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Abstract

In this paper we are interested to investigate the short-run and long-run price behaviour of related agricultural commodities. We often observe similar behaviour of these prices, apparently caused by occurrences on only one of the commodity markets. For this purpose we analyse the long-run behaviour by applying integration and co-integration tests, and estimate short-run error-correction models in various ways. The commodities of interest in this paper are coffee, cocoa, tea, and sugar. Large variation of these commodity prices in the analysed sample period (graphically) seem to have been caused by the coffee price. So we test this relationship for the short run and its possible persistence in the long run. Further we conclude that co-integration relationships between the prices exist, and that price developments on a related market clearly influence the other considered prices in the short run by means of the specification of the error-correction term computed from the earlier mentioned long-run relationship. The results are informative for empirical economists, who are modelling one market and are confronted with price movements which cannot be explained by the involved relevant variables of that particular market.

Keywords: commodity prices, unit-root tests, co-integration, error-correction, related markets.

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1 Introduction

In the present paper, we test the hypothesis that various related agricultural commodity prices deviate in the short run from long-run stochastic equilibrium levels. These commodity prices have been formed on related markets and are assumed to be influenced by common factors, which may cause similar price trends. This hypothesis stems from the observation that important events on one market do not influence the price of only that particular commodity, but also prices of related commodities, while in the absence of such events prices also develop in a comparable way, which may be caused by e.g. world inflation or common expectations about economic prospects in general. So, some stochastic equilibrium relationship may exist between the prices of related commodities, i.e. the stochastic trends in the various prices, represented by their non-stationary parts, are linearly interrelated. Monthly spot prices of coffee, cocoa, tea and sugar will be used in our analysis.

A popular approach to test this hypothesis is the use of co-integration tests to detect and estimate static long-run relationships. Short-run dynamic behaviour can be modelled by specifying an error-correction model. The analysis of co-integrated time series has been a favourite subject in econometric research in recent years, mainly because it has attractive and interesting properties in applied time-series analysis. Many, more theoretical, studies in this field have been published in the econometric literature, starting with Granger [11] who introduced the concept of co-integration and made the link with the error-correction models which were introduced earlier by Davidson, Hendry, Srba and Yeo (DHSY) [3]. Co-integrated variables have an error-correction representation. Engle and Granger [7] clearly formulate that problem and the solution for the bivariate case. The multivariate case was studied by e.g. Engle and Yoo [8], and Johansen [15, 16].

Such an approach of econometric modelling has been applied by many researchers. Many empirical studies have been published with respect to the testing of co-integration of variables of e.g. macroeconomic and commodity-market models. We give a number of examples of the broad spectrum of applied work concerning this subject. Durand and Blondal [6]: consumer and commodity prices; Wolak and Kolstad [29]: imports of steam coal; Ardeni [1], Schotman [26], and Baillie and Selover [2]: the PPP-hypothesis; MacDonald and Murphy [21]: inflation and interest rates; Johansen and Juselius [17, 18]: demand for money; Vogelvang [28]: coffee prices; Halem, Machado, and Rapsomanikis (HMR) [13] and Lloyd and Rayner [20]: land prices; Goodwin [10]: wheat prices; Rausser and Walraven [25]: financial and commodity markets; and Kunst and Neusser [19]: a macroeconomic system. Our analysis deviates from these studies in the sense that we investigate long-run relationships between prices of different markets and show its relevancy for one individual market.

Notation and definitions can be summarized as follows. Observed economic time series will mostly be non-stationary and can often be approximated by any ARIMA model. The non-stationarity of the time series may be caused by a (stochastic) time trend which implies that the series has at least one unit root. Stationarity may be obtained by differencing

the series d times, in which situation the original series is said to be integrated of order d ; notation: $x_t \sim I(d)$ Economic variables are often integrated of first order. When various related economic variables are observed with non-stationary time series data, which are all integrated of e.g. order one, it is still possible that a linear combination of these variables, in levels, is stationary. In that case the series are said to be co-integrated. Or, in the way Engle and Granger [7] define co-integration in a general way: the components of a vector time series x_t are said to be co-integrated of order d, b , [notation: $x_t \sim CI(d, b)$], if all components of x_t are integrated of order d and there exists a vector $\alpha (\neq 0)$ such that $z_t = \alpha' x_t \sim I(d - b)$, with $b > 0$. The vector α is called the co-integrating vector. The values $d = b = 1$ are predominant in the econometric practice when testing for co-integration, which will be pursued by us too. Necessary for an equilibrium relationship is that $z_t \sim I(0)$, implying that the equilibrium error will not drift from zero and the co-integrated series can be modelled by an error-correction representation. If the model concerns more than two variables, it is possible that more than one co-integration relationship exists. Engle and Granger [7] propose a two-step estimator for a co-integrated system and give a thorough survey of a number of tests for co-integration, and of the relationship between co-integration and a vector-autoregressive (VAR) or an error-correction (ECM) representation of bivariate time series. Co-integrated variables should not be modelled by a VAR model in first differences, as that model will be misspecified because the error-correction term has been omitted. Theoretical studies of methods for a multivariate tackling of testing for co-integration have been developed in the last few years. The procedure of Engle and Yoo [8] is an extension of the bivariate procedures of Engle and Granger [7] whereas a different approach has been developed by Johansen [15, 16] which concerns testing and estimation procedures within a maximum likelihood framework.

This paper proceeds as follows. In section 2 the data on the commodity prices are described. In section 3 we will test for the order of integration of the price series by using two well-known unit-root tests. Then in section 4, the empirical results from the co-integration tests, short-run and long-run estimation procedures will be presented and discussed, and finally in section 5 some conclusions are formulated.

2 The data

The commodity prices which have been investigated in this paper are the spot-market prices for coffee, cocoa, tea and sugar¹, which are plotted in Figure 1. Many similarities can be noticed between these commodities. An important fact is that they are all commodities which can be taken in store. Another important feature is that three of these commodities have been involved in an international commodity agreement (with varying success). Tea is the only one that is traded unrestrictedly. This might be a potential reason for the absence of co-integration for all the prices. Coffee, cocoa (beside other uses) and tea are

¹The prices concern "world export price indexes of primary commodities and non-ferrous base metals" taken from various issues of the U.N. Monthly Bulletin of Statistics.

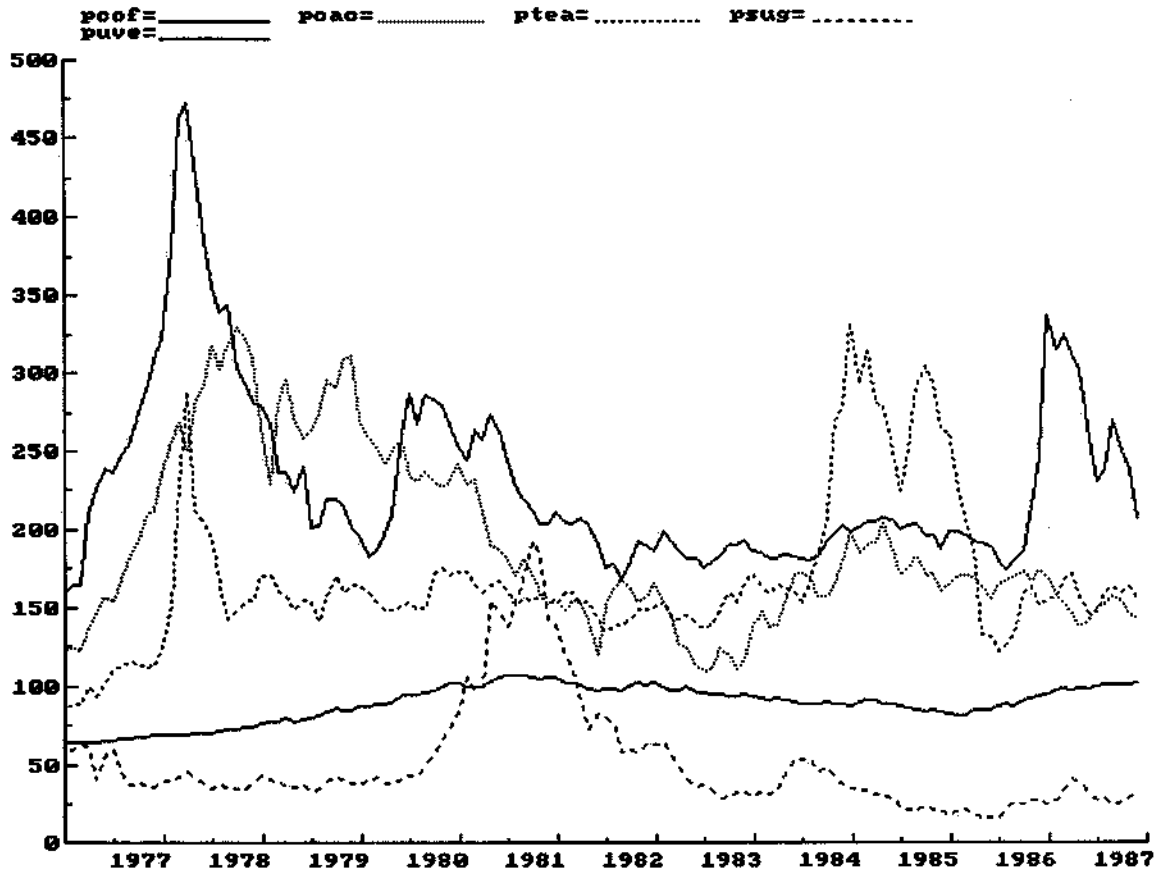


Figure 1: Monthly price indices of coffee, tea, cocoa, unit value of exports and sugar.

beverages which may be considered, to a certain extent, as substitutes for each other, while sugar is often used complementary to the others. Although futures prices are not involved in this analysis, it is well-known that some of the commodities are often traded on the same futures exchange. These are some reasons why co-integration of their prices may be expected. The prices are expressed as monthly price indices, with 1975 = 100, from the period 1976 - 1986. The data show more or less similar developments in the commodity prices, of course beside specific price movements of the particular commodities themselves. For instance, the high prices for all the commodities in 1976 and 1977 were caused by occurrences on the coffee market, while at the end of this sample period more individual price movements can be observed. Prices have their own short-term movements, but they also have the tendency to have similar stochastic trends. Therefore the hypothesis will be tested that these stochastic trends are linearly interrelated. We did not test for seasonality in the price series, as it concerns prices of commodities which can be kept in store, and so they are assumed to be less (or not) sensitive to the influence of the

harvest period, compared to commodities which cannot be stored. Some attention to this subject may be paid in a following study. In the introduction it has been mentioned that commodity prices on various related markets may be influenced by common factors, and inflation is a possible common factor. The "U.N. index of unit values of exports of manufactured goods from developed market economies" is often used as world-price deflator in the empirical econometric literature. Therefore it can be tested whether the commodity prices are possibly also co-integrated with an indicator of world inflation. Because the above-mentioned index is only available on a quarterly basis, we use the "index of export unit values in industrial countries" (abbreviated in this paper as: u.v.e.), which is monthly published in the International Financial Statistics of the I.M.F.

3 Testing the prices for a DSP or a TSP

Integrated series without deterministic components may form a linear combination of lower integration order, which make them co-integrated. Therefore it is important to test whether the series is a difference stationary process (DSP) or a trend stationary process (TSP). Variables which are DSP only, may be co-integrated. See e.g. Maddala [22] or Lloyd and Rayner [20]. Many tests can be used to test the hypothesis that a series has a unit root. Well-known tests are e.g. the (augmented) Dickey-Fuller tests [4], the Phillips Z_α test [23] and the Phillips-Perron test [24]. In addition the Durbin-Watson value of the series itself is computed sometimes, which is zero under the null hypothesis of a unit root. The choice which test to use is often made on practical computational grounds or based on discussions concerning their power which can be found in the literature. The Dickey-Fuller test is used when the process is assumed to be AR(1), and the augmented Dickey-Fuller test for an AR(p) process, where the determination of p is often difficult in empirical work. The Phillips test can be used without assuming a specific model for the process, except that it is Gaussian and that its covariance function vanishes at an exponential rate. This last condition typically holds if the process is an ARMA process with an invertible AR-lag polynomial. The Phillips test is often recommended for this more general assumption. Short surveys about the power of these tests, which are based on a number of recent studies, can be found in e.g. the 2nd editions of the textbooks of Harvey [14], en Maddala [22]. The opinions concerning the power of these tests are not always identical. Whereas some authors recommend the tests of Phillips and Perron or the Phillips Z_α test above the original Dickey-Fuller approach, one can find the opposite advice elsewhere, based on simulation experiments. For this reason it is probably not a bad strategy to follow both approaches, and to trust (or not to mistrust) the test result if both outcomes point to the same direction.

Because of the above given arguments we have calculated an " F "-statistic and the Phillips Z_α test for the logs of the prices. To limit the computational burden, we will restrict ourselves to these two different tests. We will test the null hypothesis $\alpha = 1$ and

$\beta = 0$ with the F -test in the equation:

$$y_t = \mu + \beta t + \alpha y_{t-1} + u_t, \quad (1)$$

where y_t represents the price variables, and compute the Phillips Z_α test. Critical values for these tests can be found in Dickey-Fuller [5] and Fuller [9]. The results and critical values are given in Table 1.

Table 1: Unit-root test results

Commodity	y_t		∇y_t	
	F	Z_α	F	Z_α
Coffee	3.85	0.03	31.85	-89.3
Cocoa	5.04	0.02	48.42	-101.2
Tea	3.65	0.07	36.10	-93.6
Sugar	1.08	-0.28	44.54	-102.6
U.v.e.	2.67	0.37	51.47	-117.9

5% crit. values: F : 6.49, Phillips Z_α test : -7.9

The hypothesis of a unit root in the level of the prices is not rejected, whereas the same hypothesis is clearly rejected for the variables in first differences. So we conclude that all the commodity prices and the inflation indicator are integrated of first order. And because of the calculated F -values we do not reject the hypothesis that these variables follow a difference stationary process.

4 Long-run and short-run behaviour of the prices

4.1 The number of equilibrium relationships

Now that it has been established that all the price series are $I(1)$ and follow a DSP, we will test the data for long-run relationships between the commodity prices. It is obvious that more than one relationship can exist between five variables. The likelihood-ratio test (LR-test) of Johansen is an appropriate method to test for the number of co-integrating relationships. See e.g. Johansen [15, 16] and the empirical applications in Johansen and Juselius [17, 18]. We will not consider in detail this ML approach here, but summarize the model and the tests for notational convenience only. The unrestricted VAR process of $p I(1)$ variables is considered, which can be written in the form:

$$\nabla X_t = \mu + \Gamma_1 \nabla X_{t-1} + \cdots + \Gamma_{k-1} \nabla X_{t-k+1} - \Pi X_{t-k} + \varepsilon_t, \quad (2)$$

where $\Gamma_i = -I + \Pi_1 + \cdots + \Pi_i$, $-\Pi = I - \Pi_1 - \cdots - \Pi_k$, and ε_t being a sequence of IID p -dimensional Gaussian random vectors, distributed as $N(0, \Lambda)$.

The following situations may occur concerning the matrix Π :

$\text{rk}(\Pi) = p$, The matrix has full rank, implying a stationary process X_t ;

$\text{rk}(\Pi) = 0$, The matrix Π is zero, implying an integrated vector process X_t ;
 $\text{rk}(\Pi) = r$, $0 < r < p$, implying the existence of $p \times r$ matrices α and β of rank r , giving a non-linear constraint on the coefficients Π_1, \dots, Π_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 $\nabla X_{t-1}, \dots, \nabla X_{t-k+1}$, and X_{t-k} on the same set of regressors. Denote these residuals by R_{0t} and R_{kt} , then the moment matrices S_{00} , S_{kk} and S_{k0} are computed. These matrices are defined as $S_{ij} = T^{-1} \sum_{t=1}^T R_{it}R'_{jt}$ with $i, j \in \{0, k\}$. Then solve the equation

$$|\lambda S_{kk} - S_{k0}S_{00}^{-1}S_{0k}| = 0, \quad (3)$$

giving the p eigenvalues $\hat{\lambda}_i$ and determine the corresponding eigenvectors. The number of co-integrating vectors r is determined by means of the likelihood-ratio test statistic:

$$-2 \log(Q) = -T \sum_{i=r+1}^p \log(1 - \hat{\lambda}_i), \quad (4)$$

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

We solve equation (3) for the model with unrestricted μ : $\hat{\lambda}_i$ (trend in the process) and restricted μ : $\hat{\lambda}_i^*$ (no trend in the process) and test the null of no trend with the test statistic: $-T \sum_{i=3}^5 \log[(1 - \hat{\lambda}_i^*)/(1 - \hat{\lambda}_i)] = 5.62$, which is asymptotically $\chi^2(3)$ distributed under the null of no trend. This null hypothesis of no trend is not rejected, which is the same conclusion as before. So the model with the restriction on the constant will be maintained. The results are given in the Tables 2 and 3.

Table 2: Calculated eigenvalues and eigenvectors of (3)

eigenvalues					
0.2932	0.2217	0.1394	0.0533	0.0382	0.0000
eigenvectors					
-0.8593	-1.2240	-4.4132	3.2327	-1.4820	0.2821
-4.4798	1.3345	1.4470	-1.5477	1.1077	-1.4990
2.5444	-3.0342	-1.6496	-2.6931	1.4337	-0.3787
1.0801	-0.4631	-0.1217	-1.2441	-1.2856	-1.1557
-8.3323	-3.7506	2.3517	2.5761	-1.6151	3.7185
48.0799	34.1710	14.2982	-3.0530	6.7790	-3.4442

The result of the LR-test (4) is that the null hypothesis of at most two co-integrating vectors cannot be rejected at the 5% level. So the matrix β whose columns span the co-integration space, consists of the two eigenvectors belonging to the largest eigenvalues,

Table 3: Results of the LR-test (4)

null hypothesis	$-2\log(Q)$	fractiles		
		0.90	0.95	0.975
$r \leq 4$	5.02	7.56	9.09	10.70
$r \leq 3$	12.08	17.95	20.16	22.20
$r \leq 2$	31.44	32.09	35.06	37.60
$r \leq 1$	63.77	49.92	53.34	56.44
$r = 0$	108.54	71.47	75.32	78.85

which are the first two columns of Table 3. These estimated vectors of parameters belong to the vector $(p^{cof} p^{cac} p^{tea} p^{sug} p^{u.v.e.} 1)'$.

If $r = 1$, it is possible to normalize with respect to one of the variables. But with $r > 1$ only hypotheses can be tested, concerning restrictions on the co-integrating vectors: $H_0 : \beta = H\phi$, with H a known $(p \times s)$ matrix of constants and ϕ an $(s \times r)$ matrix of unknown parameters, ($r \leq s \leq p$). With the matrix β , we have computed a basis of the co-integration space. E.g. it is possible to test whether any exclusion restriction exists, or that parameters are equal with opposite signs. Or in the way Kunst and Neusser [19] 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 . 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 following procedure can be used to test the hypothesis H_0 . First solve equation (5):

$$|\lambda H' S_{kk} H - H' S_{k0} S_{00}^{-1} S_{0k} H| = 0, \quad (5)$$

which gives the s eigenvalues λ_i^+ . Then the null is tested with the likelihood-ratio test (6):

$$-2\log(Q) = T \sum_{i=1}^r \log[(1 - \lambda_i^+) / (1 - \hat{\lambda}_i^*)], \quad (6)$$

with λ_i^+ and $\hat{\lambda}_i^*$, the r largest eigenvalues. This test statistic is asymptotically distributed as $\chi^2(r(p - s))$.

The choice which commodities to include in the analysis, is rather arbitrarily made. The commodities are related for various reasons as discussed in section 2, but it is not guaranteed that this list is exhaustive or overdone. The choice which we have made, meets the purpose of this analysis. As an application of the LR-test(6) we test whether one of the commodity prices may be excluded from the co-integration relationships. The results of the LR-test (6) [with $\chi^2(2) = 5.99$] are as follows.

Exclusion of coffee:	$-2 \log(Q) =$	1.43
Exclusion of cocoa:	$-2 \log(Q) =$	21.72
Exclusion of tea:	$-2 \log(Q) =$	13.96
Exclusion of sugar:	$-2 \log(Q) =$	9.98
Exclusion of u.v.e:	$-2 \log(Q) =$	21.46

These test results have economic interesting implications. They show that the price of coffee may be excluded from the co-integration relationships. This means that, although heavy price movements on the coffee market often cause similar price movements on other markets (see the price developments in the years 1975 - 1977), the coherent price movement probably merely concern a short-run phenomenon. This will be analysed in section 4.2. A possible reason for this phenomenon may be the fact that the coffee market has been a market with a rather effective international commodity agreement, which may have caused a different long-run price development from those of the other commodities.

4.2 Long-run and short-run relationships

For theoretical reasons we do not assume causality of one commodity price to another one, although we expect that price movements of one commodity can precede price movements of other commodities in the short run. In this context the Granger causality test can be considered. It is well-known that the Granger-causality test actually is not a causality test, but gives some insight whether one variable precedes another variable, which is quite a different subject. This problem of precedence has been considered in the analysis of the commodity prices. We have applied this test to the prices and found various "causal" relationships but not a clear pattern of "causality". It is not very informative, from an economic point of view, to show estimation results of a complete VAR system of these prices. Therefore we estimate just one possible co-integration relationship and error-correction model for these prices. The co-integrating regression is just the linear static regression between the variables. If the variables are co-integrated then o.l.s. estimates of the co-integrating vector are super consistent (as shown by Stock [27]). Otherwise, if the variables are not co-integrated, the regression is called a "spurious regression" as explained by Granger and Newbold [12]. Experimenting with different variables as the dependent variable shows few differences. So rather arbitrarily we chose to normalize for the price of tea. We find less satisfying results with respect to the signs of the coefficients when coffee and sugar are involved in the static relationship, which does not contradict the long-run results of the previous section. A result, which does not contradict those of the previous section, is e.g.:

$$p_t^{tea} = 1.11 + 0.28p_t^{cac} + 0.57p_t^{u.v.e.} + e_t, \quad (7)$$

with $DW = 0.14$. Testing the residuals for a unit root, gives a Phillips Z_α value of -14.06, which is clearly significant at the 5% level. So the null hypothesis of a unit root in the residuals is rejected, which implies a stationary linear combination of the prices in (7). An

estimated ECM for the short run is:

$$\begin{aligned} \widehat{\nabla p_t^{tea}} = & 0.003 + 0.26 \nabla p_{t-1}^{tea} + 0.34 \nabla p_t^{cof} + 0.12 \nabla p_t^{cac} \\ & (0.007) \quad (0.08) \quad (0.10) \quad (0.10) \\ & + 0.11 \nabla p_t^{sug} - 0.07 e_{t-1} \\ & (0.06) \quad (0.03) \end{aligned} \quad (8)$$

$\hat{\sigma}^2 = 0.0064$, LM test for residual autocorrelation (7 lags): $\chi^2(7) = 6.75$
Asymptotic standard errors have been given in parentheses.

The inflation indicator has no short-run influence, and is deleted for that reason. The null of no autocorrelation is definitely not rejected. So the price of coffee clearly has a significant influence on the price of tea in this short-run equation. This equation has been estimated by Recursive Least Squares (RLS) also, which shows satisfying stable parameter estimates. A high value of the R^2 cannot be expected ($R^2 = 0.25$), as this equation only shows the influence of other commodity prices on the price of tea, which can be seen as additional to the influence of the relevant variables from the tea market which determine the price. Therefore we only give the values of the residual variance in this section, to compare the various estimation results.

These two equations have been given as an example of the result after the tests for integration of the individual variables and co-integration of the joint variables have been performed. So far, we explained the short-run influence of coffee and the absence of this influence in the long run. Secondly, it is the intention of this paper to show that one need to consider occurrences on related markets to the market that is analysed. Therefore we shall conclude this paper by showing that the error-correction term e_{t-1} from equation (7), the co-integration relationship between the various related commodity prices, has explaining power in a price equation for one market. The implication of such a specification is that the prices of the various commodities are confluent in time with deviations in the short run due to their specific market developments.

We do not give a causal specified price equation for one market, but assume that such a model can be approximated by an autoregressive equation, as we wish only to show the relevance of the influence of other markets. This will turn out to be sufficient for our purpose. As we have chosen the tea market as the example in equations (7) and (8), we continue with this market. The estimated ARI(1,1) model for the price of tea is:

$$\widehat{\nabla p_t^{tea}} = 0.003 + 0.28 \nabla p_{t-1}^{tea} \quad (9)$$

(0.008) (0.08)

$\hat{\sigma}^2 = 0.0076$, LM test for residual autocorrelation (7 lags): $\chi^2(7) = 6.25$

If the error-correction term e_{t-1} from equation (7) is inserted, we get:

$$\widehat{\nabla p_t^{tea}} = 0.003 + 0.32 \nabla p_{t-1}^{tea} - 0.10 e_{t-1} \quad (10)$$

(0.007) (0.08) (0.03)

$$\hat{\sigma}^2 = 0.0070, \text{ LM test for residual autocorrelation (7 lags): } \chi^2(7) = 3.85$$

The inclusion of the error-correction term clearly improves the estimation result. Its parameter estimate has the correct sign and an asymptotic t-value of -3.25, whereas the other given statistics are still more significant. The clearly absence of autocorrelation in the residuals together with the parameter estimates, which are significantly different from zero, show the relevancy of the analysis, which is the intention here. The small value of the estimated parameter of the error-correction term indicates a slow convergence to the co-integration relationship of the prices. This seems, economically seen, rather plausible, as a fast return to this relationship should not be a logic interpretable phenomenon in the absence of short-run disturbances.

5 Conclusion

In the previous sections we have analysed the time-series properties of the spot prices of related commodities. All the variables are integrated of first order after which the ML approach of Johansen was used to test for possible co-integration and the number of co-integrating relationships. A number of at most 2 co-integration relationships was not rejected. Testing for possible exclusion restrictions in these relationships indicates that coffee can be excluded. After the estimation of a long-run relationship normalized for the price of tea, a statistical more satisfying result was obtained when the price of sugar was deleted too. We clearly found that the influence of the coffee market on the price formation of tea is a short-run phenomenon only. Further we have demonstrated that the same error-correction term has explaining power in a price equation for only one of the commodities. The addition this term in a price equation for tea, resulted in a clearly significant influence. This was demonstrated by using a simple approximation for a model of the tea market. Therefore we conclude this paper with the inference that our hypothesis has been confirmed, that estimation results for one market can improve when related markets are also considered. This can simply be done by including the error-correction term from an equilibrium relationship of an "overall" economy where that particular market forms part of.

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