Aluminium Price Discovery on the London Metal Exchange, 2007-2017

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Abstract

The aim of the paper is to extend the analysis of aluminium price discovery on the London Metal Exchange (LME) beyond the 2007-2008 global financial crisis. To this end a VEC DCC-MGARCH model on the weekly sampled price series of spot and 3-month aluminium futures in the period 3/10/2007–27/09/2017 is estimated (10 years, 522 observations). The results of the study reveal that both prices exhibit a common stochastic trend and their spread have co-integrating properties. The hypothesis stating that they equally quickly revert to the long-run equilibrium relationship is rejected. An increased conditional volatility of their returns is observed during the crisis and after that a slightly decreasing albeit very close to unity their conditional correlation coefficient. Nevertheless, a constant conditional correlation hypothesis (CCC-MGARCH) is rejected. More interestingly, the term premium is likely to be proportional to the exchange rate of US dollar into British pound.

Keywords: *aluminium futures, London Metal Exchange, VEC DCC-MGARCH*

JEL Classification: G13, Q02

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1 Introduction

The beginning of the XXI century is a period of increasing role of the aluminium industry. Major primary aluminium producers are located in China, Russia, Canada, the Middle-East, Australia, Brazil and India. From 1998 to 2016 world smelter production of aluminium increased by approximately 161%. It is a result of rising demand for commodities from emerging markets – particularly China (40% share of aluminium production) and Russia (9%) (Nappi, 2013, p. 20).

Aluminium futures contracts are traded on a small number of specialized markets: the London Metal Exchange (LME), the Commodity Exchange of New York (COMEX) and the Shanghai Futures Exchange (SFHE). The LME competes with the SHFE to dominate in the aluminium price discovery. The total volume of aluminium futures traded on the LME in 2016 was more than 1.3 billion tonnes (53.1 mln lots), which makes the LME a market in which 90% of the world aluminium futures are conducted. Furthermore, from the late 90s aluminium has been the most heavily traded non-ferrous metal on the LME (Figuerola–Ferretti and Gilbert, 2005).

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The aluminium futures trading on the LME was introduced in October 1978 and actual – the high grade primary aluminium contract (AH) – in August 1987. From the mid of 1980s aluminium has been world-wide sold on the basis of LME quotations (Figuerola–Ferretti, 2005). The primary aluminium is sold in 25 tonnes lots (with a tolerance of +/-2%) in the shape of ingots, T-bars and sows. Price quotation is in US dollars per tonne (USD/t). All aluminium deliverable against LME contracts must be of an LME-approved brand. Premium futures contracts for aluminium were introduced on 23/11/2015. They enable market participants to take delivery of readily available material in non-queued warehouses.

The price setting process at the LME is a subject of intensive research. The recent papers on the issue are listed in Table 1. Most of the papers are focused on or before the 2007-2009 world financial crisis. The main findings include those that spot and futures prices are integrated of order one variables, co-integrated and their returns variances and covariances are time-varying. Some papers focus on correlations among the LME, the COMEX and the SHFE (Figuerola-Ferretti and Gilbert, 2005; Gong and Zheng, 2016), and other on correlations between aluminium and copper futures (Vu-Nhat, 2004; Figuerola-Ferretti and Gilbert, 2008).

Table 1. Literature review.

Study	Time period	Data freq.	Model	Main conclusions
Vu-Nhat (2004)	07/1995-07/2002	weekly	VAR	Spot, 3- and 27-month futures prices of aluminium and copper are co-integrated, aluminium and copper are likely to be substitutes
McMillan (2005)	01/1989-07/2003	daily	GARCH, GARCH-X	Returns variances and covariances are time-varying
Figuerola-Ferretti, Gilbert (2005)	01/1979-12/2003	monthly	VECM	LME aluminium price is more informative than Metal Bulletin price, LME price leads COMEX one (Granger causality), price discovery is on COMEX (permanent-transitory methodology)
Watkins, McAleer	02/1986-09/1998	daily	VAR	3 structural breaks, long-run relationship between spot and futures prices

(2006)				
Figuerola-Ferretti, Gilbert (2008)	10/1982-12/2005	daily	FIGARCH-VECM	Spot and 3-month aluminium and copper volatilities follow long memory processes, they exhibit a common degree of fractional integration, the processes are symmetric
Figuerola-Ferretti, Gonzalo (2010)	01/1989-10/2006	daily	VECM	Spot and futures prices are co-integrated, price discovery takes place in futures market
Gong, Zheng (2016)	04/1995-04/2013	daily	FISC[2]	LME and SHFE aluminium futures markets are more correlated in downturns than upturns

The aim of the paper is to extend the analysis of aluminium futures price discovery beyond the 2007-2008 global financial crisis and focus on the intra LME aluminium price setting in the recent decade. To this end a combined vector error correction and dynamic conditional correlation multivariate GARCH model (VEC DCC-MGARCH) on the weekly sampled price series of spot and 3-month aluminium futures in the period 3/10/2007–27/09/2017 (10 years, 522 observations) is estimated and several hypotheses related to their dynamics are tested. Weekly time series (Wednesdays) are used to avoid the day-of-the-week effects. Computations are performed using Microfit 5 and Stata 14 SE. The data comes from the Thomson Reuters. The remainder of the paper proceeds as follows. In section 2 the methodology is described. In section 3 the data and the empirical results are discussed. The last section briefly concludes.

2 Methodology

Assuming that the logs of futures and spot prices are co-integrated, on the base of risk premium model (Watkins and McAleer, 2006), a VEC DCC-MGARCH model (Johansen, 1995; Tse and Tsui, 2002) is specified:

$$\Delta la3_t = \sum_{k=1}^{p-1} \alpha_k^{(1)} \Delta la3_{t-k} + \sum_{k=1}^{p-1} \beta_k^{(1)} \Delta la0_{t-k} + \sum_{k=1}^{p-1} \gamma_{j,k}^{(1)} \Delta lex_{t-k} + \delta^{(1)} e_{t-1} + \xi_t^{(1)} \qquad (1a)$$

[2] FISC stands for fractionally integrated stochastic copula model.

$$\Delta la0_t = \sum_{k=1}^{p-1} \alpha_k^{(2)} \Delta la0_{t-k} + \sum_{k=1}^{p-1} \beta_k^{(2)} \Delta la3_{t-k} + \sum_{k=1}^{p-1} \gamma_{j,k}^{(2)} \Delta lex_{t-k} + \delta^{(2)} e_{t-1} + \xi_t^{(2)} \quad (1b)$$

$$e_t = la3_t - \phi_0 - \phi_1 la0_t - \phi_2 lex_t \quad (1c)$$

$$\xi_t = H_t^{0,5} v_t \quad (2a)$$

$$H_t = D_t^{0,5} R_t D_t^{0,5} \quad (2b)$$

$$R_t = diag(Q_t)^{-0,5} Q_t diag(Q_t)^{-0,5} \quad (2c)$$

$$Q_t = (1 - \lambda_1 - \lambda_2) R + \lambda_1 \Psi_{t-1} + \lambda_2 Q_{t-1} \quad (2d)$$

where : $la0_t, la3_t$ – log price of spot and 3-month futures contracts, x_t – exchange rate of US dollar into British pound, $\xi_t^{(i)}$ – error term, H_t – Cholesky factor of the time-varying conditional covariance matrix, v_t – vector of i.i.d innovations, D_t – diagonal matrix of conditional variances in which each element σ_{kt}^2 evolves according to a univariate GARCH(p_k, q_k) processes $\sigma_{kt}^2 = s_i + \sum_{j=1}^{p_k} \alpha_j^{(k)} \xi_{j,t-j} + \sum_{j=1}^{q_k} \beta_j^{(k)} \sigma_{k,t-j}^2$, R_t – matrix of means to which the dynamic process in Eq. (2d) reverts, Ψ_t – rolling estimator of the correlation matrix $\hat{\xi}_t$, λ_1, λ_2 – parameters that govern the dynamics of conditional correlations such that $0 \le \lambda_1 + \lambda_2 < 1$.

The model is estimated in two steps. First, the Johansen procedure is employed to identify co-integrating vectors. Second, the residuals from co-integrating relations are used to estimate a full VEC DCC-MGARCH with the maximum likelihood method. Then it is validated by testing:

1. Constant conditional correlations, VECM CCC-GARCH vs. VECM DCC-GARCH (H_0: $\lambda_1 = \lambda_2 = 0$), VC_1 – Wald test statistic under H_0 distributed as $\chi^2(2)$,
2. No return of conditional variances to their mean levels (H_0: $\lambda_1 + \lambda_2 = 1$), VC_2 – t test statistic under H_0 distributed as $N(0,1)$ in large samples,
3. GARCH(1,1) vs. IGARCH(1,1), IG – Wald test statistic under H_0 distributed as $\chi^2(2)$,
4. IGARCH in the variance equation for the price of contract maturing at time $t + k$, IG_k – Wald test statistics under H_0 distributed as $\chi^2(1)$,

Of the particular interest are hypotheses stating whether:

5. The price of futures contracts departures from their long run equilibrium relationship do not affect the current price of contract maturing at time $t+k$ ($H_0: \delta^{(i)} = 0$, $i = 1,2$), W_k – Wald test statistics under H_0 distributed as $\chi^2(1)$,
6. The price of futures contracts departures from their long run equilibrium relationship equally quickly revert to the long-run equilibrium relationship ($H_0: \delta^{(1)} = \delta^{(2)}$), W – Wald test statistics under H_0 distributed as $\chi^2(1)$.

Fig. 1. Log aluminium prices, la3, la0 (left axis) and log exchange rate, lex (right axis), 10/2007-9/2017.

Table 2. ADF-GLS and KPSS tests results.

Variable	**Test**							
	ADF-GLS				KPSS			
	Level	Lag	Trend	Lag	Level	Lag	Trend	Lag
$la0$	-1.90	13	**-3.17**	13	0.87	18	**0.90**	18
$la3$	-1.71	12	**-3.15**	13	0.93	18	**0.09**	18
lex	-0.19	18	-2.13	18	1.14	18	0.23	18
$\Delta la0$	**-2.37**	12	**-3.90**	12	**0.07**	18	**0.05**	18
$\Delta la3$	**-2.13**	12	**-3.73**	12	**0.07**	18	**0.05**	18
Δlex	**-3.70**	12	**-3.80**	17	**0.09**	18	**0.07**	18

The 5% critical values in the ADF-GLS test are obtained using the response surface approach with a proper augmentation to solve for autocorrelation of random errors if necessary: –1.96 (h=12), –1.96 (h=13), –1.95 (h=18) (level) and –2.84 (h=12), –2.84 (h=13), –2.82 (h=17), –2.82 (h=18) (trend), h – augmentation lag (see Cheung and Lai (1995)). Critical values in the KPSS test are: 0.15 (trend), 0.46 (level).

3 Data and empirical results

The empirical research starts with the analysis of logarithmic price series of spot and 3-month futures contracts ($la0$, $la3$) and exchange rate of US dollar into British pound (lex) against time (see Fig. 1.). As demonstrated the prices sharply fall in September 2008 due to the world's financial crisis originated by the collapse of Lehman Brothers Holdings Inc. Both prices rarely pass through their mean levels which suggests they are not stationary. The results of the ADF-GLS and KPSS tests are gathered in Table 2. They indicate that the log prices and log of exchange rate are integrated of order one variables.

Table 3. Maximal eigenvalue and trace tests estimation results.

Test									
Maximal eigenvalue					Trace				
Hypothesis		Test	Crit. value		Hypothesis		Test	Crit. value	
H_0	H_A	statistic	5%	10%	H_0	H_A	statistic	5%	10%
r=0	r=1	44.64	14.79	12.83	r=0	r≥1	45.18	17.79	15.83
r≤1	r=2	0.54	8.13	6.49	r≤1	r≥2	0.54	8.13	6.49

Co-integration with no intercepts or trends in the VAR.

The lag order $p = 1$ of the VAR system is set using AIC information criterion. Next, based on the maximal eigenvalue and trace test statistics, the existence of one co-integrating vector is identified (see Table 3). So the log prices of spot and 3-month aluminium futures at LME follow a common stochastic trend. Then, setting over identifying restrictions on the parameters of co-integrating vector, aluminium price spread are found to have co-integrating properties. Since the estimate of relevant likelihood ratio test statistic $LR(1)$ = 0.07 this hypothesis cannot be rejected at the 5 % significance level. Under H_0 the LR test statistic is asymptotically distributed as $\chi^2(1)$. Its 95 per cent bootstrap critical value is 4.55. The hypothesis stating that $\phi_2 = 0$ is rejected ($LR(1)$ = 35.54, under H_0 the LR test statistic is asymptotically distributed as $\chi^2(1)$, its 95 per cent bootstrap critical value is 7.39). The term premium is likely to be proportional to the exchange rate of US dollar into British pound. The estimated co-integrating vector is: $e_t = la3_t - la0_t - 0.030837lex_t$ and the VEC model consists of two equations: $\Delta la3_t = \delta^{(1)}e_{t-1} + \xi_t^{(1)}$ and $\Delta la0_t = \delta^{(2)}e_{t-1} + \xi_t^{(2)}$, where e_t are the residuals from co-integrating vector.

Table 4. VECM DCC-MGARCH estimation and validation results.

Variable/ Test stat.	**Equation** $\Delta la3_t$		$\Delta la0_t$	
	Coef.	Std. err.	Coef.	Std. err.
	Estimation results			
e_{t-1}	-0.32	0.17	-0.20	0.17
ξ_{t-1}	0.07	0.04	0.08	0.05
σ_{t-1}	0.83	0.10	0.80	0.11
cons	0.00	0.00	0.00	0.00
	Validation results			
Statistic	Estimate	p-value	Estimate	p-value
IG_k	2.50	0.11	3.21	0.07
W_k	3.53	0.06	1.30	0.25
	Residuals			
$LB(1)$	0.19	0.66	0.42	0.52
$LB(4)$	2.58	0.63	3.09	0.54
$LB(13)$	12.20	0.51	12.36	0.50
$LB(26)$	17.70	0.89	18.60	0.85
	Sq. of residuals			
$LB(1)$	0.45	0.50	0.42	0.52
$LB(4)$	5.06	0.28	4.47	0.35
$LB(13)$	10.48	0.65	9.95	0.70
$LB(26)$	21.06	0.74	17.68	0.89

IG = 4.15, VC_1 = 671.85, VC_2 =16.14, W = 19.97

The VEC DCC-MGARCH is estimated with maximum likelihood method (using AIC informational criterion the DCC-MGARCH(1,1) is set). The estimation and validation results are gathered in Table 4. They indicate that the mean and variance equations of VEC DCC-MGARCH model are properly specified as the Ljung-Box portmanteau test applied on standardized residuals from Eq. (1a)-(1b) and their squares shows that they are non-autocorrelated processes up to the 26th order (see the estimates of LB(k) – Ljung-Box portmanteau test statistic for autocorrelation of order up to k, under H_0 distributed as χ^2(k)). Second, a DCC-MGARCH is more likely than a CCC-MGARCH (VC_1 = 671.85). The hypothesis of integrated MGARCH is rejected only for the first equation at the 10% significance level (see the estimates of IG and IG_k test statistics in T4.). More interestingly, the hypothesis stating that the price departures from their long run equilibrium relationship do not affect the time t price of 3-month aluminium futures contract is rejected at the 10% significance level (see the estimates of W_3 test statistic in Table 4.). However, the same hypothesis cannot be rejected for spot contract (see the estimates of W_0 test statistic in Table 4.). The hypothesis stating that they equally quickly revert to the long-run equilibrium relationship is rejected (see the estimates of W test statistic in Table 4.).

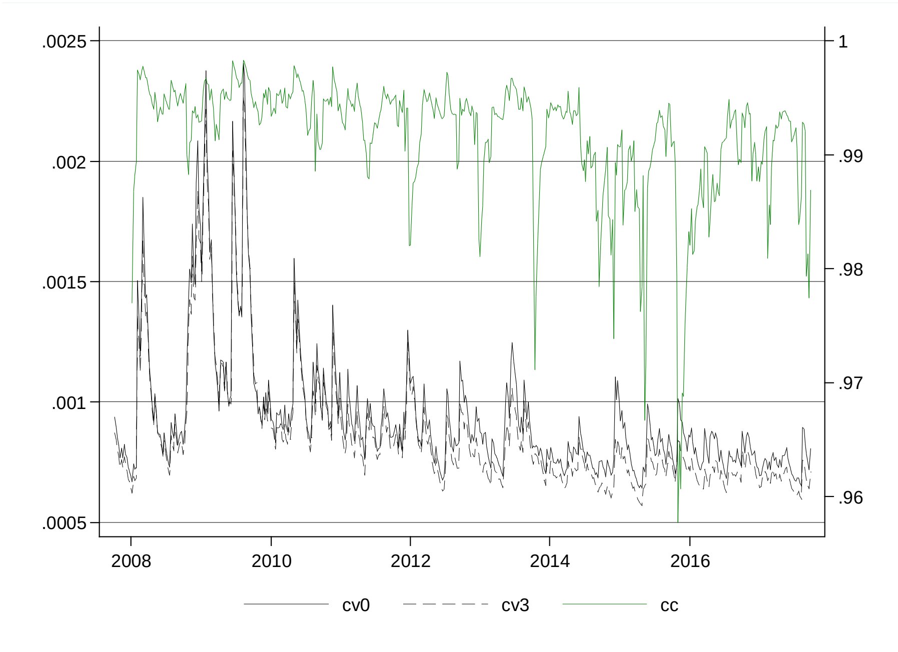

Fig. 2. Conditional correlation, cc (right axis) and conditional variances, cv0, cv3 (left axis) of the weekly log rates of return on aluminium futures prices at LME, 10/2007-9/2017.

Finally, the conditional correlation coefficient and conditional variances for the log rates of returns on spot and 3-month aluminium futures at LME are plotted in Fig. 2. There are 3 periods of an increased conditional volatility of the log returns between 2008-2010 resulting from stages of the crisis on financial markets. After 2010 the levels of conditional volatilities are smaller, but still sudden, though moderate, increases are locally observed. At all times their conditional correlation remain almost stable and is close to one, however two of its slightly different levels are observed before and after 2014.

Conclusions

In the paper the aluminium price discovery on the LME was analysed in the period 2007-2017. The results of the study reveal that the price series of spot and 3-month futures exhibit a common stochastic trend and their spread have co-integrating properties. Based on VEC DCC-MGARCH model the hypothesis stating that they equally quickly revert to the long-run equilibrium relationship is rejected. Moreover, 3 periods of an increased conditional volatility of their returns are observed during the crisis. After 2010 levels of conditional volatilities are smaller, but still sudden, though moderate, increases are locally observed. At all times their conditional correlation remain almost stable and is close to one, however two of its slightly different levels are observed before and after 2014. Nevertheless a constant conditional correlation hypothesis (CCC-MGARCH) is rejected. More interestingly, it is showed that the term premium is likely to be proportional to the exchange rate of US dollar into British pound.

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