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WOOL PRICE VARIABILITY IN THE LONG RUN*

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Introduction

In this paper time series properties of the price of wool are examined in order to assess the importance of non-linear storage behaviour in generating the data. Williams and Wright (1991) showed theoretically why rational storage can be expected to introduce non-linearities into commodity price series. Deaton and Laroque (1992) showed how to test this prediction econometrically using only price data, and they examined real annual price data for 13 commodities from 1900 to 1987. They found clear evidence that these commodity prices were stationary but non-linear, and that the data were consistent with the rational storage models described by Williams and Wright.

There are two issues in the time series modelling of commodity prices. The first is linearity. Is the optimal predictor of future prices a linear function of past prices? Linear models, in particular ARIMA models, are overwhelmingly predominant in time series modelling. The second is stationarity. Commodity prices usually display high levels of autocorrelation; when examined using the tools of linear time series analysis they typically look rather like random walks (see the discussion in Williams and Wright Chapter 6). They either appear to be linear and non-stationary (a unit root), or linear and stationary but with a long memory (a root close to one). The random walk assumption is common in finance, and there is a long tradition in the literature on commodity options of assuming that commodity prices can be described well by a continuous time random walk or diffusion (for example Black 1976, Hoag 1983, Bobin 1990; see also Cuddington and Urzua 1989).

It is this tradition which is called into question by the rational storage literature. The non-linearities found by Deaton and Laroque are not small. They are responsible for rare but violent price fluctua-

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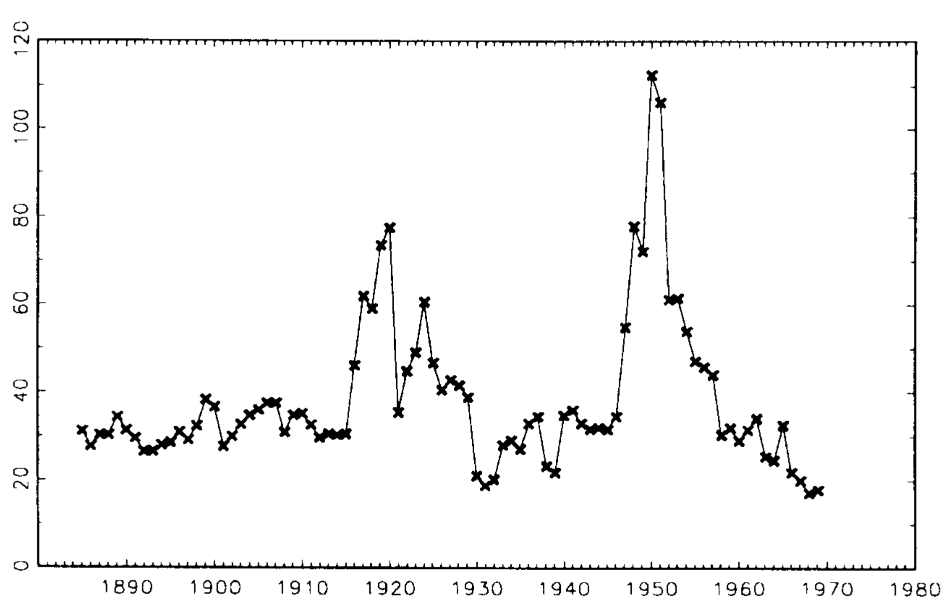
tions, typically taking the form of brief, sharp price spikes followed by a reversion to a relatively stable run of lower prices. The instantaneous volatility of these series is subject to even more marked non-linearities. Do these conclusions also apply to wool? The Deaton and Laroque methodology will be applied below to investigate this question.

There are good policy reasons why one wants to understand the true nature of commodity price series. Two examples are particularly relevant to the recent history of the wool industry. The first is the feasibility of stabilising the price, and what went wrong when it was attempted (Watson 1990, Bardsley 1994). The second, which follows on from the failure of price stabilisation, is the design of appropriate institutions and instruments for risk management in the industry, both up and down the production and marketing chain (Figlewski and Fizgerald 1983, Bobin 1990). It will be shown below that the linearity or non-linearity of the price series is crucial to how one should approach both of these issues.

FIGURE 1

Real Price of Port Phillip Merino Wool



Data and Preliminary Analysis

The price series which we examine is the average annual price for Victorian greasy merino wool from 1885 to 1969, deflated by the consumer price index.[1] Our choice of 1969 as the end point of the sample is dictated by the introduction of the stabilisation scheme in 1970. The data, which are displayed in Figure 1, show a pattern that is typical of many commodities: occasional price spikes and the absence of any discernible trend. In this section of the paper the price series will be analysed under the assumption that it is linear. Given the background set out above, one may anticipate that this assumption will prove unsatisfactory. However it is interesting and useful to see what the data looks like under a standard analysis. Thus the results in this section should be interpreted in the spirit of descriptive statistics, as a way of describing the autocorrelation structure of the data.

The first question to be considered is stationarity. Traditionally, this question is addressed using any of the well known tests for a unit root (Dickey and Fuller 1979, Phillips and Perron 1988 etc.) These tests, however are known to have low power against stationary alternatives characterised by a near-unit root, and are size distorted should the shocks have a moving average representation[2] (Schwert 1987, 1989; Campbell and Perron 1991). Therefore, we adopt the alternative testing strategy of specifying stationarity as our null hypothesis and applying the test developed by Kwiatowski et al (1992).[3] The results, for various lag lengths, are in Table 1.[4]

Table 1: Stationarity Tests

Lag Length	KPSS Statistic
2	0.214
4	0.150
6	0.126
8	0.115

1 Deflation by the CPI removes any non-stationary in the data caused by the general upward trend in prices over the sample period. Annual rather than high frequency data are used since these are the only data that are available for such a long period of time. All the data used in this paper are described in the Appendix.

2 For reference, we did perform augmented Dickey-Fuller and Phillips-Perron tests on the data. The augmented Dickey-Fuller test (implemented without a trend term) indicated a unit root in the data for specifications having, respectively, zero, one, two and four lags of the dependent variable; stationarity was indicated with three lags. In contrast, the Phillips-Perron test indicated stationarity for all lag lengths ranging from zero to four. These test results are available from the authors on request.

3 There is some evidence that stationarity tests are relatively more robust to non-normal error distributions than tests for a unit root (Silvapulle 1993).

4 The empirical implementation of this test requires Newey and West's (1987) estimator of the long-run variance of the data. This, in turn, requires specification of the lag length used in the triangular kernel, implemented to ensure that the estimate of the long-run variance is positive.

None of these test statistics are significant at the 5 percent level.[5] Hence, we cannot under these assumptions reject the view that real wool prices are mean reverting in the long-run.

Figure 2 plots the sample autocorrelation and partial autocorrelation functions for real wool prices together with 95 percent confidence bounds. These are consistent with the view that real wool prices follow a first order autoregressive process. To check, we fitted an AR(1) specification to the data. This yielded a coefficient value of 0.81 with a standard error of 0.06, and a value for the Box and Ljung (1979) test statistic for residual autocorrelation of only 5.506. Shocks to wool prices, therefore, do have some degree of persistence but this is less than that displayed by a random walk. Prices do revert, eventually, to their long-run mean.

There are other features of the data that are also of interest. In particular, the data are extremely volatile with a coefficient of variation of 0.452. This makes wool prices more variable than 8 of the 13 commodities originally analysed by Deaton and Laroque. Tests also indicate that the data are positively skewed and leptokurtic.[6] To summarise, real wool prices are autocorrelated and extremely variable but they appear to be generated by a stationary process. On the basis of the autocorrelations and partial autocorrelations one might be tempted to model them as an AR(1). However they are asymmetrically distributed with a sharper peak than would occur if the distribution were normal.

In all respects these conclusions are similar to those reached by Deaton and Laroque with respect to the commodities which they studied. They showed, however, that these stylised facts are also consistent with a different explanation in which the autocorrelation structure of the data is generated by a non-linear storage model. They then went on to reject the AR(1) specification for the commodities which they studied in favour of the non-linear model.

The Rational Storage Model

The basic idea behind the rational storage model is that storage smooths the variability of prices from year to year. If supply is high relative to demand in year one, then prices are low and it is cheap to put the commodity into storage. The plentiful supply in storage then has a depressing effect on prices in year two. Low prices thus tend to persist from year to year. If prices in year one are higher, then less will be stored, and a high price next year will be more likely. Another way to look at it is that extreme downward price spikes will not be seen

5 The critical value for the test is 0.463 (Kwiatowski et al 1992).

6 An index of skewness, S_k, has the value 2.15; the measure of kurtosis, *kur*, is 8.46. These indices are calculated using the formulae in Kirk (1978).

FIGURE 2

Autocorrelation Function for Real Wool Prices

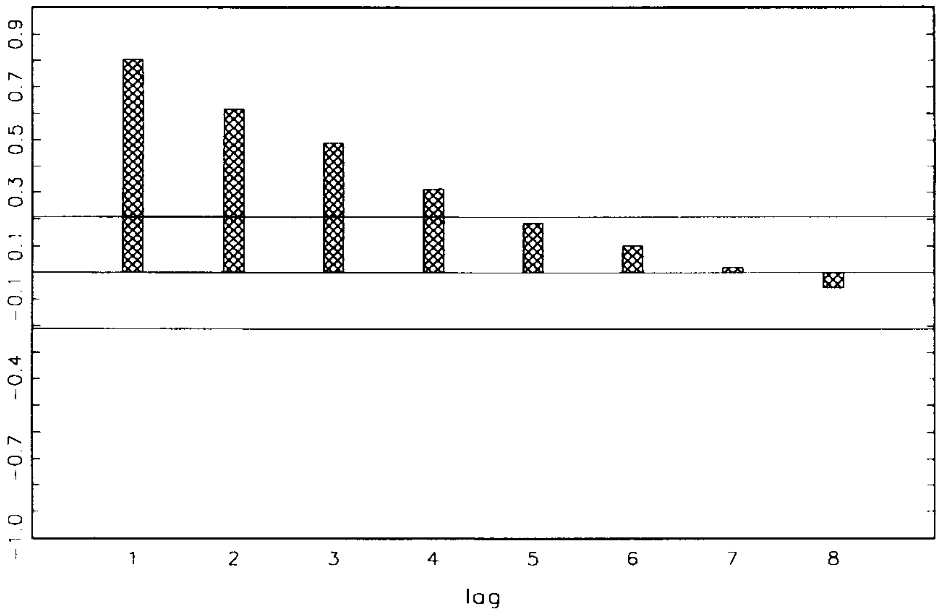
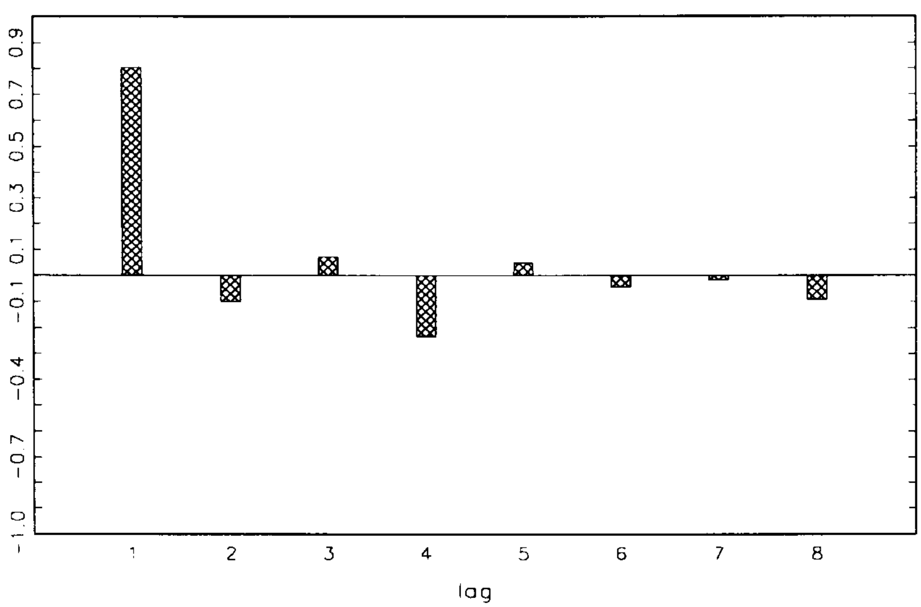


FIGURE 3

Partial Autocorrelation Function for Rela Wool Prices



because there is always some speculative demand for storage. However this inter-temporal smoothing breaks down if prices become high because storage must be non-negative. If the same mechanism were at work to smooth high prices then negative storage would be necessary. Thus there are two regimes: in one prices are low and relatively stable from year to year, and some of the commodity is carried over in storage; in the other storage breaks down and there is nothing to prevent extremely high but brief price spikes. This pattern is evident to the eye in Figure 1; and it is typical of many primary commodities.

Deaton and Laroque show that under an optimal storage strategy, prices follow the non-linear autoregressive process,

$$E(p_{t+1}|p_t) = \min(p^*, p_t) / [\beta(1-\delta)]. \quad (1)$$

In this equation, δ, β, and p^* are constants: δ is a measure of commodity deterioration or storage costs, $\beta = 1/(1+r)$, where r is the rate of interest, and p^* is the critical price which separates the storage regime from the non-storage regime. When p is above p^* there is no storage or intertemporal price smoothing.

If p^* is infinite, then the rational storage model reduces to a linear AR(1) specification. Thus linearity may be tested by testing the size of p^*. Following Deaton and Laroque, we will reject the AR(1) specification unless our estimate of p^* is significantly greater than any observation in the sample.

Equation (1) forms the basis for the empirical work to follow. The innovations to the wool price are,

$$u_1 = p_t - \gamma \min(p_{t-1}, p^*), \quad (2)$$

where $\gamma = [\beta(1-\delta)]^{-1}$. Under the rational storage model these innovations are stationary and have zero covariance with prices and quantities dated $t-1$ or earlier. This orthogonality condition can be exploited to recover estimates of the parameter vector $\theta = (\gamma, p^*)$ using a generalised method of moments estimator.[7]

We apply the technique to our wool price data using three different sets of instruments; the first has lagged prices, the second augments this with lags of Victorian sheep numbers, and the third adds lags of British GDP. Sheep numbers are included as a means of controlling for supply side factors, while British GDP is a proxy for demand influences. The results are in Table 2.

7 Since under the rational storage model, prices are conditionally heteroscedastic, the standard errors for the parameter estimates are calculated so they are consistent using the formula given in Deaton and Laroque (1992).

TABLE 2

GMM Estimates[8]

	Instrument Set 1	Instrument Set 2	Instrument Set 3
γ	1.014 (0.014)	1.012 (0.016)	1.202 (0.009)
p^*	77.950 (8.105)	77.950 (12.565)	75.843 (4.630)
stock-outs	0.03	0.03	0.04
OID	1.076 (0.300)	2.307 (0.511)	5.269 (0.384)
D–W	1.894	1.891	1.836

These results are very similar to those found by Deaton and Laroque. The slope coefficients exceed unity for all three instrument sets (although this difference is not significant at the 5 percent level), and the over-identifying and Durbin-Watson statistics show that the innovations are not characterised by autocorrelation.[9]

None of this rejects a random walk or an AR(1). The question of whether the rational storage model is appropriate for these data rests on the estimate of p^*. Had this estimate significantly exceeded the largest sample observation, we would not be able to reject a random walk. However, the estimate is well within the range of observations, allowing us to reject the linear AR(1) model. The fact that stock-outs

8 Instrument Set 1 comprises a constant and two lags of real wool prices. Instrument Set 2 = Instrument Set 1 + two lags of the natural logarithm of sheep numbers. Instrument Set 3 = Instrument Set 2 + two lags of the natural logarithm of U.K. GDP. Figures in parentheses underneath the coefficient estimates are the standard errors. Stock-outs refer to the proportion of prices in the sample greater than p^*. OID is a test statistic for the over-identifying restrictions (under the null this has the Chi-squared distribution of freedom given by the number of over-identifying restrictions less the number of estimated parameters); the figure in parentheses is the significance level at which the null can be rejected. D-W, is the Durbin-Watson statistic.

9 The overidentifying test statistic is calculated from $OID = \hat{u}'W(W'\hat{D}W)^{-1}W'\hat{u}$ where W is the TxK matrix of instruments, and D is the TxT diagonal matrix with the t'th diagonal element equal to $\hat{u}^2$ (Deaton and Laroque 1992). The logic of the test stems from the fact that under the rational storage model, the innovations should not be correlated with lagged variables.

are predicted by our results supports the view that the process underlying wool prices is driven by the competitive storage model and thus features important non-linearities.

Conclusions

It appears that the rational storage model fits wool prices at least as well as it fits the price series examined by Deaton and Laroque. It is interesting to see that this pattern extends to yet another commodity.

This finding makes clear how hazardous was the attempt by the Australian wool industry between 1970 and 1991 to stabilise the wool price. The rational storage model predicts that prices will alternate between long periods of low but fairly steady prices and occasional price spikes. On the basis of the parameter estimates obtained here, these sharp but brief booms are to be expected about once in thirty years. It appears that managers of the stabilisation scheme interpreted one of these episodes as a structural shift in demand, possibly brought about by their advertising and promotion efforts (Watson 1990). Bardsley (1994) explains how and why this error then escalated into a ruinous attempt to defend the scheme.

It also has implications for risk management in the wool industry in the aftermath of the collapse of stabilisation. The industry is concerned at present with the type of risk trading institutions which may emerge in the future, and the possible role for public policy in fostering appropriate markets. There are important issues to consider both horizontally (across wool types and characteristics) and vertically (up the production, processing and marketing chain). The nature of the price risk has a bearing on these questions, and the results presented here suggest caution.

Risk management in financial markets is carried out using highly developed and very efficient instruments and institutions. Among the most important examples are swaps, options, portfolio insurance and synthetic instruments. The development of these risk management tools is known as financial engineering, and it relies almost entirely on a theoretical framework in which stochastic calculus is used to value contingent assets which are driven by a diffusion process (Black 1976, Hoag 1983, Jarrow 1987, Bobin 1990, Myers and Hansen 1993). A diffusion process is just a continuous time random walk; this is precisely the type of model which we have rejected here, and which was rejected for a range of other commodities by Deaton and Laroque. Our data and method of analysis applies only to the long run behaviour of annual price levels, but there is no reason that the nonlinearity which we have detected should not be reflected in high frequency data.[10] If so then one would expect that financial engineering might not work as

10 A non trivial extension of the storage model would be needed to explore this conjecture.

well for commodity markets as it does for financial markets. See Figlewski and Fitzgerald (1983) for a description of the range of diffusion specifications which have been tried, and an account of the persistent pricing anomalies which are observed in commodity markets.

The implications for the wool industry are straight forward. The lack of good pricing models means that participants in commodity markets cannot manage their risk as effectively. This raises the cost of handling and holding commodities, particularly as working inventories. Thus an improvement in risk markets is similar in its effects to a research induced shift in supply and demand curves. Both producers and processors would be affected,[11] but the problem is more important as one moves up the value adding manufacturing chain. We thus conjecture that better institutions for managing commodity price risk would lead to a demand shift and higher incomes for Australian producers.[12] The discovery that non-linear storage effects are an important influence on commodity price risk should be followed up. It would be useful now to direct some research effort into the implications of rational storage for commodity option pricing, especially with respect to short run inventory behaviour within the season.

11 Myers 1988 has shown that the introduction of risk markets may lead to a supply shift which harms the interests of producers.

12 Off shore markets are more important than domestic institutions. It misses the point entirely to ask whether wool producers would trade in risk markets.

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Data Appendix

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