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How integrated are world beef markets? The case of Australian and U.S. beef markets

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Abstract

The objective of the paper is to examine market integration between Australian and U.S. beef prices at the farmgate level. If these two prices are found to be integrated then it can be alleged that Australian beef prices can be used as a world price in empirical analyses and/or as a 'reference price' to measure the level of support accorded the U.S. beef sector. Co-integration analysis and a time-varying parameter estimation procedure based on the Kalman filter model are applied. The paper distinguishes between steer and cow beef segments and it uses monthly data over the 1972:1 to 1993:2 period. The results indicate that Australian and U.S. beef prices are co-integrated, albeit not fully and that the degree of convergence between the various price pairs has not substantially increased over time. The results also suggest that Australian prices can not unequivocally be adopted as a world price in empirical analyses.

1. Introduction

Integrated markets are defined as markets in which prices of differentiated products do not behave independently (Monke and Petzel, 1984). The distinction between integrated and non-integrated markets has obvious importance for the formulation of empirical models of international trade in general, and for measuring the level of support in particular. Markets which are independent must be modelled in a disaggregate manner, while markets which are integrated may be amenable to aggregate analysis. Hick's composite commodity theorem guarantees that commodities can be treated as a single aggregate when relative prices of the commodities remain constant.

This paper is concerned with market integration of world beef markets. Beef is a highly heterogeneous product both across countries and within countries. Beef quality is influenced by a combination of factors such as the breed of cattle, feeding practices, sex and age of slaughter, differences in processing and marketing. However, the contribution of each of these factors to overall quality of beef is difficult to gauge. The two major quality differences are the method of

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feeding (grain versus grass-fed animals) and the animal health status of the country of origin. Further, the marketing chain at which measurement should be made, in tandem with the form that beef takes (i.e., live cattle, carcasses or cuts), is all of paramount importance in assessing the extent to which beef markets are integrated.

In addition, the existence of non-tariff measures (quotas, voluntary export restraints) in the major import markets also exacerbates the difficulties encountered in empirical studies. Australia and New Zealand, for example, produce predominately grass-fed beef, although, in recent years, there has been rapid growth in the feedlot industry. In the United States, Canada and Japan, however, grain-fed beef is overwhelmingly the most important. The U.S. is a net importer of manufacturing beef and a net exporter of high-value beef produced from grain-fed steers. [2] Although beef production in Australia is almost entirely influenced by market forces, the United States, the largest beef importer, has a quota on beef imports which varies inversely with the size of domestic production (Simpson, 1982; Allen et al., 1983; Hahn et al., 1990). [3] Although, Australia's meat and livestock exports have undergone major changes in type and destination over time, the U.S. has been Australia's largest single export market for beef since the mid-1960s.

The paper is particularly concerned with examining market integration between Australian and U.S. beef prices at the farmgate level. If these two prices are found to be co-integrated then it can be alleged that Australian beef prices can be used as a world price in empirical analyses or as a 'reference price' to measure the level of support accorded to the domestic beef sector for the country concerned. The analysis distinguishes between cowbeef and steerbeef prices and uses monthly prices covering the period 1972:1–1993:2. The method of analysis is that of co-integration of time series. It also attempts to test the hypothesis of whether convergence among the various beef prices has increased over time. This is done by using a time-varying parameter estimation procedure based on the Kalman filter model.

2. Testing market integration

The use of prices and their movements to suggest the nature and extent of market integration has received renewed interest over the last few years. (For recent discussion of this issue, see Uri and Lin, 1992; Alderman, 1993; Ardeni, 1989; Dries and Unnevehr, 1990; Faminow and Benson, 1990; Monke and Petzel, 1984; Ravallion, 1986; Sexton et al., 1991). The theory of the Law Of One price (LOOP) states that in a competitive market, the price of the same product at different points in different forms will differ by no more than transport, transaction and transformation costs. Thus, close price relations among products over a substantial period of time are sufficient to establish a strong presumption that the products should be included in the same market. When attempting to delineate a market, the variation in the price of any good or service will tend to affect, in the same direction, the price of all like goods or services. Commodities, for example, need not be physically identical nor would one expect their prices to be always equal. But prices will move together over time.

Bivariate price regressions and hedonic index estimation are commonly used to identify whether differentiated products are amenable to treatment as a homogeneous commodity (Monke and Petzel, 1984; Ravallion, 1986; Faminow and Benson, 1990; Heytens, 1986; Alderman, 1993; Sexton et al., 1991; Goodwin and Schroeder, 1991; Raboy and Simpson, 1992). The traditional methodology to study market integration relies on correlations

[2] There is some evidence showing that the U.S. is a price maker at the international level as a result of being the world's largest beef importer, producer, and consumer (Simpson, 1982; Dries and Unnevehr, 1990).

[3] Beginning in the 1960s provisions were implemented for restricting meat imports. During the 1970s, rising imports and falling domestic cattle prices led to the introduction of the Meat Import Law (MIL), which provides for a beef import quota which is effectively a VER negotiating with exporting countries. It aims to protect the domestic cattle by limiting imports of fresh, chilled or frozen beef, veal, goat and sheep meat. The MIL has been triggered on eight occasions since 1979, including three times in the 1990s.

between the prices in pairs. There are a number of limitations, however, in using simple price correlations to infer anything about the extent of market integration and they are not unequivocal indicators of market conditions. The basic problem is that two functionally isolated markets can appear to be synchronized if prices in each are influenced by a third market or by a common factor (Heytens, 1986). Foremost among the limitations is that simple price correlations do not imply causality. For example, two price series that poses significant upward trends due to general inflationary pressure, common seasonality or any other synchronous common factor will yield a relatively high positive correlation, but spurious price changes. Such trends must be removed before performing analyses for inferential purposes. Another shortcoming is that dynamic properties of the series are overlooked by the simple correlation analysis. Consequently, the fact that two commodities, for example, may be distinct at a given point in time yet are becoming unified over time would be missed.

Although a number of methodological improvements have been achieved to date, few attempts have been made to address these limitations via statistical techniques (see Heytens, 1986; Ravallion, 1986; Alderman, 1993; Delgado, 1986; Goodwin and Schroeder, 1991; Faminow and Benson, 1990). The conventional approaches for measuring market integration may have yielded unreliable results insofar as they have failed to explore the time-series properties (e.g., stationarity) of the variables analysed Nelson and Plosser, 1982) or they have inappropriately applied various ad hoc transformations and filters on these variables (e.g., first differentiating) (Ardeni, 1989; Goodwin and Schroeder, 1991).

In this paper it is suggested to use the econometric concepts of integration and co-integration. The general co-integration procedures appeal to the fact that deviations from equilibrium conditions for two economic variables, which are nonstationary when taken by themselves, should be stationary. The intuition is that economic forces should prohibit persistent long-run deviations from equilibrium conditions, although significant short-run deviations may be observed. Co-integration of a pair of prices is a necessary condition for them to share a common long-run component.

Table 1
Correlation of beef prices over three sub-periods

	AUST	AUCW	USST	USUT	USCU	USCO	USCA
Sub-period: 1972:1–1979:12							
AUST	1.000						
AUCW	0.967	1.000					
USST	0.591	0.525	1.000				
USUT	0.849	0.787	0.839	1.000			
USCU	0.860	0.807	0.813	0.997	1.000		
USCO	0.830	0.758	0.844	0.994	0.990	1.000	
USCA	0.869	0.825	0.783	0.989	0.997	0.982	1.000
Sub-period: 1980:1–1985:12							
AUST	1.000						
AUCW	0.938	1.000					
USST	0.501	0.491	1.000				
USUT	0.716	0.702	0.559	1.000			
USCU	0.706	0.695	0.470	0.975	1.000		
USCO	0.663	0.642	0.569	0.965	0.911	1.000	
USCA	0.705	0.680	0.406	0.931	0.973	0.841	1.000
Sub-period: 1986:1–1993:2							
AUST	1.000						
AUCW	0.900	1.000					
USST	0.747	0.693	1.000				
USUT	0.685	0.634	0.860	1.000			
USCU	0.644	0.709	0.771	0.914	1.000		
USCO	0.676	0.591	0.847	0.977	0.869	1.000	
USCA	0.600	0.693	0.727	0.875	0.982	0.821	1.000

3. Correlation coefficients

A straightforward test for whether the integration of various pairs of beef prices are significant and whether they have changed over time is to compute the correlation coefficients over separate time periods: a significant increase in the correlation coefficient will imply that the corresponding beef markets have become more integrated over time. Correlation coefficients were calculated for three sub-periods: 1972:1–1979:12; 1980:1–1985:12; 1986:1–1993:2. The correlation coefficients were tested to discover changes in price integration over time. Table 1 reports correlation coefficients of different pairs of beef prices in Australia and the USA, for each of the sub-periods. The prices examined are: Australian steers (AUST), Australian cowbeef (AUCW), American Choice steer (USST), American Utility Cow (USUT), American Cutter Cow (USCU), American Commercial Cow (USCO) and American Canner Cow (USCA). The prices are at the farmgate level. Australian steer prices refer to Queensland steers in the weight range of 261–300 kg and cow prices to Queensland cows in the weight range of 201–250 kg; these prices are adjusted for transport costs. Correlation coefficients are very high between the various cow prices in the U.S. They are also high between Australian steer and cow prices. In no case does there appear to be a marked increase in the correlation over time, and a test statistic for equality of correlation coefficients across the three sub-periods is in each case highly insignificant. [4] These results suggest that there has been no significant increase in the correlation of beef prices either between cows and steers or between Australian and U.S. beef markets.

4. Integration and co-integration analysis

The fundamental insight of co-integration analysis is that, although many economic time series may tend to trend upwards or downwards over time in a non-stationary fashion, groups of variables may drift together. If there is a tendency for some linear relationships to hold between a set of variables over a long period of time, then co-integration analysis assists us to discover it.

Co-integration tests begin with the premise that for a long-run equilibrium relationship to exist between two variables it is necessary that they have the same intertemporal characteristics. The first step, therefore, requires testing the stationarity of the variables. Integration tests are prerequisite for co-integration. Economic interest in the theory of testing for unit roots has led to the development of a variety of tests aimed at examining the order of integration and the presence of unit roots in time series data. The most widely applied unit root tests and the first ones used are: the Durbin-Watson test of Sargan and Bhagrava (CRDW); the Dickey-Fuller test (DF); and the augmented Dickey-Fuller test (ADF). All test the null hypothesis that the series are I(1); the alternative that is generally accepted is that the data is I(0). The underlying intuition in these tests is that large absolute values of the (generally negative) coefficients of lagged residuals indicate that changes in X_t or U_t will be reversed over time, that is, that they are stable over the long run. Critical values are provided in Fuller (1976). See also Dickey and Fuller (1981).

A potential problem and source of error when applying the Dickey-Fuller tests is that they are sensitive to the presence of drift and time trends in the regression (i.e. inclusion of a constant and a time trend in the estimating equation). As a result of this shortcoming, the paper also presents the integration tests proposed by Phillips (1987), Perron (1988), Phillips and Perron (1988) and Phillips and Ouliaris (1990) (PPO). The PPO tests, which are essentially modifications of the DF and ADF tests, have a number of advantages. As they are based on a nonparametric correction to account for serial correlation, the need to estimate nuisance parameters in the asymptotic distributions of the statistics proposed by Dickey and Fuller is reduced.

There are also a number of tests that can be used for testing co-integration. These can be grouped into residual-based approach and the maximum likelihood approach. The residual-based approach, proposed by Engle and Granger (1987), relies on the premise that if a set of

[4] The test statistic for the equality of the correlation coefficients was constructed as follows. If r is the sample correlation coefficient, then the statistic $\zeta = 1/2 \ln \{(1+r)/(1-r)\}$ is approximately normally distributed, with approximate mean and variance of $1/2 \ln \{(1+\rho)/(1-\rho)\}$ and $1/(T-3)$, respectively, where T is the sample size and ρ is the population correlation coefficient. Moreover, these approximations will be close in sample sizes greater than 50. Hence, denoting two samples by subscripts 1 and 2, under the null hypothesis $H_0 = \rho_1 = \rho_2$, the statistic:

$$Z = \frac{\ln[(1+r_1)/(1-r_1)] - \ln[(1+r_2)/(1-r_2)]}{2\sqrt[2]{\frac{1}{T_1-3} + \frac{1}{T_2-3}}}$$

will be distributed approximately standard normal (see Kendall and Stuart, 1967, pp. 292–293).

variables is co-integrated of order (1, 1) then the residual from the co-integrating regression should be I(0). Thus, co-integration could be tested by subjecting the co-integration residuals to the DF, ADF, CRDW, or the Phillips-Perron tests. See also Engle and Yoo (1987).

One of the most important results in co-integration analysis is the Granger representation theorem (Granger, 1969,1983; Engle and Granger, 1987). The theorem states that if a set of variables are co-integrated of order (1, 1), then there exists a valid error correction representation of the data. The converse of this theorem also holds, namely if a set of variables are all I(1) and generated by an error correction model (ERM) then this set of variables are necessarily co-integrated. The existence of the ERM suggests that, at the very least, the lagged value of one variable must enter the other determining equation. That is, if X_t and Y_t are co-integrated and individually I(1), then either X_t must Granger-cause Y_t or Y_t must Granger-cause X_t.

The Engle-Granger method consists of a two-step procedure. First estimate the equation:

$$Y_t = \beta X_t + u_t \tag{1}$$

by OLS and test for stationarity of the residuals. Second, if this is not rejected estimate the Error Correction Model (ECM):

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta X_t + \alpha_2 (Y_{t-1} - \beta X_{t-1}) + \varepsilon_t \tag{2}$$

and replacing β by its previously computed OLS estimate $\hat{\beta}$. The condition of the identical order of $(Y_{t-1} - \hat{\beta} X_{t-1})$ integration for the variables in the preceding equation are all met: ΔY_t, ΔX_t, and are all I(0) and consequently, provided the model is properly specified, ε_t is also I(0).

One problem about the Engle-Granger procedure concerns its first step, namely the variables Y_t and X_t are nonstationary. Hence the use of OLS is inappropriate and the resulting OLS estimators are inconsistent. It should be borne in mind that the Engle-Granger method does not provide proof that the relation of the first equation (i.e., β) is really a long-run one. A number of alternative ways of how the long-run relationship should be estimated have been suggested in the literature (see Phillips and Loretan, 1991; Palaskas, 1993). One way, and this is the approach adopted in this paper, is through the use of an autoregressive distributed lag model (ADL). The unrestricted ADL(n) model for the variables Y_t and X_t is of the form:

$$Y_t = \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{i=0}^{n} \beta_i X_{t-1} + \varepsilon_t \tag{3}$$

where α_i, β_i are coefficients, and ε_t is an error term. The above equation can be estimated instead of the first one by OLS and then the long-run coefficient β^* (when $Y_t = Y_{t-i}$ and $X_t = X_{t-i}$ for all i) is derived from the estimated OLS coefficient as:

$$\beta^* = \frac{\sum_{i=0}^{n} \hat{\beta}_i}{1 - \sum_{i=1}^{n} \hat{\alpha}_i} \tag{4}$$

After testing for co-integration of Y_t, X_t with the co-integrating vector $[1, -\beta^*]$, the ECM model can now be estimated by OLS, substituting β^* in place of β. That is:

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta X_t + \alpha_2 (Y_{t-1} - \beta^* X_{t-1}) + \varepsilon_t \tag{5}$$

The general idea of the Engle-Granger and ADL methods is essentially the same. Both methods start from the estimation of the long-run relationship, either directly in the case of Engle-Granger or by using the ADL form equation in the ADL method, and then insert the deviations from the long-run path, lagged, appropriately, as the error correction mechanism in the short-run equation. The difference consists in the method of estimation of the long-run relationship.

The term $\alpha_2(Y_{t-1} - \beta^* X_{t-1})$ in Eq. (5) is the mechanism for adjusting any disequilibrium in the previous period. The speed with which the system approaches its equilibrium depends on the proximity of α_2 to -1. The term $\alpha_1 \Delta X_t$ reflects the variation of Y_t associated with X_t and is considered to be the immediate or short-run effect.

The issue of testing market segmentation is similar to that of testing the Law of One Price. Thus, in addition of testing for co-integration for the hypothesis of full price transmission to hold requires that the coefficients of the long-run relationship between the co-integrated series be unity so the independent variable is proportional to the dependent one in equilibrium. For market integration and full price transmission there is a sequence of tests to be undertaken (Palaskas, 1993; Monke and Petzel, 1984): first, the pair of price series under consideration are tested for co-integration; second, the co-integrating or error correction vector β^* is tested if it is equal to unity; and third in the error correction model (Eq. 5), the restriction $-\alpha_2 = \alpha_1 = \beta^* = 1$ or the weaker form restriction $\alpha_1 = 1$ is tested. Independence of the two price series suggests that price movements are distributed randomly with respect

Table 2
Integration tests: Phillips-Perron, DF and ADF tests

(A) Phillips-Perron tests

	$Z_{t\bar{\beta}}$	$Z(\Phi_2)$	$Z(\Phi_3)$	$Z(\hat{\alpha})$	$Z(t_{\hat{\alpha}})$	$Z(\Phi_1)$	$Z(\tilde{\alpha})$	$Z(t_{\tilde{\alpha}})$
AUST	−80	0.5	0.5	−6.7	−1.9	0.65	−12.6	−1.2
AUCW	−48	0.6	0.8	−6.3	−1.8	0.49	−10.9	−1.5
USST	29 **	2.7	3.5	−4.6	−1.7	1.80	−15.6	−3.1
USUT	−90	1.0	0.8	−5.0	−1.7	1.25	−11.5	−1.4
USCU	−88	0.6	0.4	−5.3	−1.8	1.10	−10.0	−1.1
USCO	−76	1.3	1.3	−5.3	−1.8	1.39	−13.1	−1.7
USCA	−86	0.4	0.3	−5.8	−1.8	0.98	−9.7	−1.1
ΔAUST	−0.4	50 ***	75 ***	−212 ***	−12.7 ***	76 ***	−219 ***	−11 ***
ΔAUCW	0.1	57 ***	86 ***	−219 ***	−13.3 ***	86 ***	−219 ***	−12 ***
ΔUSST	0.7	57 ***	85 ***	−149 ***	−13.0 ***	86 ***	−149 ***	−18 ***
ΔUSUT	−0.5	48 ***	71 ***	−190 ***	−12.1 ***	72 ***	−190 ***	−12 ***
ΔUSCU	−0.9	46 ***	70 ***	−195 ***	−12.0 ***	70 ***	194 ***	−11 ***
ΔUSCO	−0.6	64 ***	97 ***	−237 ***	−14.1 ***	97 ***	−237 ***	−13 ***
ΔUSCA	−0.8	45 ***	67 ***	−191 ***	−11.8 ***	67 ***	−190 ***	−11 ***
Critical values ($T = 250$)								
10%	2.38	4.07	5.39	−11.2	−2.57	3.81	−18.0	−3.13
5%	2.79	4.75	6.34	−14.0	−2.88	4.63	−21.3	−3.43
1%	3.49	6.22	8.43	−20.3	−3.46	6.52	−28.4	−3.99

(B) DF and ADF tests

	DF		ADF (4)	
	No trend	With trend	No trend	With trend
AUST	−1.37	−1.73	−1.87	−2.49
AUCW	−1.39	−1.89	−1.75	−2.39
USST	−1.86	−2.97	−1.85	−2.61
USUT	−1.44	−1.82	−1.85	−2.60
USCU	−1.54	−1.52	−1.96	−2.37
USCO	−1.58	−2.11	−1.83	−2.67
USCA	−1.52	−1.50	−1.99	−2.37
ΔAUST	−12.33 **	−12.3 **	−5.88 **	−5.89 **
ΔAUCW	−13.16 **	−13.14 **	−6.55 **	−6.54 **
ΔUSST	−13.13 **	−13.10 **	−8.61 **	−8.60 **
ΔUSUT	−12.03 **	−12.01 **	−6.45 **	−6.44 **
ΔUSCU	−11.85 **	−11.86 **	−6.14 **	−6.15 **
ΔUSCO	−13.96 **	−13.94 **	−6.29 **	−6.29 **
ΔUSCA	−11.61 **	−11.61 **	−6.22 **	−6.23 **
Critical values ($N = 250$)				
5%	−3.4289	−2.8731	−3.4292	−2.8733

Sources: Fuller (1976); Dickey and Fuller (1981).

to each other, and that the β^* coefficient is expected to be zero. A significant t-statistic for the β^* coefficient suggests interdependence of the two prices. If the β^* coefficient is significantly positive, four price relationships may exist. If β^* is not significantly different from one and the constant term is not significantly different from zero, the two prices are statistically identical. If β^* is significantly different from one and zero and the constant term α_0 is not significantly different from zero, a pure percentage premium is suggested. An absolute premium results when $\beta^* = 1$ and $\alpha_0 \neq 0$, reflecting a fixed differential between the two qualities. Finally, both percentage and absolute elements may be present in the premium ($\beta^* \neq 0$, $\beta^* \neq 1$, $\alpha_0 \neq 0$). The hypothesis of full price transmission (integration) requires that $-\alpha_2 = \alpha_1 = \beta^* = 1$. A weaker hypothesis of short-run price transmission is performed by testing $\alpha_1 = 1$ in Eq. (5).

Table 3
Tests for long-run 'equilibrium' and full price transmission

		β^*	$\bar{R}^2$	DF [a]	ADF [b]	DW [c]	LM [d]	$\beta^* = 1$ [e]	$\beta^* = 1$ [f] $\alpha_0 = 0$
AUST									
	AUCW	0.855 ***	0.992	−5.08 **	−4.91 **	−0.2 [g]	0.80	16.2 ***	18.1 ***
	USST	1.666 ***	0.977	−3.39 **	−3.99 **	2.05	3.73 ***	6.5 **	6.6 **
	USUT	1.466 ***	0.978	−3.84 **	−4.24 **	2.04	2.31 ***	15.8 ***	15.9 ***
	USCU	1.398 ***	0.978	−4.03 **	−4.50 **	2.04	2.26 **	14.5 ***	14.9 ***
	USCO	1.460 ***	0.978	−4.05 **	−4.52 **	2.03	2.34 **	11.5 ***	11.6 ***
	USCA	1.362 ***	0.978	−3.96 **	−4.41 **	2.03	2.21 **	11.6 ***	12.9 ***
AUCW									
	USST	1.896 ***	0.971	−3.53 **	−3.93 **	2.00	1.61 *	7.9 ***	8.6 ***
	USUT	1.631 ***	0.972	−3.90 **	−4.29 **	1.99	0.75	15.3 ***	15.5 ***
	USCU	1.566 ***	0.973	−4.21 **	−4.73 **	1.99	0.67	18.4 ***	18.5 ***
	USCO	1.632 ***	0.972	−3.76 **	−3.977 **	1.99	0.79	11.6 ***	11.8 ***
	USCA	1.532 ***	0.973	−4.21 **	−4.79 **	1.98	0.64	18.5 ***	18.5 ***
USST									
	USUT	0.759 ***	0.969	−4.08 **	−4.75 **	1.97	2.54 ***	10.0 ***	10.7 ***
	USCU	O.702 ***	0.967	−3.65 **	−4.27 **	1.97	2.69 ***	11.2 ***	60.9 ***
	USCO	0.750 ***	0.968	−4.27 **	−4.76 **	1.97	2.59 ***	10.6 ***	11.3 ***
	USCA	0.659 ***	0.967	−3.31 *	−3.94 **	1.97	2.71 **	9.7 ***	10.3 ***
USUT									
	USCU	0.950 ***	0.997	−2.58	2.72	1.04 [g]	1.65 *	1.10	1.21
	USCO	0.993 ***	0.996	−6.45 **	−4.53 **	2.01	1.07	0.10	0.37
	USCA	0.888 ***	0.995	−2.73	−2.76	0.34 [g]	1.08	2.04	2.43
USCU									
	USCO	1.019 ***	0.994	−3.63 **	−2.74	−0.3 [g]	1.45	0.23	0.76
	USCA	0.957 ***	0.998	−4.03 **	−3.67 **			2.22	3.45
USCO									
	USCA	0.874 ***	0.989	−3.28 *	−2.59	−2.8 [g]	1.40	2.60	3.07

[a] Dickey-Fuller test: The null hypothesis is that the two series in question are I(1). The rejection region is {DF < c} with $c = -3.37$ and -3.03, at significant level 5% and 10%.
[b] Augmented Dickey-Fuller test: The null hypothesis is that the two series in question are I(1). The rejection region is {ADF < c} with $c = -3.77$, -3.17 and -2.84, at significant level 1%, 5% and 10%.
[c] Durbin-Watson statistic.
[d] Langrange multiplier test of residual serial correlation (F-test).
[e] Wald statistic for testing the null hypothesis $\beta^* = 1$: $\chi^2(1)$.
[f] Wald statistic for testing the null hypothesis $\beta^* = 1$ and the intercept $(\alpha_0) = 0$: $\chi^2(2)$.
[g] It refers to the Durbin's h-statistic.

Table 4
Regression results from the error correction model-dependent variable: AUST

Constant	0.123	−0.359	−0.386	−0.337	−0.389	−0.268
	(2.694) **	(3.216) ***	(5.030) ***	(5.461) ***	(5.339) ***	(5.333) ***
α_2	−0.096	−0.072	−0.127	−0.138	−0.134	−0.129
	(2.665) **	(3.230) ***	(5.049) **	(5.500) ***	(5.383) ***	(5.364) ***
AUCW	0.659					
	(16.66) ***					
USST		0.139				
		(1.163)				
USUT			0.319			
			(2.515) ***			
USCU				0.322		
				(2.680) ***		
USCO					0.270	
					(2.303) **	
USCA						0.311
						(2.751) ***
$\bar{R}^2$	0.626	0.061	0.132	0.145	0.135	0.137
DW	2.311	1.649	1.830	1.837	1.826	1.837
LM(12,236)	2.216	4.272	2.975	2.947	2.861 **	2.861
RESET (1,247)	2.019	3.439	1.246	1.304	1.25	1.050
CHOW (3,244)	1.200	0.226	0.368	0.129	0.074	0.401
ARCH	0.928	25.23 ***	19.516 ***	17.996 **	13.487 ***	14.572 **
HET (1,249)	1.785	13.20 ***	6.584 **	3.432 *	0.530	2.754 *
PF (12,235)	0.617	0.192	0.249	0.195	0.179	0.256
$\alpha_2 = -1$	852.5 ***	2860 ***	1416 ***	1315 ***	1358 ***	1370 ***
$\alpha_1 = 1$	111.9 ***	87.71 ***	45.00 ***	48.1 ***	63.49 ***	56.918 ***
$-\alpha_2 = \alpha_1 = 1$	893.8 ***	2867 ***	1460 ***	1365 ***	1420 ***	1421 ***

AUCW, USST, USUT, USCU, USCO and USCA refer to the coefficient o:i of the corresponding right-hand side variable in Eq. (10).

5. Empirical results

The aforementioned tests of integration were applied to the following price series: Australian steers (AUST), Australian cowbeef (AUCW), American Choice steer (USST), American Utility Cow (USUT), American Cutter Cow (USCU), American Commercial Cow (USCO) and American Canner Cow (USCA). All series are in logs and seasonally adjusted. [5] The integration tests were applied to the levels and first differences of the series for the sample period 1972:1–1993:2 are reported in Table 2.

As can be seen from Table 2, none of the tests is able to reject the unit root hypothesis and they are all insignificant at the 10% level. The hypothesis was, however, rejected when the tests applied to the first differences of the series. It is interesting to note that the results between the Phillips-Perron and the DF, ADF test statistics are in conformity with each other in all cases. From the results of all tests it is apparent that all variables used do not seem to contain a deterministic trend component and all of them seem to be integrated process with a drift component. However, there is a slight possibility that the USST variable may contain a deterministic trend. The overall conclusion is that there is strong evidence for the presence of a unit root for all variables and all are stationary in first differences. Hence all series are integrated of order I(1).

The next step was to test for co-integration of the series. The null hypothesis is no co-integration and the residuals contain a unit root. The

[5] The moving average method for performing the seasonal adjustment of series was applied using the SAMA procedure of TSP computer package.

Table 5
Regression results from the error correction model-dependent variable: AUCW

Constant	−0.473	−0.513	−0.513	−0.442	−0.477
	(3.141) ***	(4.321) ***	(4.694) ***	(4.026) ***	(4.699) ***
α_2	−0.068	−0.116	−0.133	−0.099	−0.138
	(3.114) ***	(4.295) ***	(4.672) ***	(3.994) ***	(4.670) ***
USST	0.153				
	(1.160)				
USUT		0.297			
		(1.948) *			
USCU			0.366		
			(2.535) **		
USCO				0.283	
				(2.115) *	
USCA					0.391
					(2.674) **
$\bar{R}^2$	0.055	0.113	0.143	0.101	0.154
DW	1.778	1.90	1.922	1.863	1.931
LM (12,236)	1.494	0.867	0.764	1.033	0.727
RESET (1,247)	4.203 **	2.969 *	2.817 *	1.889	0.474
CHOW (3,244)	0.543	0.510	0.184	0.515	0.162
ARCH	4.641 *	3.088 *	3.315 *	2.980 *	3.953 **
HET (1,249)	5.730 **	9.105	8.898 ***	6.414 **	13.485 ***
PF (12,235)	0.411	0.456	0.340	0.448 *	0.318
$\alpha_2 = -1$	2936 ***	1653 ***	1459 ***	1982 ***	1401 ***
$\alpha_1 = 1$	57.4 ***	31.77 ***	28.44 ***	39.87 ***	30.75 ***
$-\alpha_2 = \alpha_1 = 1$	3199 ***	1679 ***	1483 ***	2016 ***	1425 ***

USST, USUT, USCU, USCO and USCA refer to the coefficient α_1 of the corresponding right-hand side variable in Eq. (10).

alternative is that the variables in the corresponding regression are co-integrated and the residuals are stationary. First Eq. (3) was estimated and β^* was calculated. Table 3 reports $\bar{R}^2$, DF and ADF tests and the value of β^*. The selection of the lag structure of the estimated equation was based on the values of the SBIC test. [6] (Non-)Acceptance of the hypothesis that each series contains a unit root is also conditional on the statistical adequacy of the estimated autoregressive models. Therefore, results of several misspecification tests (i.e. $\bar{R}^2$; Durbin-Watson statistics; LM for testing serial correlation in error terms; Bera and Jarque tests for normality; ARCH statistic developed by Engle for testing whether the conditional variances behave autoregressively; stability of the parameters) should be reported to support the maintained specifications. As can be seen from Table 3 and Tables 4–9, the results are quite satisfactory. The values of $\bar{R}^2$ are quite high. The values of β^*s are very close to unity in most cases. The DF and ADF tests reject the null hypothesis of I(1) co-integrating residuals (i.e., non-co-integration) implying that all pair of prices are co-integrated.

Since the slope coefficient β^* is close to unity it is endeavoured to test that the co-integration is in fact unity. The null hypothesis is rejected in all cases except for the various US cow prices (i.e., USUT, USCU, USCO, USCA). Thus, it can be inferred that only the aforementioned price pairs are co-integrated with a unit co-integrating parameter, implying that there is a long-run equilibrium relationship between them. In contrast, such relationship does not seem to exist between Australian and U.S. prices, cow or steers prices. The hypothesis that $\beta^* = 1$ and $\alpha_0 \neq 0$ was also rejected for Australian and U.S. prices and be-

[6] The Akaike IC and PE criterion were also used. In almost all cases the three tests yielded the same results. In the few cases that the tests gave different results the final choice was based on the h-Durbin-Watson and the $\bar{R}^2$-tests.

Table 6
Regression results from the error correction model-dependent variable: USST

Constant	0.294	0.302	0.295	0.284
	(4.259) ***	(3.827) **	(4.124) ***	(3.536) ***
α_2	−0.140	−0.117	−0.136	−0.096
	(4.278) ***	(3.837) ***	(4. 143) ***	(3.539) ***
USST	0.417			
	(5.404) ***			
USUT		0.370		
		(4.913) ***		
USCU			0.333	
			(4.421) ***	
USCO				0.321
				(4.853) ***
USCA				
$\bar{R}^2$	0.190	0.160	0.156	0.137
DW	1.904	1.863	1.889	1.826
LM (12,236)	2.139 **	2.404 *	2.096 **	2.498 **
RESET (1,247)	3.140 *	3.811 *	1.087	3.948 **
CHOW (3,244)	0.850	1.514	0.706	1.481
ARCH	24.744 ***	24.378 ***	21.342 ***	21.344 **
HET (1,249)	0.295	0.637	0.161	0.500
PF (12,235)	0.224	0.438	0.209	0.443
$\alpha_2=-1$	912.1 ***	1095 ***	890 ***	1433.6 ***
$\alpha_1=1$	77.889 ***	93.53 ***	119.5 ***	122.02 ***
$-\alpha_2=\alpha_1=1$	961.3 ***	1164.4 ***	963.5 ***	1521 ***

USST, USUT, USCU, USCO and USCA refer to the coefficient α_1 of the corresponding right-hand side variable in Eq. (10).

Table 7
Regression results from the error correction model-dependent variable: USUT

Constant	0.027	0.004	0.049
	(1.931) *	(1.541)	(2.037) *
α_2	−0.063	0.068	−0.050
	(1.873) *	(1.733)	(2.038) *
USCU	0.908		
	(4.0332) ***		
USCO		0.790	
		(8.273) ***	
USCA			0.785
			(27.728) ***
$\bar{R}^2$	0.864	0.763	0.751
DW	1.990	2.556	2.050
LM (12,236)	1.605 *	3.304 **	1.133
RESET (1,247)	3.000 *	0.798	3.522 *
CHOW (3,244)	0.742	0.764	5.284 **
ARCH	21.344 ***	63.542 ***	5.274 **
HET (1,249)	0.039	605.5 ***	0.014
PF (12,235)	0.453	0.510	1.522
$\alpha_2=-1$	1072.9 ***	462.9 ***	1520 ***
$\alpha_1=1$	18.798 ***	57.0 ***	56.6 ***
$-\alpha_2=\alpha_1=1$	1085 ***	516.4 ***	1542.7 ***

USCU, USCO and USCA refer to the coefficient α_1 of the corresponding right-hand side variable in Eq. (10).

Table 8
Regression results from the error correction model-dependent variable: USCU

Constant	0.009	0.030
	(1.667)	(2.499) **
α_2	−0.045	−0.074
	(1.728)	(2.409) **
USCO	0.769	
	(8.196) ***	
USCA		0.881
		(45.173) ***
$\bar{R}^2$	0.682	0.887
DW	2.192	2.351
LM (12,236)	1.106	2.103
RESET (1,247)	1.190	0.278
CHOW (3,244)	1.668	1.764
ARCH	52.698 ***	16.009 ***
HET (1,249)	519.411 ***	0.003
PF (12,235)	0.743	1.238
$\alpha_2=-1$	1181.4 ***	9955 ***
$\alpha_1=1$	48.18 ***	35.893 ***
$-\alpha_2=\alpha_1=1$	1229 ***	1002 ***

USCO and USCA refer to the coefficient α_1 of the corresponding right-hand side variable in Eq. (10).

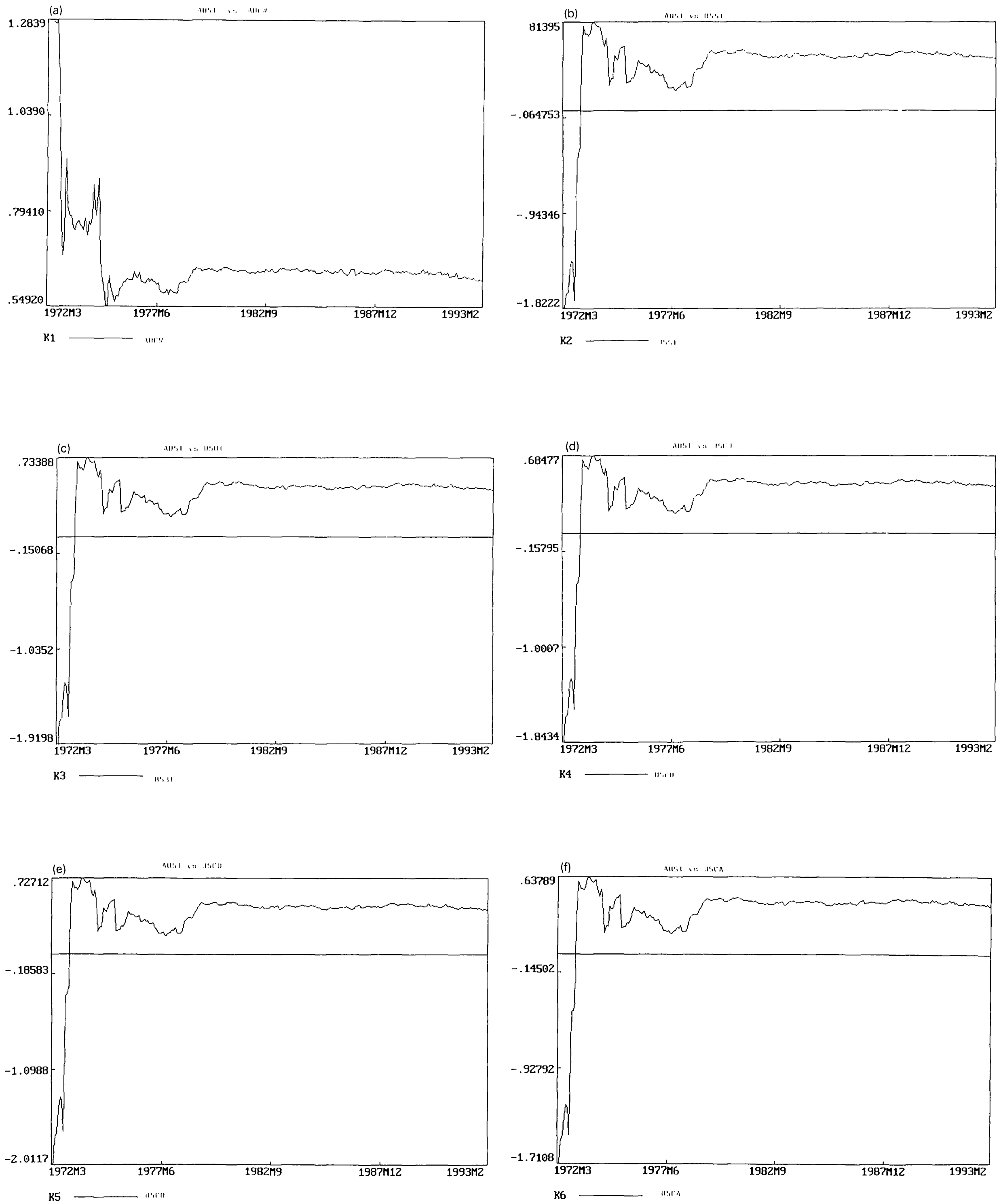

Fig. 1. Australian steer price: AUST vs. (a) AUCW; (b) USST; (c) USUT; (d) USCU; (e) USCO; (f) USCA.

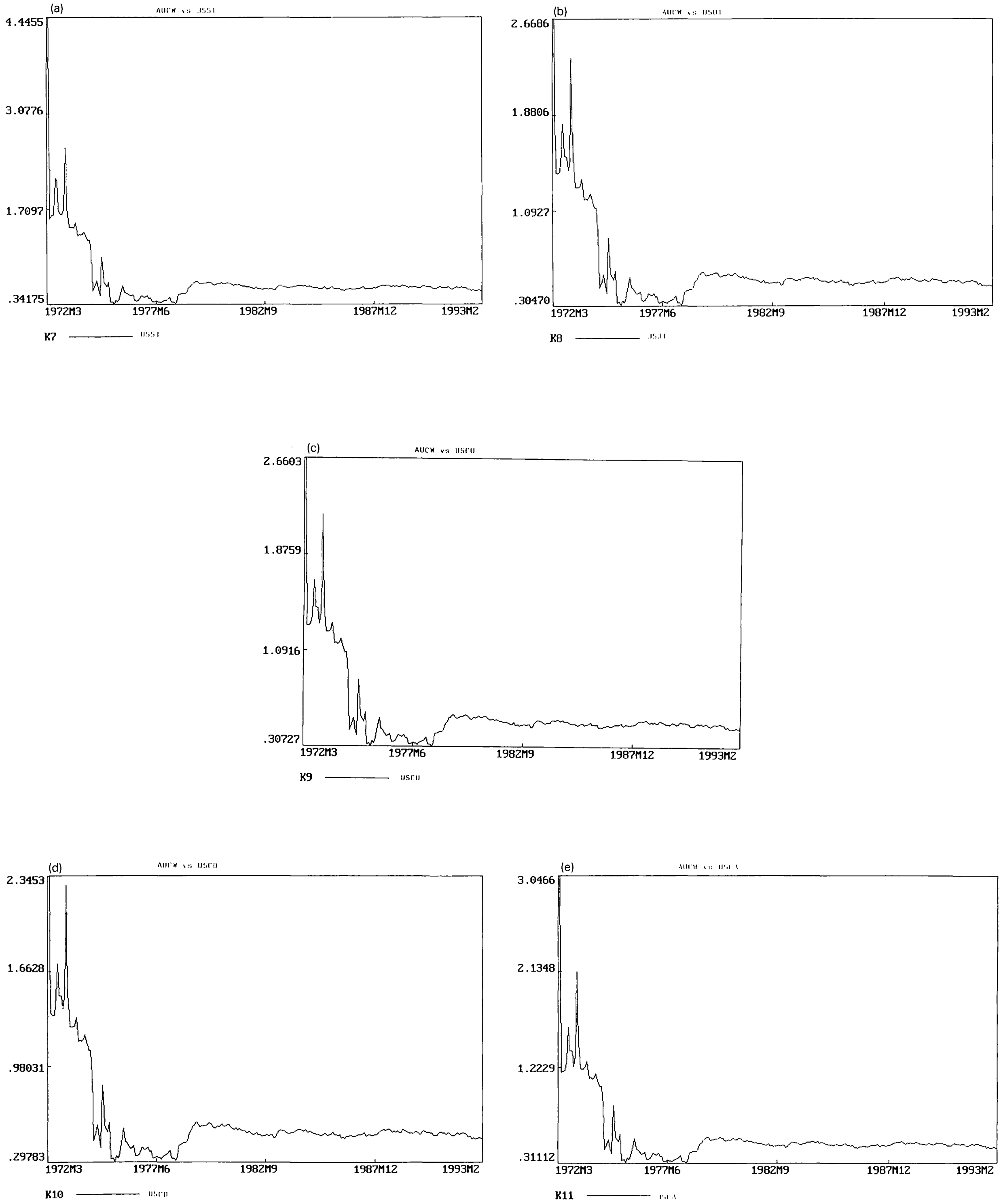

Fig. 2. Australian cow price: AUCW vs. (a) USST; (b) USUT; (c) USCU; (d) USCO; (e) USCA.

tween Australian cow and steer prices, implying that a fixed differential between these price pairs. The results amply suggest that neither the weaker nor the stronger form of co-integration are accepted as the corresponding null hypotheses were rejected in all cases (see Tables 4–9). In addition, the short-run effects are very slow as the null hypothesis of $\alpha_1 = 1$ is rejected in all cases.

6. Time varying estimations

Another approach to test whether beef prices converge over time is the use of time varying parameter estimation. This technique has the advantage that is inherently a model of structural change. This means that it is able to describe both the extent and the timing of the process of converge as it occurs, as opposed to the co-integration analysis which is only able to measure converge once it has taken place.

In this paper the Kalman filter to estimate time varying coefficient was adopted. The Kalman filter model is a set of equations which allows an estimator to be updated once a new observation becomes available. The procedure used when estimating a model with the aid of the Kalman filter is to express the model in a state space form. The model consists of a *measurement equation*:

$$Y = X_t' \alpha_t + \varepsilon_t \quad t = 1, 2, \ldots, T \tag{6}$$

and a *transition equation*:

$$\alpha_t = T \alpha_{t-1} + R_t \nu_t \tag{7}$$

where X_t is a $(m \times 1)$ fixed vector (the indepen-

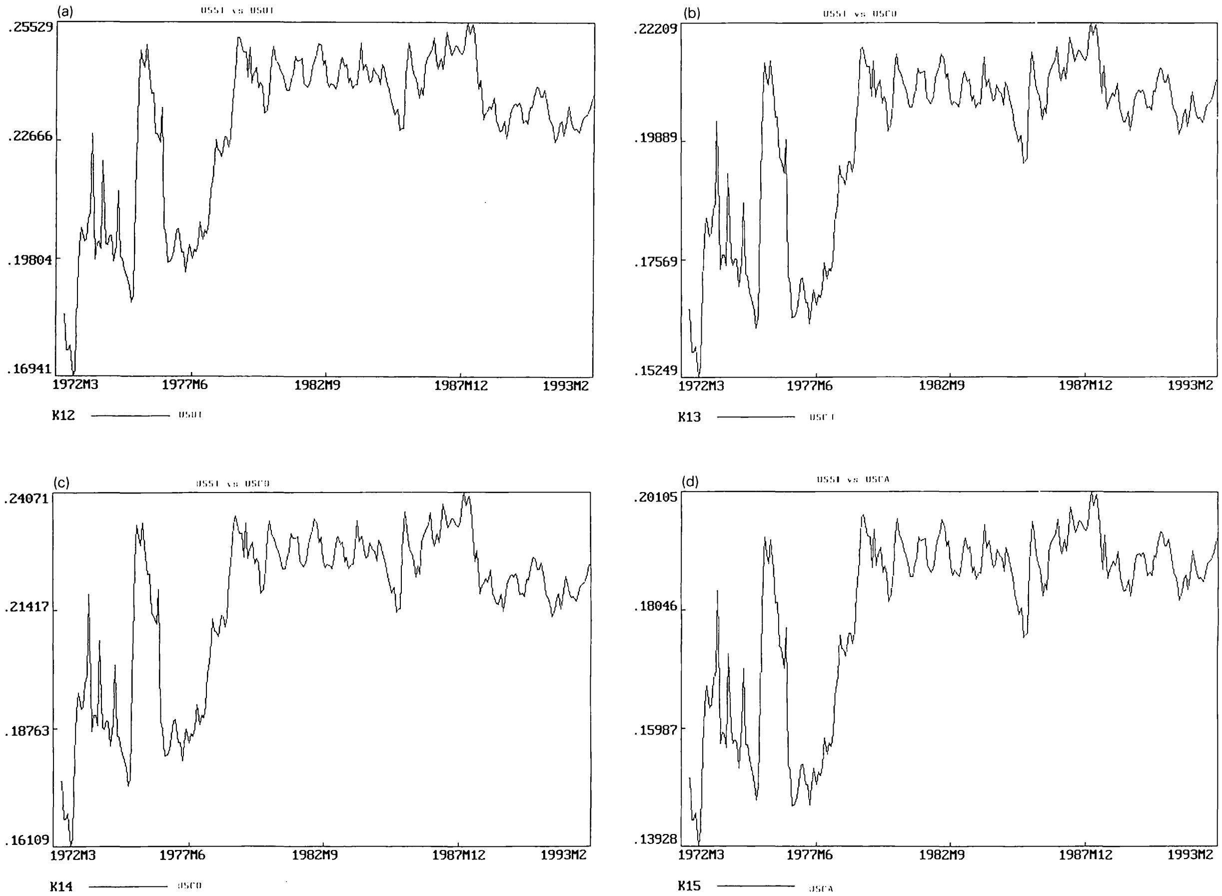

Fig. 3. U.S. steer price: USST vs. (a) USUT; (b) USCU; (c) USCO; (d) USCA.

Table 9
Regression results from the error correction model-dependent variable: USCO

Constant	0.039
	(1.615)
	−0.036
	(1.555)
USCA	0.761
	(21.462) ***
$\bar{R}^2$	0.576
DW	2.458
LM (12,236)	1.942 **
RESET (1,247)	2.11
CHOW (3,244)	0.924
ARCH	60.371 ***
HET (14,29)	0.287
PF (12,235)	0.545
$\alpha_2 = -1$	1285 ***
$\alpha_1 = 1$	33.62 ***
$-\alpha_2 = \alpha_1 = 1$	1298 ***

USCA refers to the coefficient α_1 of the corresponding right-hand side variable in Eq. (10).

dent variable), α_t is an $(m \times 1)$ *state* vector, T_t and R_t are fixed matrices of order $(m \times m)$ and $(m \times s)$, and ε_t and n_t, are, respectively, a scalar disturbance and an $(s \times 1)$ vector, which are distributed independently of each other. Is assumed that $\varepsilon_t \sim N(0, \sigma^2 H_t)$ and $n_t \sim N(0, \sigma^2 Q_t)$, where H_t is a fixed scalar, Q_t is a fixed $(m \times m)$ matrix, and σ^2 is a scalar. Is assumed that the matrices H, Q are identity matrices, implying that the parameters are random variables (this allows them to exhibit trend like behaviour). A very comprehensive discussion of the approach can be found in Harvey (1981).

In Figs. 1–6, the convergence of beef prices are considered. Fig. 1 displays the Australian steer prices and reports the $\alpha_{(t)}$ coefficient for each of the beef price series and Fig. 2 the Australian cow price, Fig. 3 for U.S. steer price (USST), Fig. 4 for Utility cow price, Fig. 5 for Cutter cow price, and Fig. 6 for Commercial cow price. Visual inspection of these figures suggests that, in general, the link has tended to strengthen over the whole period. Moreover, there has been little change in the pattern since the structural shift that took place around 1980, but since then there has been little further convergence. For the Australian steer prices (AUST), the convergence

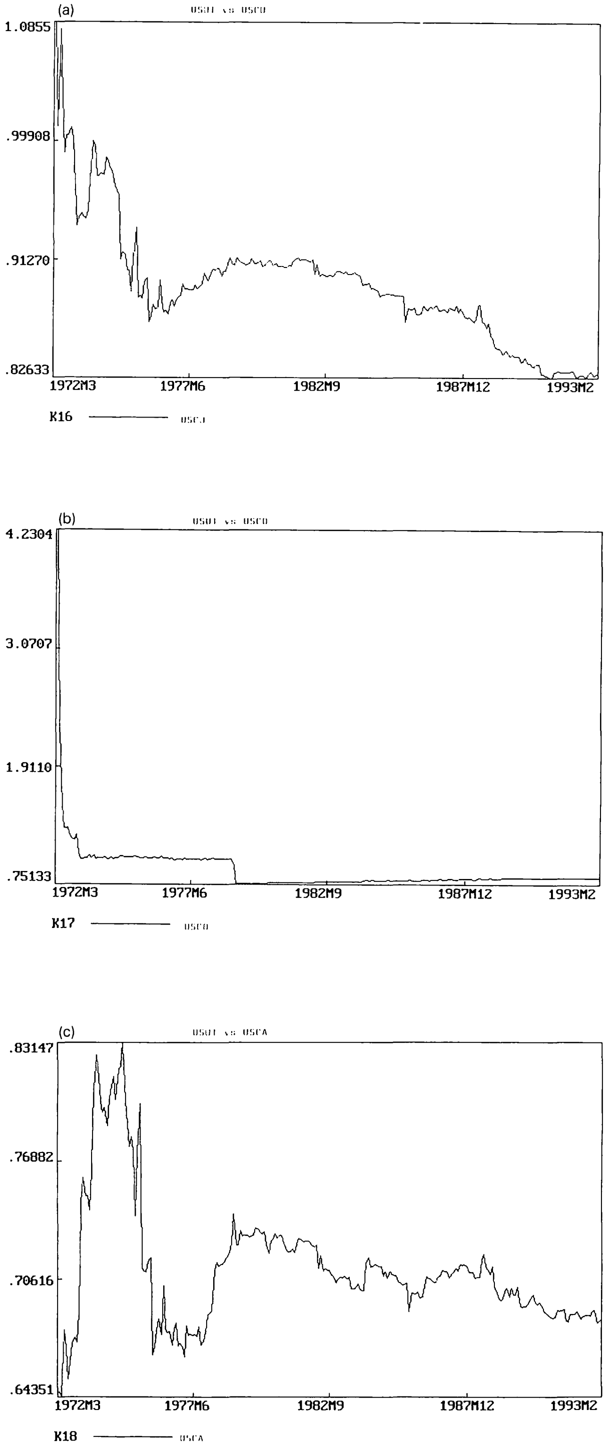

Fig. 4. Utility cow price: USUT vs. (a) USCU; (b) USCO; (c) USCA.

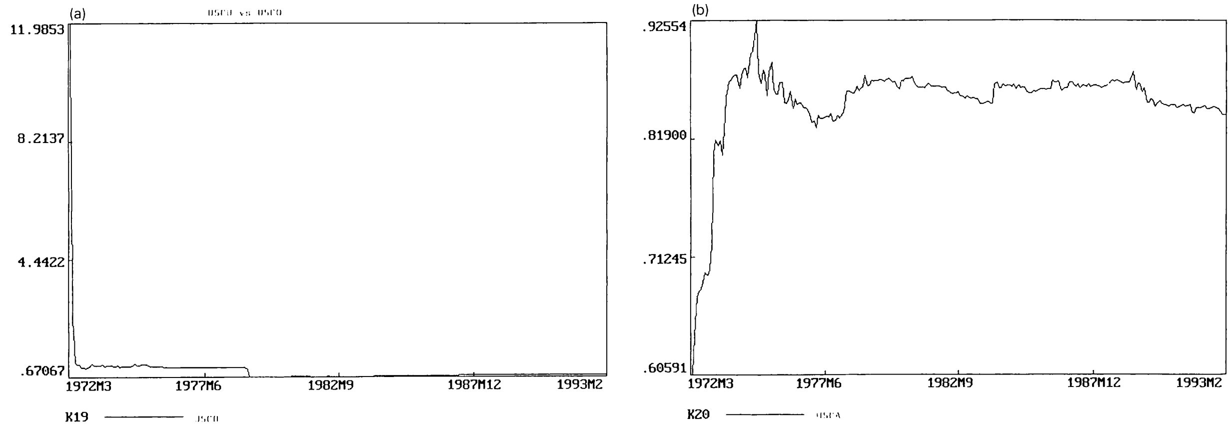

Fig. 5. Cutter cow price: USCU vs. (a) USCO; (b) USCA.

is closer to one with the Australian cow prices (AUCW). Australian cow prices (AUCW) are different from one and do not exhibit any discernible tendency to increase further towards unity. In contrast with the cases of Australian beef prices, the most surprising feature of the figures depicting convergence for the U.S. steer prices (USST) is its marked volatility. Integration of USST prices with the various types of U.S. cow prices has somewhat increased over time. Further, the corresponding figures show that the convergence is quite low and it tended to decreased after 1987. The linkage between U.S. utility cow beef prices (USUT) there has been a steady decline with the U.S. cutter beef prices (USCU), but yet the linkage is the highest observed. U.S. cutter beef prices (USCU) appear to have been stabilised in late 1970s with the U.S. commercial beef prices (USCO), whilst the convergence patter with the U.S. canner beef prices (USA) is rather volatile. However, the linkage between USCU and USA beef prices is the strongest observed from all the regression undertaken. Finally, the relation between U.S. commercial cowbeef prices (USCO) and USA is rather unstable and low, despite the tendency to increase after 1982.

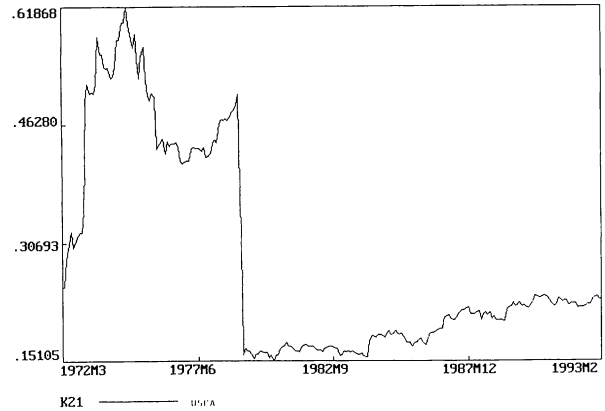

Fig. 6. Commercial cow price: USCO vs. USCA.

These results of the time varying regression exercise purport to suggest that there has not been a definite tendency for the coefficient to move towards unity for any of the regressions undertaken. Complete convergence has never been achieved and, overall, for most cases the process of convergence has been remarkably stable since early 1980s.

7. Conclusions

The assumptions of substitutability and comparability between domestic and imported beef is crucial in empirical analyses, including estimation of the rates of support and protection afforded to the beef industry and the effects of trade liberalisation. Comparability between domestic and reference price is a sina qua non for meaningful measurement of the level of support afforded to the beef sector. When prices of different products behave independently, these commodities must be modelled in a disaggregate manner. This paper used co-integration analysis based on the OLS approach and time varying parameter estimation analysis to examine the causal dynamic relationships between Australian and U.S. beef prices. The Australian beef sector is almost entirely influenced by market forces, whilst in the United States the main policy instrument is that of an import quota aimed at stabilizing prices and protecting producer incomes. The co-integrated analysis indicate that Australian and U.S. beef prices are co-integrating, although not fully. Further, the time varying parameter estimation analysis indicates that the degree of convergence between the various price pairs has not substantially increased over time.

Although the OLS approach of co-integration analysis is relatively simple and intuitive, it suffers from a number of shortcomings. One disadvantage is that the distribution of the test statistics is not invariant with respect to the nuisance parameters and therefore the critical values given in Engle and Granger (1987) can be taken only as a rough guide. The more fundamental drawback, however, is that as the co-integrating regression has more than two variables it is quite possible that there may be more than one co-integrating vector, implying that it is possible for several equilibrium relations to govern the joint behaviour of the variables and so the OLS estimate is a linear combination of them. In other words, there is no guarantee that the OLS estimate is a *unique* co-integrating vector. The co-integration tests, however, represent necessary, rather than sufficient conditions for aggregation and must be supplemented by information on market structure. With these caveats in mind, the empirical analysis in this paper should be considered as a first attempt in examining the extent to which world beef markets are integrated.

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