A new test of the theory of storage comparing historical and contemporary data

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1. Introduction

In this paper, we adopt an historical perspective to analyse commodity price volatility and its relationship with market fundamentals. In particular, we work on a balanced sample, comparing the 1920s (1921-1929) with the present decade (2000-2011) and focusing on two staple commodities, cotton and tin.[1]

The main reasons to expect a change over time in the relations of interest are related to the growing financialization of commodity markets observed in recent years (UNCTAD 2009; Tang and Xiong 2010) and to the absence, in the 1920s, of a fully developed theory of fair pricing and market efficiency orientating trading strategies. At the same time, the two periods are comparable in terms of available trading instruments, if not of rapidity in the transmission of relevant information, and in terms of a trading environment free of State intervention.[2]

Our analysis is grounded in the theory of storage. This theory illuminates the benefit of holding stocks of physical commodities. Inventories have a productive value, a convenience yield, deriving from the possibility of meeting unexpected demand, while

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[1] The paper is part of a wider research project investigating, among other issues, J.M. Keynes's trading activity on commodity markets, his views on the causes and consequences of volatility, his proposals about possible remedies. The fact that Keynes was particularly active on the cotton and tin markets and that most of his trading activity took place in the 1920s motivates the choice of our sample.

[2] We chose not to extend the sample to the 1930s because of the massive State intervention which occurred then in response to the collapse of prices.

avoiding the cost of frequent revisions in the production schedule and of manufacturing disruptions (Geman 2005). At the same time, holding stocks involves carrying costs, that is physical storage costs and financial (opportunity) costs. According to the theory of storage, the difference between future and spot prices mirrors carrying costs net of convenience yield. The latter, in turn, depends on available stocks which also affect volatility.

This work makes two main contributions to the empirical literature on commodity prices. The first consists in constructing a new database on the spot and future prices of cotton and tin for the 1920s, drawing on the historical archives of *The Times*. The second contribution consists in testing: 1) whether the diffusion of information across commodity markets is significantly different between the two periods, 2) whether the relationship between volatility and net storage costs is consistent with the predictions of the theory of storage and with Samuelson's (1965) maturity effect.

We present an innovative test of this theory—as set out in Pindyck (2001)—based on the interrelation between net storage costs and spot price returns conditional volatility. Our approach follows Ng and Pirrong (1994) in so far as we analyse interactions between net storage costs and the conditional variability of commodity prices but introduces a more restrictive sign assumption. Moreover, the structure of our model is more closely related to the dynamic properties of the time series. As to this, whereas Ng and Pirrong (1994) regress the rate of change of spot and futures prices on lagged net storage costs in order to avoid multicollinearity problems in the second stage GARCH analysis, we use bivariate VECM and standard Constant-Conditional Correlation (CCC) GARCH models (Bollerslev 1990) to obtain unbiased parameterizations of respectively the short-run return dynamics and the corresponding volatilities. The a priori requirement that the correlation between the time series be constant is not unduly restrictive in our context since the fair pricing ensures that futures and spot prices co-move over time. An accurate analysis of the correlation between net storage costs and spot returns conditional variances is set out over the full sample and, in order to accommodate periods of stress, using rolling correlations. A priori causality is not imposed on the analysis, since both variables are simultaneously affected by the outstanding stock of commodities.

The main findings of the paper may be summarized as follows. As expected, the diffusion of information is slower and less complete in the 1920s than in present times. This results from the observed behaviour of returns and from the structure of the estimated VECM and GARCH parameterizations. Using full sample correlations, the theory of storage seems to capture the dynamics of data with the exception of historical tin. Rolling correlations, however, qualify this result in two ways. First, dynamic correlation for historical tin corroborate the theory of storage but for one notable exception in 1925. Second, the recent inroads of financial agents in commodity markets seem to have affected the cotton market, reducing the impact of fundamentals on pricing.

The rest of the paper is organized as follows. Section 2 contains an essential review of the relevant literature. Section 3 describes the empirical methodology. Section 4 reports the preliminary empirical analysis of the data. Section 5 analyses their conditional first and second moments. The full sample and rolling correlations between net storage costs and spot returns conditional variances are set out in Section 6, and Section 7 concludes.

2. Literature review

Holbrook Working was the first to propose the theory of storage (Working 1948; 1949a) building on the notion of convenience yield introduced by Kaldor (1939). The convenience yield can be defined as the stream of implicit benefits, in terms of planning security and stock-out avoidance, accruing to consumers or producers from holding a stock of a given commodity. On this see Cristiano and Paesani (2012). The theory of storage was developed, from the 1940s to the 1960s (Brennan 1958; Telser 1958; Cootner 1960), in alternative to the Keynes-Hicks theory of 'normal backwardation' and has become standard reference ever since.[3] According to the theory of storage, the

[3] See Williams (1986), Bresnahan and Spiller (1986), Williams and Wright (1989), Brennan (1991), Deaton and Laroque (1992) among others. On the concept of 'normal backwardation' see Keynes (1923, 1930), Hicks (1939), Blau (1944), Hirshleifer (1989).

difference between future and spot prices mirrors carrying costs (storage costs plus interest rate) net of convenience yield. *Ceteris paribus*, when inventories are abundant the convenience yield is small and futures prices tend to exceed spot prices for a given interest rate. In the opposite case, when stocks are scarce the convenience yield is high and spot prices tend to exceed futures prices.[4] An additional effect, discussed by Ng and Pirrong (1994: 209), relates stocks availability to price variability. *Ceteris paribus*, as buffers provided by stocks decline, the elasticity of supply decreases and prices become more volatile for a given demand shock. Combining the two effects a negative relation between volatility and net storage costs obtains. This relationship is central to our paper and is going to be accurately explored in the following sections.

Geman (2005: 25) identifies three main strands in the literature on commodity price volatility and market fundamentals. The first strand models the convenience yield as a random exogenous quantity (e.g. Gibson and Schwartz 1990). A second approach directly analyses the role of inventory in explaining commodity spot price volatility (Geman and Nguyen 2005). Finally, Routledge et al. (2000) propose an equilibrium model in which the convenience yield appears as an inventory-dependent endogenous variable.

A statistical study performed by Fama and French (1987) shows that the variance of prices decreases with inventory levels. Williams and Wright (1991) analyse a quarterly model with a yearly production of the commodity and identify that price volatility regularly increases after harvest time until the next one. Milonas and Thomadakis (1997), modelling convenience yields as call options, find empirical support for the hypothesis that convenience yields are related negatively to stocks and positively to spot price volatility. For analogous findings see Heaney (2002). As shown below our assessment of the theory of storage and our results are consistent with this approach.

[4] On this see Fama and French (1988: 1077 Fig. 1) and the literature cited therein.

3. The dynamics of the theory of storage

3.1 Theoretical considerations

Indicating by $F_{t,T}$ the futures price contracted at time t for delivery at time $t+T$ and by S_t the spot price, fair pricing and the theory of storage imply that the two prices are related in the following way (Clark et al. 2001)

[1] $$F_{t,T} = S_t e^{(k_{t,T}+r_{t,T}-c_{t,T})\tau}$$

Where $k_{t,T}$ represents storage costs as a proportion of the price of the commodity, $r_{t,T}$ is the riskless rate of interest, $c_{t,T}$ is the proportional convenience yield and *(Tt)/365* is equal to the difference between the delivery date (or time to maturity) T and the current date t. In logarithmic terms, the above relationship can be used to define net storage costs z_t

[2] $$z_t = f_t - s_t - r_{t,T}\tau = (k_{t,T} - c_{t,T})\tau$$

where $f_t = log\ F_{t,T}$ and $s_t = log\ S_t$. This relationship posits that markets are sufficiently liquid and that prices convey all relevant information. The theory of storage and the associated tests would be affected by failure of these hypotheses.

We model the dynamic relationship between volatility and net storage costs extending Pindyck (2001), who distinguishes between spot markets for commodities and markets for storage. Our theoretical model consists of the following three equations:

[3] $$S_t = S_{t-1} + \frac{1}{\alpha}(N_t - N_{t-1}) + \varepsilon_t$$

[4] $$c_t = \phi_1\sigma_t^2 - \phi_2 N_t + \gamma_t$$

[5] $$z_t = k_t - c_t$$

Equation [3] establishes a direct relationship between the spot price S_t in first difference and the change in outstanding stocks ΔN_t, taken as a proxy of net demand. The random vector ε_t captures unexpected shifts in demand and supply. Equation (4) reflects the direct relationship between (spot) price volatility σ_t^2 and the (unobservable) marginal convenience yield c_t and the inverse relationship between c_t and the level of outstanding stocks N_t. The random vector γ_t captures unexpected changes in the demand and supply of storage. Equation [5] defines net storage costs z_t as the difference between gross storage costs k_t and convenience yield. Gross storage costs are assumed to be a fixed proportion of the price of the commodity. All the parameters in Equations [3] to [5] are assumed to have a positive sign.

Solving the model [3] to [5] we obtain the equation, which clarifies the dynamics between volatility and net storage costs under the assumption that the theory of storage holds

[6] $$\Delta z_t = \Delta k_t + \alpha \phi_2 \Delta S_t - \phi_1 \Delta \sigma_t^2 + \omega_t$$

Where ω is a linear combination of the stochastic components of the model

$$\omega_t = -\alpha \phi_2 \varepsilon_t - \Delta \gamma_t .$$

3.2 Statistical methodology

The statistical methodology we employ to investigate the linkages between volatility and commodity price dynamics consists of three steps. First, after preliminary analysis of the time series properties of the data, we estimate a bivariate Vector Error Correction model (see Equations [7] and [8]) to filter away any serial correlation of the spot and futures returns, controlling also for the common stochastic trend driving prices in the long-run. Inter-temporal arbitrage should bring about cointegration between spot and futures prices.

[7] $$\Delta s_t = a_0 + \sum_{j=1}^{n} a_j \Delta s_{t-j} + \sum_{k=1}^{m} g_k \Delta f_{t-k} + \pi_1 (f_{t-1} - b_0 - b_1 s_{t-1}) + u_{\Delta s,t}$$

[8] $$\Delta f_t = c_0 + \sum_{j=1}^{n} c_j \Delta s_{t-j} + \sum_{k=1}^{m} d_k \Delta f_{t-k} + \pi_2 (f_{t-1} - b_0 - b_1 s_{t-1}) + u_{\Delta f,t}$$

The residuals of the VECM equations, $u_{\Delta s,t}$ and $u_{\Delta f,t}$, are used in a second step to obtain measures of volatility using the bivariate CCC-GARCH model set forth below (see Equations [9] to [12])

[9] $$u_t = \begin{bmatrix} u_{\Delta s,t} \\ u_{\Delta f,t} \end{bmatrix}; \quad (u_t|\Omega_{t-1}) \sim N(0, H_t); \;\; H_t = \Delta_t R \Delta_t$$

[10] $$R = \begin{bmatrix} 1 & \rho_{\Delta s,\Delta f} \\ \rho_{\Delta s,\Delta f} & 1 \end{bmatrix}; \qquad \Delta_t = \begin{bmatrix} h_{\Delta s,t} & 0 \\ 0 & h_{\Delta f,t} \end{bmatrix}$$

[11] $$h^2_{\Delta s,t} = \omega_s + \alpha_s u^2_{\Delta s,t-1} + \beta_s h^2_{\Delta s,t-1}$$

[12] $$h^2_{\Delta f,t} = \omega_f + \alpha_f u^2_{\Delta f,t-1} + \beta_f h^2_{\Delta f,t-1}$$

Finally, we calculate full sample and rolling correlations between the conditional volatilities and net storage costs as defined in Equation [2] above. Equation [6] cannot be estimated directly since, given the definition of z_t, ΔS_t would not be orthogonal to the residual ω_t[5] This being the case, a correlation analysis between z_t and $h^2_{\Delta s,t}$ is the correct approach to investigate the implications and the explicatory potential of the theory of storage where, following Pindyck (2001) and Equation [6] we expect to find a negative sign. Two types of correlation are investigated, static (Equation [13]) and dynamic.

[13] $$\rho = 1 - \frac{6\sum_{t=1}^{n} d_t^2}{n^3 - n}$$

where d_t , according to Spearman, is the difference between the ranks of the t^{th} pair of the set of n pairs of elements. The Spearman correlation coefficient is non parametric and provides consistent results when the pair of variables are related by any monotonic function. The exact sampling distribution can be obtained without requiring preliminary knowledge of their joint probability distributions. Static correlations are computed over the full sample ($t = 1, 2, \ldots, n$) and the effects of relevant events that impact on the relations of interest may cancel out. The likely presence of volatility clustering in the series (and of its impact on their co-movement) suggests complementing the static

[5] The choice of instruments for assets priced in efficient markets is somewhat arbitrary, which hinders the implementation of a standard instrumental variable procedure. Indeed, spot price first differences show little serial correlation, and the traditional use of own lagged values as instruments becomes inappropriate.

analysis by *m*-period rolling correlations where *m* is equal to 52 weeks.[6] These are calculated according to Equation [1]

[14] $$\rho(m)_t = 1 - \frac{6\sum_{i=-m/2}^{\frac{m}{2}-1} d_{t+i}^2}{m^3 - m}$$

The corresponding standard errors, used for inference purposes, are approximated by

$$se(\rho(m)_t) = \sqrt{\frac{1-\rho(m)_t^2}{m}}$$

4. Preliminary statistical analysis

To test the dynamic relationship between volatility and market fundamentals we employ weekly data on spot, one month and three month futures prices for cotton and tin, observed over two distinct periods: 7 January 1921-31 December 1929; 2 January 2000-15 September 2011 (See Appendix 1).

The historical cotton and futures prices and the interest rate, used to compute net storage costs, come from the online archives of *The Times* (Sections: home commercial markets, money markets). Cotton prices refer to the Liverpool American Future Contract (100 bales, 48,000 pounds) and are quoted in British pounds.[7] Tin prices are quoted in pounds per tonne. The interest rate is the Three month Discount Bank Bill rate.

The contemporary cotton spot and futures prices come from the US Department of Agriculture and the Intercontinental Exchange (NYSE: ICE) respectively and are quoted in US cents per pound. The contemporary tin prices come from the London Metal Exchange (LME) and are quoted in US dollars per metric tonne. Eurodollar (Three-

[6] Each time *t* rolling correlation is centered at mid-sample, i.e. is computed over a window that runs from $t-(m/2)$ to $t+(m/2)-1$.

[7] Hubbard (1923: 288-95) provides full details on this type of contract and on the functioning of the Liverpool exchange for American Futures Contracts on Cotton.

month Eurodollar Deposit Rate, London) and Three month Treasury Bill rates are used to compute the net storage costs for, respectively, tin and cotton. Prices are provided by Datastream and interest rates by Fred Database.

According to the ADF unit root tests, the logarithms of the spot and futures prices turn out to be *I(1)* in levels and *I(0)* in first differences, a stylized finding of financial time series (tests available from the authors upon request). As expected z_t time series are always stationary.

Returns are measured as weekly first differences of log prices. If markets are efficient, prices should behave as martingales and the corresponding first differences should be serially uncorrelated, i.e. have fair game properties. From an economic point of view, these properties imply that any serial correlation due to noise trading should be wholly eliminated by compensatory trading by informed arbitrageurs/speculators. Comparing the four sets of returns the following characteristics emerge (see Tables 1 and 2).

Table 1: Analysis of returns. Cotton

1921-1929				2000-2011			
	Δs_t	Δf_t^1	Δf_t^3		Δs_t	Δf_t^1	Δf_t^3
Mean	–0.0002	–0.0002	–0.0002	Mean	0.0013	0.0013	0.0012
Std dev	0.0386	0.0389	0.0378	Std.dev.	0.0450	0.0475	0.0421
Skew	0.0102	–0.0874	–0.1569	Skew	0.1614	–0.2922	–0.3313
Kurt	4.666	4.521	5.070	Kurt	3.987	7.282	7.221
JB	54.1	45.7	85.5	JB	27.4	474.7	464.0
Auto (1)	**0.133**	**0.102**	**0.086**	Auto (1)	0.031	0.049	0.011
Auto (3)	**0.012**	0.008	0.017	Auto (3)	0.017	–0.003	–0.006
Auto^2 (1)	**0.260**	**0.253**	**0.189**	Auto^2 (1)	0.045	**0.109**	**0.212**
Auto^2 (3)	**0.229**	**0.202**	**0.114**	Auto^2 (3)	**0.083**	**0.013**	**0.089**

Notes: Skew: Skewness; Kurt: Kurtosis; JB: Jarque-Bera normality test; Auto (n): Ljung-Box test statistic for n-th order serial correlation; Auto^2 (n): Ljung-Box tests statistic for n-th order serial correlation of the squared time series; bold print indicates statistically significant test at the 5 per cent level.

First, in both time periods standard deviations are comparable and futures standard deviations decrease with maturity, which corroborates Samuelson's hypothesis (Samuelson 1965). Second, the JB tests statistics show that deviations from normality, due to both skewness and excess kurtosis, are larger for contemporary than for historical data. Third, heteroskedasticity looms large in all cases. We detect, however, a significant difference in the serial correlation of the returns. The historical data are inconsistent with the martingale hypothesis, which casts some doubts on the efficient dissemination of information on commodity prices in the 1920s as risk-free arbitrage opportunities seem to persist over time.

Table 2: Analysis of returns. Tin

1921-1929				2000-2011			
	Δs_t	Δf_t^1	Δf_t^3		Δs_t	Δf_t^1	Δf_t^3
Mean	–0.0004	–0.0005	–0.0004	Mean	0.0023	0.0022	0.0022
Std dev	0.0244	0.0236	0.0224	Std dev	0.0418	0.0417	0.0409
Skew	–0.6250	–0.4712	–0.4803	Skew	–0.7270	–0.7203	–0.7409
Kurt	5.469	4.576	4.774	Kurt	6.696	6.820	6.867
JB	149.3	65.8	79.4	JB	401.0	423.7	435.9
Auto (1)	**0.107**	**0.191**	**0.174**	Auto (1)	–0.074	–0.071	–0.060
Auto (3)	**0.015**	**0.046**	**0.039**	Auto (3)	0.048	0.038	0.050
$Auto^2$ (1)	**0.120**	**0.279**	**0.154**	$Auto^2$ (1)	**0.164**	**0.160**	**0.135**
$Auto^2$ (3)	**0.105**	**0.115**	**0.081**	$Auto^2$ (3)	**0.246**	**0.246**	**0.252**

Notes: Skew: Skewness; Kurt: Kurtosis; JB: Jarque-Bera normality test; Auto (n): Ljung-Box test statistic for n-th order serial correlation; $Auto^2$ (n): Ljung-Box tests statistic for n-th order serial correlation of the squared time series; bold print indicates statistically significant test at the 5 per cent level.

5. Analysis of the short run conditional mean and conditional variance dynamics

Since the information matrix of our system is block diagonal (see Equations [7] to [12] above) with respect to the conditional mean and conditional variance parameters, it is possible to adopt a two-step estimation approach with no reduction in efficiency (Pagan and Schwert 1990).

Table 3: Characteristics of the Vector Error Correction Models

Cotton				
1921-1929		2000-2011		
	Δs_t, Δf_t^1	Δs_t, Δf_t^3	Δs_t, Δf_t^1	Δs_t, Δf_t^3
VAR order	3	3	1	1
Cointegration characteristics	Restricted constant	No cointegration	Restricted Constant	Restricted Constant
Tin				
1921–1929		2000–2011		
	Δs_t, Δf_t^1	Δs_t, Δf_t^3	Δs_t, Δf_t^1	Δs_t, Δf_t^3
VAR order	3	1	2	2
Cointegration Characteristics	Restricted constant	Restricted Constant	Linear deterministic trend	Linear deterministic trend

The preliminary estimation of the VECM equations is performed using the FIML Johansen procedure. We cannot report, for evident lack of space, the estimates of the bi-variate Vector Error Correction Models that have been used to parameterize the short run dynamics of the spot and futures price rates of change. The corresponding Johansen cointegration tests are set out in Appendix 2. The cointegration characteristics and the autoregressive order of the VECMs are summarized in Table 3. The order of the systems computed with historical data is consistently higher than the order of those obtained with contemporary data, corroborating the hypothesis, mentioned above, of a speedier diffusion of information in recent times along with more efficient arbitrage.

The conditional variability of the VECM residuals is then parameterized with the help of the bivariate CCC-GARCH model, as specified above. Tables 4 and 5 provide some relevant results.

Table 4: GARCH analysis. Cotton

	ω	α	β	$\rho_{\Delta s,\Delta f}$	$E(v_t)=0$	$E(v^2_t)=1$	*JB*	*LLF*
1921-1929								
Δs_t , Δf_t^1								
$h^2_{\Delta s,t}$	0.0002 (21.09)	0.362 (31.54)	0.575 (124.54)	0.957 (880.13)	–0.139	0.983	19.548 [0.00]	2364.2
$h^2_{\Delta f1,t}$	0.0002 (21.22)	0.303 (38.78)	0.604 (139.50)		–0.142	0.982	13.821 [0.00]	
Δs_t , Δf_t^3								
$h^2_{\Delta s,t}$	0.0004 (28.88)	0.258 (15.79)	0.495 (43.61)	0.929 (403.48)	–0.061	0.998	37.469 [0.00]	2259.9
$h^2_{\Delta f3,t}$	0.0002 (21.75)	0.214 (17.51)	0.617 (68.61)		–0.067	0.998	37.789 [0.00]	
2000-2011								
	ω	α	β	$\rho_{\Delta s,\Delta f}$	$E(v_t)=0$	$E(v^2_t)=1$	*JB*	*LLF*
Δs_t , Δf_t^1								
$h^2_{\Delta s,t}$	0.0003 (13.96)	0.105 (8.34)	0.755 (65.93)	0.038 (0.94)	0.036	1.000	20.016 [0.00]	2059.1
$h^2_{\Delta f1,t}$	0.0001 (9.19)	0.102 (12.65)	0.838 (109.49)		0.024	1.001	17.902 [0.00]	
Δs_t , Δf_t^3								
$h^2_{\Delta s,t}$	0.0001 (9.50)	0.090 (18.82)	0.844 (112.26)	0.028 (0.75)	0.035	1.000	8.609 [0.01]	2154.9
$h^2_{\Delta f3,t}$	0.0002 (11.22)	0.154 (11.66)	0.753 (64.77)		0.035	1.000	13.900 [0.00]	

Notes: *t*-ratios in parentheses and probability values in square brackets.

Table 5: GARCH analysis. Tin

1921-1929								
	ω	α	β	$\rho_{\Delta s,\Delta f}$	$E(v_t)=0$	$E(v^2_t)=1$	*JB*	*LLF*
Δs_t, Δf_t^1								
$h^2_{\Delta s,t}$	0.0002 (33.43)	0.120 (9.19)	0.401 (27.26)	0.943 (576.04)	0.002	1.002	39.901 [0.00]	2733.6
$h^2_{\Delta f1,t}$	0.0002 (31.93)	0.114 (9.29)	0.505 (40.75)		0.001	1.002	9.068 [0.01]	
Δs_t, Δf_t^3								
$h^2_{\Delta s,t}$	0.0003 (30.37)	0.156 (7.27)	0.263 (12.88)	0.903 (357.46)	0.003	1.002	93.762 [0.00]	2612.9
$h^2_{\Delta f3,t}$	0.0002 (33.12)	0.131 (8.98)	0.526 (40.29)		–0.0004	1.002	24.795 [0.00]	
2000-2011								
	ω	α	β	$\rho_{\Delta s,\Delta f}$	$E(v_t)=0$	$E(v^2_t)=1$	*JB*	*LLF*
Δs_t, Δf_t^1								
$h^2_{\Delta s,t}$	0.0002 (78.94)	0.056 (24.67)	0.808 (423.97)	0.990 (5565.4)	-0.003	1.001	338.407 [0.00]	3460.5
$h^2_{\Delta f1,t}$	0.0002 (71.18)	0.062 (21.42)	0.780 (307.09)		-0.002	1.001	379.677 [0.00]	
Δs_t, Δf_t^3								
$h^2_{\Delta s,t}$	0.0001 (3.33)	0.060 (3.84)	0.835 (24.04)	0.984 (335.42)	-0.004	1.002	323.919 [0.00]	3333.4
$h^2_{\Delta f3,t}$	0.0001 (3.07)	0.060 (3.67)	0.830 (19.94)		0.000	1.002	359.326 [0.00]	

Notes: *t*-ratios in parentheses and probability values in square brackets.

The usual misspecification tests suggest that the standardized residuals v_t are well behaved and that the heteroskedasticity of the original return time series is captured by the model ($E(v_t)=0$, $E(v^2_t)=1$ and the corresponding Jarque-Bera (JB) statistics are systematically smaller).[8] Of great interest is the difference in persistence between the historical and contemporary estimates, with β (which measures volatility persistence) significantly lower in the former case. Conversely coefficient α (which gauges the impact of innovations) is much larger with historical than with contemporary data.

These findings reflect the difference in the dissemination of information which, as already documented above, was less rapid and pervasive in the 1920s than in the present day. This implies that new information had a much larger impact on pricing and on volatility, the latter being, in turn, less affected by its own lagged value.

It is noteworthy, finally, that the GARCH structure of the contemporary cotton and tin returns shares the stylised characteristics of financial assets: a large persistence coefficient, a small coefficient of the innovations, their sum being close to one.

The theory of storage as developed by Working, is based, among other things, on the assumption of market information efficiency (Working 1949b).

As a consequence, the inefficiencies detected in the 1920s might impair the quality of our results. In other words, we expect to find a stronger corroboration of our a priori with contemporary rather than with historical data.

6. Correlation analysis

Correlation analysis provides some interesting results on the co-movement between conditional return volatility and net storage costs and allows to test the dynamics implied by Equation [6] above. If, in a given time period, inventories are significantly above their average value, we posit that: 1) net storage costs z_t exceed their average value (irrespective of the sign of their average) and 2) volatility $h^2_{\Delta s,t}$ is likely to be smaller than its average value. The covariance and the correlation are thus expected to be negative. This holds true also in the opposite case.[9]

[8] The conditional normality of the standardized residuals, however, is rejected by the Jarque-Bera test statistics, and the *t*-ratios reported in the tables are based on the quasi-maximum likelihood estimation procedure of Bollerslev and Wooldridge (1992).

[9] If inventories are significantly below their average value: 1) storage costs net of convenience yield will be lower than their average and 2) volatility will be above its average value.

Based on this argument, we interpret observed positive correlations as deviations from market fundamentals due to additional financial considerations, possibly related to risk factors and/or to inefficiencies in the pricing of information.[10] This corresponds to cases where increases in volatility are associated with falls in the convenience yield, i.e. to cases where the coefficient ϕ_1 of Equation [4] is negative, violating our *a priori*.[11]

Table 6 shows full sample Spearman and Pearson correlation between the conditional variances of the spot rates of return $h^2_{\Delta s,t}$ and net storage costs at time *t*.[12]

[10] The empirical approach by Ng and Pirrong (1994), disregarding sign considerations, would interpret incorrectly this finding as a validation of the theory of storage. As is well known, (expected) returns are positively related with risk. Increases in volatility can thus be associated with positive basis changes which, in turn, induce a positive correlation between net storage costs and spot return volatility. Moreover, a stylised aspect of recent commodity price behaviour is the leading role of futures price movements which reflect changes in market outlook.

[11] This claim is based on the stylized observation that low stocks entail high volatility, low storage costs and high convenience yield.

[12] We repeated the analysis replacing z_t with its one-period lagged values (estimates available upon request). No significant differences appear with respect to results discussed in the main text.

Table 6: Full sample correlation coefficients

Cotton			
	Maturity	Spearman	Pearson
1921-1929			
$h^2_{\Delta s,t}$	1	–0.1506 (–3.28)	–0.0390 (–0.84)
$h^2_{\Delta s,t}$	3	–0.1291 (–2.81)	0.0224 (0.48)
2000-2011			
$h^2_{\Delta s,t}$	1	0.0948 (2.35)	0.0107 (0.26)
$h^2_{\Delta s,t}$	3	–0.0782 (–1.93)	–0.4002 (–10.77)
Tin			
	Maturity	Spearman	Pearson
1921-1929			
$h^2_{\Delta s,t}$	1	0.0379 (0.82)	–0.0078 (–0.17)
$h^2_{\Delta s,t}$	3	0.0704 (1.52)	0.0774 (1.67)
2000-2011			
$h^2_{\Delta s,t}$	1	–0.2373 (–6.02)	–0.0681 (–1.68)
$h^2_{\Delta s,t}$	3	–0.4130 (–11.18)	–0.3309 (–8.64)

Note: *t*-ratios in parentheses.

We include both one and three months spreads in the analysis in order to assess whether, as expected, the convenience yield rises with maturity (see Milonas and Henker 2001, among many others), focusing on results obtained with the Spearman procedure for the reasons mentioned in Section 3. The findings seem to corroborate the maturity effect.

In the case of cotton, the theory of storage is borne over both periods, with the exclusion of the contemporary one month contract. In the case of tin, the theory of storage does not seem to apply for historical data whilst contemporary data strongly support it. This might be partly explained by the observed improvement in the contemporary transmission of information.

In order to investigate the effects on the relations of interest of the large price gyrations (see Figures A1 to A4 of Appendix 1) and of the observed volatility clustering (see Tables 1 and 2), we perform the dynamic Spearman rolling correlation analysis as detailed by Equation [14] above, using three months futures contracts. The results, based on a 52 weeks window (m = 52), are reported in Figures 1 to 4 below.

Historical data exhibit an irregular pattern.[13] In the case of cotton (Figure 1), the theory of storage is strongly rejected only in 1926 and again in the early months of 1928. In both cases this appears to be connected with falling prices (see Figure A1), high volatility and excess stock accumulation (see Table A1). In the case of tin (Figure 2), in line with full sample results and with our conjecture about the likely blurring impact of market disfunctions, most rolling correlations are statistically not significant.

Contemporary cotton data (Figure 3) are less informative. The theory of storage is rejected for long bouts of time, especially in 2001, 2003 and from the second quarter of 2007 to 2010, mostly in connection with periods of price declines as in the case of historical data.[14] The theory of storage fares better for tin, especially from 2003 to 2005 and from the second half of 2007 to 2010. This reflects the highly efficient structure of the London Metal Exchange.

[13] For evident lack of space we have chosen to comment only four of the sixteen possible correlations as reported in Table 6 above.

[14] The significant and positive correlations of these periods might be explained by the financial risk consideration mentioned above.

Figure 1: Dynamic correlations for cotton, 1921-1929

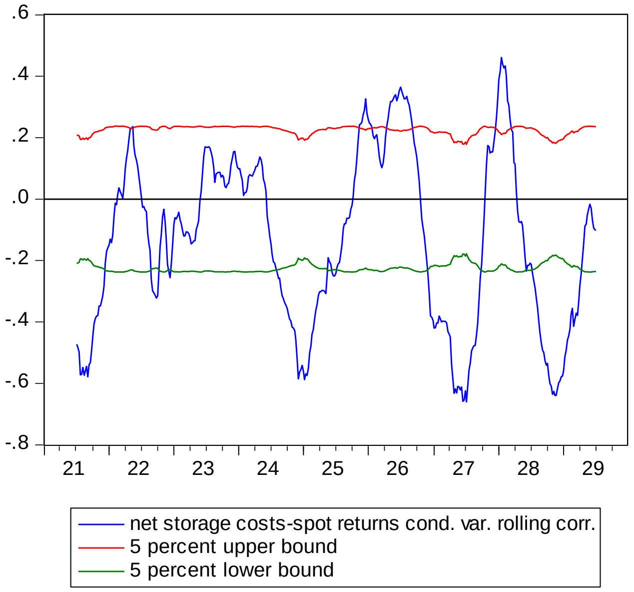


Figure 2: Dynamic correlations for tin, 1921-1929

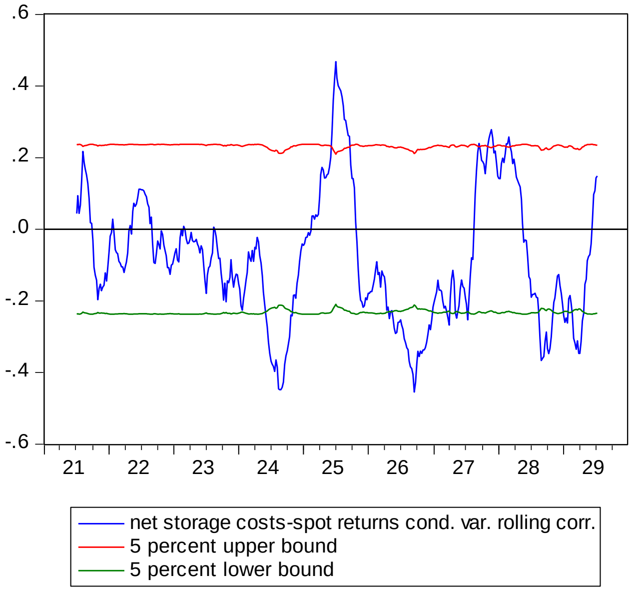


Figure 3: Dynamic correlations for cotton, 2000-2011

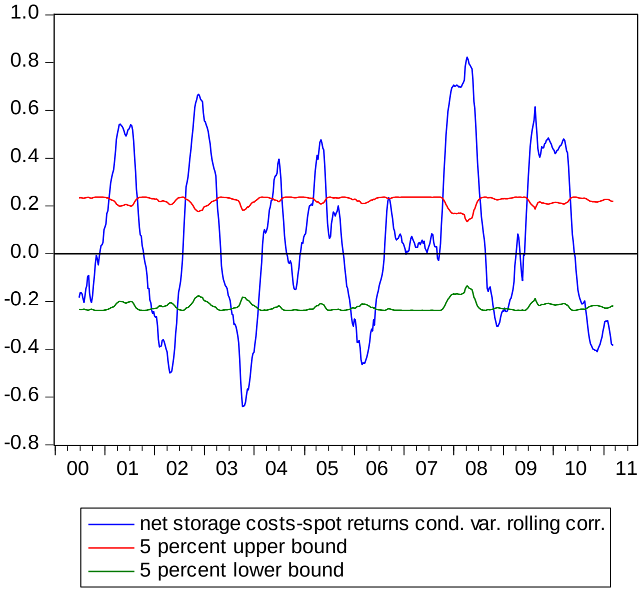
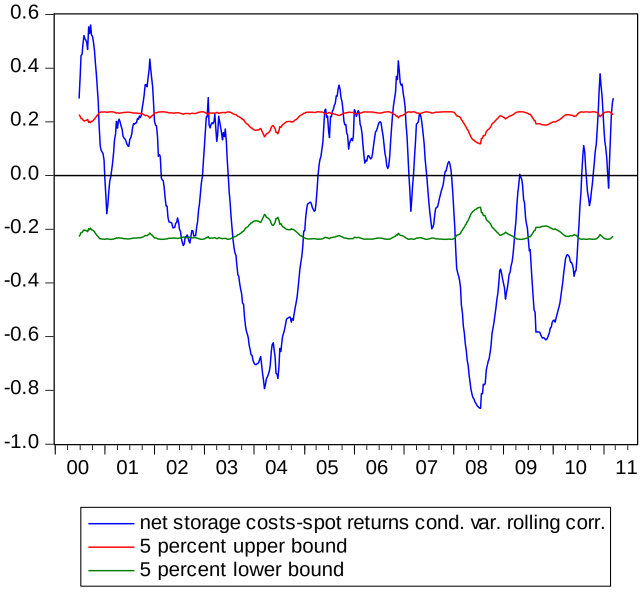


Figure 4: Dynamic correlations for tin, 2000-2011



7. Conclusions

In this paper we investigate the relationship between commodity price volatility and market fundamentals, proxied by the interest rate adjusted basis, comparing the 1920s with the present decade focusing on cotton and tin. In this context we develop an innovative test of the theory of storage grounded on recent strands of the literature. Our first result is to find that the series have widely different properties which reflect the speedier diffusion of information in the markets today. This emerges both from the analysis of the dynamics of returns and from the structure of the GARCH parameterization of their conditional volatilities. Our second finding is to show that, based on full sample correlations, the theory of storage seems to capture the dynamics of data with the exception of historical tin. Rolling correlations, however, qualify this result and suggest that recent inroads of financial agents in commodity markets might have affected the cotton market, giving prominence to financial risk factors.

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Appendix 1[+]

The *Special Memoranda on Stocks of Staple Commodities*, written by J.M. Keynes for the London and Cambridge Economic Service, provide essential information on the fundamental dynamics of commodity markets in the 1920s (Keynes 1923-30). Total stocks of American cotton declined as a result of falling crops and increasing consumption between 1921 and 1923. This contributed to rising prices and was followed by three years of very abundant crops which pushed prices down in spite of increasing consumption. Finally, the curtailment of crops and of stocks contributed to the partial recovery of prices between 1927 and 1929 (see Figure A1 and Table A1). In the case of tin, the upward trend in prices, observed between 1922 and 1926, was accompanied by consumption increasing at a more rapid pace than production and by diminishing stocks. The surge in production between 1927 and 1929 contributed to observed inversion in the price trend (see Figure A2 and Table A1). According to data reported in Table A2 both world production and consumption of cotton have been moving in step over the sample period, increasing from an average of 93.7 and 94.9 (million of 480 lb bales) respectively, between 2000 and 2003, to an average of 114.8 and 115.5, between 2004 and 2010. The sharp fall in stocks registered in 2009 and 2010, the result of falling production in 2008-2009 and of steady consumption, possibly coupled with a bout of speculative activity, accompanied the observed surge in prices at the end of the sample period (see Figure A3 and Table A2). Coming to tin, world production has ebbed and flowed over the sample period. Meanwhile, consumption has been systematically higher than production, with the sharpest imbalances observed between 2006 and 2008, and again at the end of the sample period. This, together with global financial factors, might contribute to explain the two peaks in prices observed over the sample period (see Figure A4 and Table A2).

[+] We would like to thank Carlo Cristiano, Nicolò Cavalli and Leonardo Maria Giuffrida for their help in collecting the data.

Figure A1: Cotton prices, 1921-1929

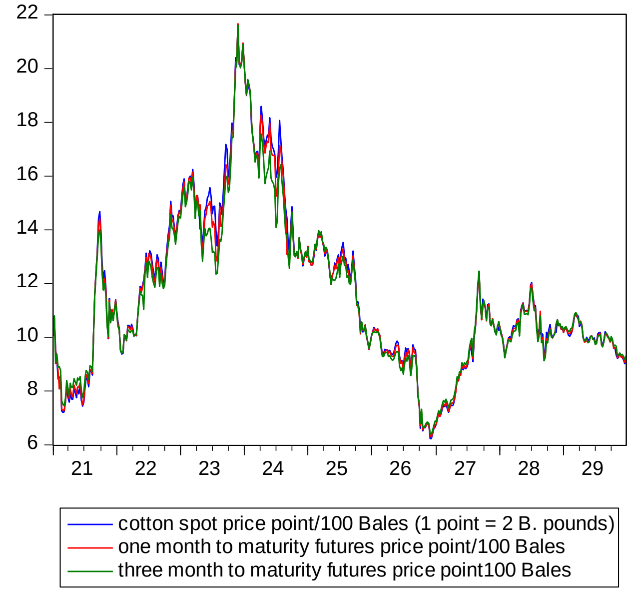

Figure A2: Tin prices, 1921-1929

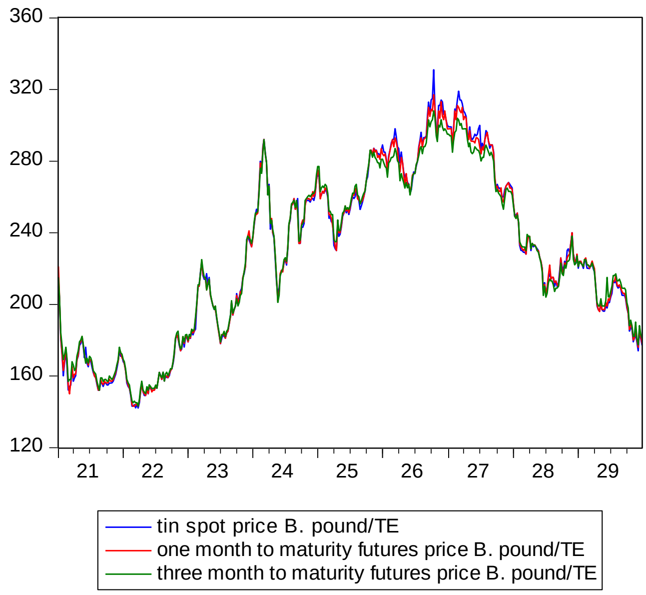

Figure A3: Cotton prices, 2000-2011

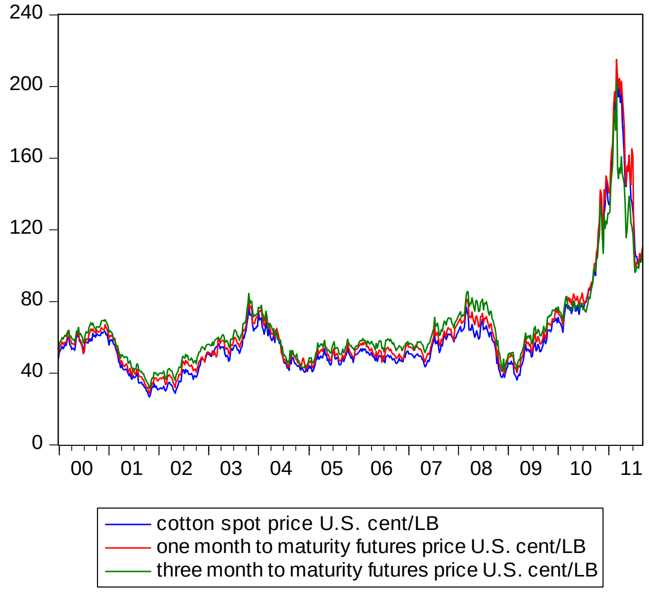

Figure A4: Tin prices, 2000-2011

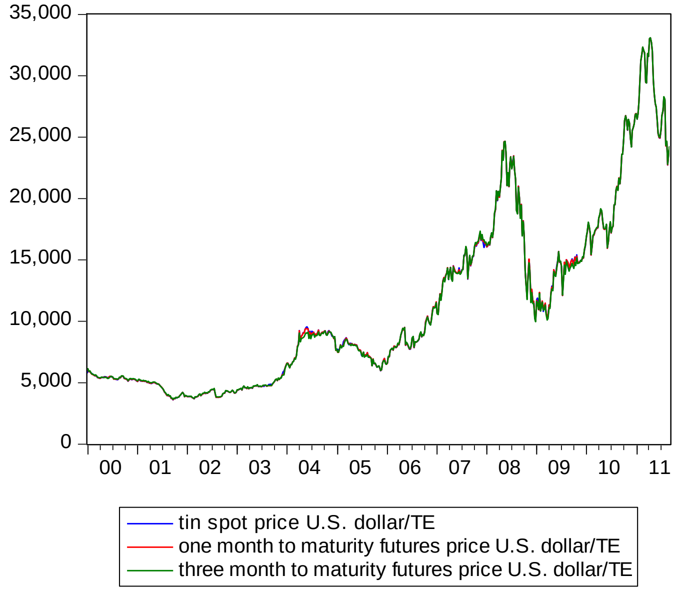

Table A1: Flows and stocks, 1921-1929

	Cotton[1],[2]			Tin[3],[4]		
	Production	Consumption	Stocks at end of season (1 Aug)	Production	Consumption	Stocks at end of year
1921	8,442	12,556	7,066	–	–	43,500
1922	9,738	12,666	3,081	130,000	132,000	45,400
1923	10,128	10,955	2,554	127,500	139,000	36,000
1924	13,639	13,256	3,141	140,000	144,500	32,000
1925	16,122	13,730	5,666	144,500	154,500	22,000
1926	17,977	15,780	7,637	143,000	146,500	18,500
1927	12,956	15,407	5,020	157,500	155,000	21,000
1928	14,478	15,076	4,417	175,000	167,500	29,000
1929	14,749	13,023	6,613	188,000	181,000	36,000

Notes: (1) American cotton 1,000 bales; (2) Source (Keynes 1923-30: 585); (3) Tons of 2,240 lb; (4) Source (Keynes 1923-30: 604).

Table A2: Flows and stocks, 2000-2011

	Cotton[1],[2]			Tin		
	Production	Consumption	Stocks at end of season (1 Aug)	Production[3]	Consumption[4]	Stocks at end of year
2000	89.1	90.8	49.4	277	–	–
2001	98.7	93.7	54.5	281	277.9	–
2002	91.0	97.6	47.6	241	275.8	–
2003	96.7	97.2	48.1	257	296.6	–
2004	121.6	107.9	60.6	287	318.2	–
2005	116.4	115.0	61.9	297	332.1	–
2006	121.8	122.8	62.3	296	355.8	–
2007	119.7	121.1	60.7	307	360.5	–
2008	107.1	107.3	60.5	273	338.4	–
2009	101.5	118.4	44.0	279	307.2	–
2010	115.5	116.1	43.4	261	–	–

Notes: (1) Source: http://www.fas.usda.gov/cotton/circular/2010/December/cotton_full12-10.pdf; (2) Millions of 480 lb bales, Total world; (3) Sources: United States Geological Survey Mineral Resource Program, British Geological survey, Millions of metric tons, Total world; (4) Source: www.itri.co.uk

Appendix 2

Table A3: Johansen cointegration tests: trace test statistics

Cotton					
	Hypothesized No. of Cointegration Relationships	Trace Statistic	5 per cent Critical Value	N. of lags in VAR	Deterministic Trend Assumption
1921-1929					
s_t , f_t^1	None at most 1	48.6949* 3.1434	20.2618 9.1645	3	Restricted constant
s_t , f_t^3	None at most 1	18.1090 3.2364	20.2618 9.1645	3	Restricted constant
2000-2011					
s_t , f_t^1	None at most 1	90.2499* 1.6098	20.2618 9.1645	1	Restricted constant
s_t , f_t^3	None at most 1	37.4795* 1.6191	20.2618 9.1645	1	Restricted constant
Tin					
	Hypothesized No. of Cointegration Relationships	Trace Statistic	5 per cent Critical Value	N. of lags in VAR	Deterministic Trend Assumption
1921-1929					
s_t , f_t^1	None at most 1	82.0492* 1.8175	20.2618 9.1645	3	Restricted constant
s_t , f_t^3	None at most 1	82.8599* 0.9883	20.2618 9.1645	1	Restricted constant
2000-2011					
s_t , f_t^1	None at most 1	182.2550* 0.04675	15.4947 3.8415	2	Linear deterministic trend
s_t , f_t^3	None at most 1	50.7235* 0.0573	15.4947 3.8415	2	Linear deterministic trend

Note: * denotes rejection of the null hypothesis at the 5 per cent level.