economic interpretation of the matrices α and β, which is not straightforward in this multivariate analysis. If $r = 1$, it is probably possible to normalize with respect to one of the variables, and to test for any exclusion restriction. But with $r > 1$ we cannot arbitrarily normalize the co-integration equations. In fact, only the

hypotheses which co-integrating vectors exist can be tested. With the matrix β, we have computed a basis of the co-integration space. Therefore hypotheses can be tested, stemming from economic knowledge, which we have of the problem that we are investigating, concerning restrictions on the co-integrating vectors: H_0: $\beta = H\phi$, with H a known ($p \times s$) matrix of constants and ϕ a ($s \times r$) matrix of unknown parameters, ($r \leq s \leq p$). The restriction $\Pi = \alpha\beta'$ results in estimating an r-dimensional subspace of the p-dimensional space, while the restriction $\beta = H\phi$ restricts the subspace to lie in the s-dimensional space. Or in the way Kunst (1988) formulates the problem: one is interested in testing whether the co-integrating vectors which make up the columns of the ($p \times r$) matrix β are included in the space generated by the columns of a ($p \times s$) matrix H. So one tests whether the space spanned by the empirically determined co-integration vectors corresponds to a space spanned by vectors stemming from e.g. economic knowledge. According to Johansen: if $s = p$, then no restrictions are placed upon the choice of the co-integration vectors, and if $s = r$, then the co-integration space is fully specified. These restrictions are imposed on all the co-integration vectors, as otherwise no meaningful conclusions can be drawn. Johansen proves that the next procedure can be used to test the hypothesis H_0. First solve the equation:

$$|\lambda H' S_{kk} H - H' S_{k0} S_{00}^{-1} S_{0k} H| = 0,$$

which give the s eigenvalues λ_i^*. Let E^* be the matrix with eigenvectors, then E^* is normalized such that $E^{*'} H' S_{kk} H E^* = I$. Further the null is tested with the likelihood-ratio test:

$$-2\ln(Q) = T \sum_{i=1}^{r} \ln[(1 - \lambda_i^*)/(1 - \hat{\lambda}_i)], \tag{2.4}$$

with λ_i^* and $\hat{\lambda}_i$ the r largest eigenvalues. This test statistic is asymptotically distributed as $\chi^2(r(p-s))$. Johansen and Juselius (1988) find some indications concerning the formulation of various hypotheses H_0 from considering the eigenvectors in β, where e.g. opposite signs can indicate that the difference of two variables has to enter a co-integration relationship or one large coefficient may indicate that the corresponding variable is stationary, although that is contradicted by the outcome of the earlier computed unit-root test. This implies for the matrix H that its columns consist of vectors with one -1 and further figures which equal 0 or

+1, so that one price may be proportional to a linear combination of other prices.

3. EMPIRICAL RESULTS OF HYPOTHESES TESTING WITH COFFEE PRICES

Unit-root test

In this section we apply the tests of Johansen on coffee prices; in fact we follow the way like it has been applied by Johansen and Juselius (1988) to the problem of testing for and estimating of co-integration vectors in a multivariate context. First we have to verify that the four coffee prices are all integrated of first order [notation: $p_t^i \sim I(1)$], which implies that they are all non-stationary, after which we will look for stationary linear combinations (co-integration relationships) of the variables involved. In Vogelvang (1990) the results of various unit root tests have been compared by applying them on various agricultural commodity price series. This concerns the Dickey-Fuller tests, the Durbin-Watson statistic and the Phillips test. The Phillips test for unit roots (Z_α) [Phillips (1987)] is an appropriate test for theoretical reasons, as the series may have any ARMA representation. This was confirmed by the empirical results. Therefore we use only the Phillips test in the present study. The quarterly data concern the ICO-indicator prices of the sample period 1960^I through 1982^{III}, which is the same data set as used in Vogelvang (1988). The results of the unit root tests are reported in Table 1.

Table 1: *Phillips Z_α test values, $H_0 : p_t^i \sim I(1)$, variables in levels and 1st differences, quarterly $1960^I - 1982^{III}$*

Coffee price	levels	1st differences
Robusta	-1.30	-51.78
Unw. Arabica	-1.51	-51.00
Col. Milds	-.37	-66.46
Other Milds	-.85	-63.46

Critical value at the 5% level: -7.8

In many empirical studies, these tests are applied on the logs of the variables implying possible long-run relationships between relative changes in the variables. From section 1 it is clear that we are looking here for equilibrium in levels, so the tests are performed on the levels of the variables.

These results clearly show that the Z_α test does not reject the null for the variables in levels, but it does reject quite clearly the null for the first differences of the variables, implying that the levels are non stationary and the first differences are stationary. So, the prices are all integrated of first order.

Order of the VAR-model

The order of k of the VAR model (2.1) is determined by estimating this model for various lag lengths and inspecting the autocorrelations of the residuals. Because the price series contain a unit root, no LR-test-statistics or Box-Pierce statistics have been computed. If four lags are specified the results seem satisfying according to visual inspection. We give the first eight autocorrelations of each series, where the approximated confidence interval $\pm 2/\sqrt{T}$ equals $\pm.22$:

```
ROB   .08 -.09   .09 -.21   .06   .10 -.01 -.11
UA    .13 -.17   .02 -.04   .05 -.09 -.24 -.25
CM   -.05 -.04   .07 -.14 -.06   .04   .01 -.08
OM    .04   .02   .06 -.15   .10   .05 -.05 -.13.
```

Some indication of present seasonallity can be found in the autocorrelations of the price series of Robusta (4 quarters) and Brazilian coffee (2 years). Although this may be not quite satisfactory we leave the treatment of seasonallity for future research, as these seasonal correlations are only just above the significance level, and go on with model (2.1) with $k = 4$.

Test for co-integration

After the necessary regressions have been run to determine the matrices with residuals R_{0t} and R_{kt}, we computed the moment matrices S_{00}, S_{kk} and S_{k0}. These matrices are defined as $S_{ij} = T^{-1}\Sigma_{t=1}^{T} R_{it}R_{jt}'$ with $i,j \in \{0,k\}$, and the resulting matrices are given below.

$S_{00} \times .001$ $\qquad$ $S_{kk} \times .001$ $\qquad$ $S_{k0} \times .001$

$$
\begin{bmatrix}
.12 & & & \\
.07 & .12 & & \\
.10 & .07 & .12 & \\
.13 & .07 & .12 & .16
\end{bmatrix}
\quad
\begin{bmatrix}
2.94 & & & \\
3.70 & 7.80 & & \\
3.22 & 4.10 & 3.57 & \\
3.00 & 3.80 & 3.31 & 3.09
\end{bmatrix}
\quad
\begin{bmatrix}
-.13 & -.16 & -.12 & -.14 \\
-.06 & -.11 & -.06 & -.07 \\
-.10 & -.13 & -.10 & -.12 \\
-.12 & -.14 & -.11 & -.14
\end{bmatrix}
$$

With these matrices we compute the eigenvalues and eigenvectors of the generalized real symmetric eigenvalue problem $|\lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k}| = 0$, which are given in Table 2.

Table 2: *Eigenvalues* $\hat{\lambda}_i$ *and eigenvectors* $\hat{e}_i$ *of*
$$|\lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k}| = 0$$

eigenvalues			
.4496	.2370	.1011	.0199
eigenvectors			
-.0459	.1440	.1370	-.0129
.0162	.0807	-.0665	-.0160
-.2269	-.1016	.0063	.0824
.2729	-.1279	-.0577	-.0389

The results of Johansen's likelihood ratio test statistic (2.3), to test for the number of co-integrating vectors, are given in Table 3, together with the fractiles at the .10, .05 and .025% significance level.

Table 3: *Results of the likelihood ratio test statistic* (2.3)
H_0: *There exist at most* r *co-integrating vectors*

null hypothesis	$-2\ln(Q)$	fractiles		
		.90	.95	.975
$r \leq 3$	1.74	2.9	4.2	5.3
$r \leq 2$	11.02	10.3	12.0	13.9
$r \leq 1$	34.55	21.2	23.8	26.1
$r = 0$	86.50	35.6	38.6	41.2

The result of the LR-test in Table 3 is that the null hypothesis of at most two co-integrating vectors cannot be rejected at the 5% level, and of at most three co-integrating vectors at the 10% level. So the matrix β, introduced in the previous section, consists of the two or three eigenvectors belonging to the largest eigenvalues from Table 2. We may conclude that the expectation, to find three co-integrating relationships, is not contradicted by this result. Therefore we will perform the LR-test (2.4) for the values $r,s \in \{2,3\}$.

Test results concerning possible relationships

First we can report that all hypotheses that we have formulated with respect to two relationships ($r = s = 2$) are all clearly rejected. The results improve substantially when proportionality to three relationships is specified ($s = 3$, $r = 2$). Testing hypotheses with $s = r = 3$ did not give significant results too, although the values of the test statistic are lower compared to the first situation. This implies that we will test whether the co-integration space is included in the space which we specify with our hypotheses concerning three relationships.

Without looking at the matrix β we wish to test first the hypothesis that ROB, CM and OM are related to UA, which concerns the relations that have been explained in section 1. The matrix H and the test result are:

$$H_1 = \begin{bmatrix} -1 & 0 & 0 \\ 1 & 1 & 1 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix},$$

Test-statistic (2.4) is distributed as $\chi^2(2)$, with table value 5.99 at the 5% level; $-2\ln(Q) = 16.84$

with the vector of variables: $X_t' = (p^{ROB} \quad p^{UA} \quad p^{CM} \quad p^{OM})_t'$.

So this hypothesis is rejected, which is not unexpected as the columns of H_1 cannot be carried back to the matrix β. Although the earlier estimated constants, representing the quality differences of the coffee types, are realistic, the error-correction models do not seem to be the models which display the dynamic adjustment to long-term coherence between the coffee prices.

Inspection of β learns that the first vector indicates a possible stationary difference of OM and CM, and the second vector of OM and CM with ROB. These two relationships appeared to be very stable in all the various hypotheses that we tested. The specification of only these two relationships is rejected with a $\chi^2(4)$ value of 23.83 (table: $\chi^2_{.05}(4) = 9.48$)

The specification of the third relationship additional to these two relations results in various hypotheses that are not rejected. It is well-known that linear combinations of co-integrating vectors are also co-integrating vectors. So we have looked for linear combinations of the vectors of β which indicate that some prices may be related, by more or less equal magnitude in absolute value of its components, which are also larger than the others. Then we assume that they are proportional to the vectors which are given in the matrices H. In this way we tested the third relationship. A number of possible specifications give significant values and are now presented. At first we test interrelationships between all the prices. The first column of the matrices H_2 through H_5 specify that one price depends on the behaviour of the three other prices.

The vector of price variables is $X'_t = (p^{ROB} \quad p^{UA} \quad p^{CM} \quad p^{OM})'_t$.

$$H_2 = \begin{bmatrix} -1 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & -1 & -1 \\ 1 & -1 & 1 \end{bmatrix}, \quad H_3 = \begin{bmatrix} 1 & 1 & 0 \\ -1 & 0 & 0 \\ 1 & -1 & -1 \\ 1 & -1 & 1 \end{bmatrix}, \quad H_4 = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 0 \\ -1 & -1 & -1 \\ 1 & -1 & 1 \end{bmatrix}, \quad H_5 = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & -1 & -1 \\ -1 & -1 & 1 \end{bmatrix}.$$

$$\chi^2(2) = 2.99 \qquad \chi^2(2) = 14.16 \qquad \chi^2(2) = 3.39 \qquad \chi^2(2) = 3.39$$

$$\text{Table: } \chi^2_{.05}(2) = 5.99$$

The implications of these tests are clear and realistic. They confirm once more the price-setting behaviour of Brazil by indicating that the coffee price of Brazil does not depend on the prices of the other coffee types. The prices of OM, CM and even more ROB depend on each other and on UA. Brazil and Colombia have been modelled in Vogelvang (1988) as price setters, while the countries belonging to the other groups were assumed to be price takers. These roles are confirmed by this analysis except for Colombia. Lastly we give one hypothesis which results in a lower χ^2-value

than we presented above:

$$H_6 = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 0 \\ -1 & -1 & -1 \\ 0 & -1 & 1 \end{bmatrix}.$$

$$\chi^2(2) = 2.44$$

The hypothesis H_6 implies that the price of CM fluctuates with the price of UA and ROB, the price of ROB with those of OM and CM, and lastly that the price of OM and CM move together.

4. CONCLUSIONS

In this paper we investigated the form of relationships between the prices of the four main types of coffee: Robusta, Unwashed Arabica, Colombian Milds and Other Milds. We used the likelihood ratio tests of Johansen, as these tests indicate the number of co-integrating relationships and allow to test for the specification of these relationships. A priori we expect that these prices will be co-integrated, which was confirmed by the analysis by allowing for two co-integration relationships.

When testing for the form of these relationships, we found two "strong" vectors: CM and OM, and ROB with CM and OM, while various hypotheses concerning a third relationship are not rejected. The price of Brazilian coffee does not depend on other prices, and is clearly the result of price-setting price behaviour. It is often assumed that the price of CM is also achieved by price-setting behaviour of the Colombian coffee trade. E.g. the Composite Indicator Price '79 (and earlier the CIP '76) is based on ROB and OM coffee types only, because they are assumed to reflect the market situation in a better way than the prices of UA and CM, which are often traded with special deals. This price behaviour of Colombia has not been validated by the present analysis. For the third relationship we found four hypotheses which are not statistically rejected, and which can be interpreted all economically in a realistic way, specified by the matrices

H_2, H_4, H_5 and perhaps the best: H_6. The matrix H_6 indicates firstly the coherence of Robusta and Unwashed Arabica with Colombian Milds, secondly of Other Milds and Colombian Milds with Robusta, and thirdly of Other Milds and Colombian Milds.

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