COPPER PRICE AND EXCHANGE RATE DYNAMICS IN CHILE

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Abstract

This empirical study analyses the relationship and dynamics between the real copper price and the real Chilean peso/USD exchange rate. Chile adopted in 1999 a free-floating regime and its copper output represents 49% of the total exports. Therefore, the dynamics between these two variables largely affect Chilean's macro economy and important decision making such as large-scale mining investment. The study of Granger causality using Toda and Yamamoto (1995) procedure based on a Vector Autoregressive Model (VAR) demonstrates that exists a stable long-run relationship between the copper price and the Chilean peso (CLP), showing that latter has a robust power to forecast the copper price. This finding confirms CLP as a 'commodity currency.' However, copper price does not Granger cause the Chilean currency. Regarding the long-run behavior between the two variables, the Vector Error Correction Model (VECM) shows that their relationship is inverse. The CLP reverse to its long-run equilibrium at 6.02% monthly after a positive shock in the copper price, being eleven months the average half-life of a shock (HLS). Meanwhile, the copper price reverts 14.76% monthly due to innovations in the CLP with five months of HLS. The Impulse-Response function (IRF) analysis demonstrate that the variables respond in the very short-run to its shocks jumping, and gently decreasing in the successive periods. The perturbations never die out due to the stationarity of the series. Finally, the Forecast Error Variance Decomposition (FEVD) analysis has reinforced the idea that CLP has become more resilient to shocks in the metal because the variance which is attributable to price's innovations is just 25% in 24 months.

1 Introduction

This study analyses the relationship between real copper price and the real Chilean peso/US dollar exchange rate to understand its dynamics in the short-run and the long-run. Understanding the dynamics of this relationship can have a significant impact on macroeconomic policies and investment decisions such as mining projects in Chile. The Chilean economy is extremely dependent on copper exports. Therefore, it would be expected that the copper price would be a leading indicator of the country's exchange rate. However, this research demonstrates that the CLP has a robust forecasting power over copper price, while copper price does not have this power over CLP. This issue has been debatable among researchers, but the findings of this study are in line with authors such as Chen, Rogoff, and Rossi (2008) and Chen et al. (2014), but refutes Wu (2013), confirming that CLP constitutes a 'commodity currency.'

There exist many other important variables to address to understand the dynamics between copper price and the CLP such as how the variables involved influencing the other toward a long-run equilibrium? How long does this process take? How they react to shocks in the other variable? In this sense, this study delivers important information which is not extensively developed in the related literature. Nevertheless, this study is focused on the structural analysis of the relationship more than forecasting.

2 Background

Chilean history and copper are intimately related. During the early years of the 20^{th}-century, grand scale copper extraction had begun in the northern region. Two World Wars led Chile to become a major contributor to world copper output. In the early 1970s, during the nationalization of copper (expropriation of copper mining companies), the Chilean state created CODELCO, which is the world largest copper producer. In the early 1990s, Chile returned to democracy and its economy started an intense period of growth. A high proportion of this growth was due to the development of large-scale mining projects. Thus, Chile became the world largest copper producer.

According to the Chilean Copper Commission (2016), in 2015 the country produced 5.76million metric tonnes, accounting for 30% of the total world copper mine production (FIGURE 1). The participation of the mining industry in Chilean GDP between 2006 and 2015 averaged 14.3%. In the same period, authorized foreign investment was USD52.4billion (USD18billion realized). In 2015, mining exports represented 55% of total Chilean exports and copper accounted for 49%.

INSERT FIGURE 1 HERE

FIGURE 2 plots the importance of the mining industry in the Chilean tax collection. When copper prices are high, the Chilean state collects great amounts in taxes (i.e. 2006-2008; 2010-2012). However, when copper prices are low, the tax collected decreases (i.e. 2009, 2014, and 2015). As a consequence, the Chilean economy seems to be extremely dependent on copper price and impacted by its volatility. According to the U.S. Geological Service (2016), 30% of total world copper reserves are located in Chile. Thus, it is expected that copper exports will continue to be a major contributor to the Chilean economy in the future.

INSERT FIGURE 2 HERE

Chile conducts its monetary policy under flexible Inflation Targeting (IT) framework from 1999 (Claro and Soto 2013). In this context, a free-floating exchange rate is a significant input to make policy decisions. The exchange rate impacts the level and the stability of inflation directly among other relevant macroeconomic variables. In September 1999, Chile adopted the free-floating regime using the short-run nominal interest rate as its most important instrument of adjustment and the Central Bank of Chile (CBC) has been one of the most committed banks on exchange rate flexibility (Claro and Soto 2013). Therefore, the value of the CLP adjusts to shocks without almost no intervention. However, the free-floating exchange rate can also make the local economy vulnerable to external shocks.

3 Review of literature

There is limited literature which relates copper price and real Chilean peso/US dollar exchange rate. Chen, Rogoff, and Rossi (2008) argue that the ‘commodity currencies’ which include the Australian, Canadian, and New Zealand dollars, the South African rand, and the Chilean peso have strong power in forecasting global commodity prices. However, they also point out the contrary observation that commodity prices do not accurately forecast exchange rates. They found strong evidence of Granger-causality from the real exchange rates of these small economies to commodity prices. De Gregorio and Labbé (2011) study the impact of the copper price on the macroeconomic performance of Chile. Their paper focused on the understanding of the response of the Chilean economy to several external shocks including copper price. They found that the Chilean economy has become resilient to these shocks mainly due to its macroeconomic policies. Le Roux (2012) studies the relationship between the exchange rates of five of some of the so-called ‘commodity currencies’ that is Australia, Canada, Chile, China, and South Africa and the copper price. The study found strong evidence of a long-run relationship in four of the five currencies studied. The only exception was the Chinese Yuan. Wu (2013) investigates the variables that affect the movements of the Chilean exchange rate using a Vector Error Correction model. This study argues that copper price is a major determinant of the real exchange rate in the long run. The author also points outs that other factors such as interest rate differential, global financial distress, local pension funds' derivative position, and the Federal Reserve's quantitative easing affect the Chilean peso in the short-run.

Other literature also reviews the relationship between the exchange rate of some economies and important commodities in relative terms. Zhou (1995) studies the impact of externals shocks over the real exchange rate of Japan and Finland. Through Vector Autoregressive modeling, the author researches and tests the long-run response of the exchange rate of these two economies to these shocks. One interesting finding is the strong impact of the oil price over their currency. Chen and Rogoff (2002) examine the empirical behavior of the exchange rate of Australia, Canada, and New Zealand. In these economies, commodities share a substantial portion of their exports. The authors found that the price of their commodity exports has a tight relationship with their floating real exchange rates. They proposed that the results can be extended to other commodity-exporting economies. Cashin, Cespedes, and Sahay (2003) study the relationship between the real exchange rate and the real commodity price for fifty-eight commodity-exporting economies. The study showed that in two-fifths of this group of countries, evidence exists in support of a long-run co-movement among the exchange rates and commodity prices.

There are two recent studies which relate exchange rates and commodity prices. Haque, Topal, and Lilford (2015) investigate the relationship between iron ore price and the nominal Australian dollar (AUD). They examine the stability of this relationship and the existence of Granger causality through Vector Autoregressive models. They suggest the existence of a single-direction Granger causality from nominal iron ore price to nominal AUD/USD exchange rate. However, the nominal AUD/USD exchange rate does not Granger-cause movements in nominal iron ore price. They also conduct several other tests to understand the nature of this relationship. Finally, Chipili (2016) investigates the dynamics between the real copper price and the real kwacha/USD exchange rate (Zambia's currency). The study revealed the existence of long-run equilibrium. The author also points out that a positive shock in copper price leads to a long-run appreciation of the exchange rate, leading it to a new equilibrium. The main finding according to the author is that the kwacha constitutes a 'commodity currency.'

This study will be based on the most recent data available. Therefore it will constitute an updated revision of the Chen, Rogoff, and Rossi (2008) findings. Also, it will be focused only on the two variables and its reciprocal relationship; consequently the results will not have a comprehensive macroeconomic analysis as De Gregorio and Labbé (2011) did it. However, the analysis will be developed based on Vector Autoregressive (VAR) and Vector Error Correction (VEC) models which are more complex than the models used by Le Roux (2012).

4 Methodology and Data Description

In his Nobel Lecture, Granger (2004) explains that 'integrated' (non-stationary) series are those time series that does not present some desirable statistical properties, therefore unsuitable to conduct the standard statistical analysis. Lütkepohl (2005) defines a data generating process as stationary if it has time-invariant first and second moments. According to Giles (2016), the application of a test over data which is potentially integrated (or non-stationary) is unwise. The analysis based on 'spurious-correlation' can lead to wrong conclusions because this test does not follow an asymptotic chi-square distribution under the null hypothesis. Nevertheless, if a pair of integrated time series have a linear combination which is stationary, they are 'cointegrated.' As Granger (2004) explains the presence of cointegration generates many other interesting properties. For example, if two variables are cointegrated it is said that both are generated by an 'error-correction model' in which changes in one of the variables can be explained in relation with the lags of the difference between both series (Granger 2004).

To remedy the potential presence of integration, and conduct properly a Granger causality testing this study follows the Toda and Yamamoto (1995) procedure:

1) The natural logarithms of the real copper price (CUP) and real CLP/USD exchange rate (RER) will be tested to determine their order of integration using two unit root

tests: the Augmented Dicky-Fuller (ADF) and the Phillips-Perron (PP) test, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test to cross-check stationarity. At this stage, d_{max} will be the maximum order of integration found between the two series.

2) An unrestricted VAR model in the levels of the data (not differentiated) is set up. The appropriate maximum lag length of the model p is determined using the Akaike Information Criterion (AIC), the Schwarz Information Criterion (SIC), and the Hannan-Quin Information Criterion (HQ).

3) The obtained VAR model is checked to ensure that it is well-specified by analyzing its residuals to check for serial correlation. Otherwise, the lag lengths of the model would be increased. Other additional tests will be performed to ensure correct specification.

4) After obtaining a proper VAR model, Granger non-causality will be tested using the Engle and Granger (1987) approach. In this study, CUP is said to Granger-cause RER if RER can be better predicted using the histories of both CUP and RER than it can by using the history of RER alone or vice versa (Giles 2016).

Next, based on the obtained VAR model a VEC model will be built to study the short- and the long-run relationship between CUP and RER. Finally, using the same model we will analyze the Impulse Response Functions (IRFs) and the Forecast Error Variance Decomposition (FEVD) to understand the reaction of both variables to shocks in each other.

5 Model specification and estimation method

According to Lewis (1995), a standard asset-pricing model can be written as follows:

$$rer_t = (1-\theta)\sum_{j=0}^{\infty}\theta^j E_t f_{t+j} \quad (1)$$

where rer_t is a measure of the real exchange rate expressed in logarithms, f_{t+1} represents a set of 'fundamentals' expressed in logarithms, E_t represents the rational expectations operator based on available information and θ is the discount factor (Chipili 2016). The 'fundamentals' that define the value of the real exchange rate can include among others terms of trade, real interest rate differentials, productivity, and inflation (Cashin, Cespedes and Sahay 2003; Lewis 1995). However, as Cashin, Cespedes, and Sahay (2003) point out for a commodity-dependent country such as Chile, the fundamental determinant can be the commodity price. Therefore, Equation (1) can be rewritten to make it suitable for the Chilean economy. The estimated empirical model can be expressed as:

$$rer_t = \gamma_0 + \gamma_1 cup_t + \varepsilon_t \quad (2)$$

where rer_t is the logarithm of the RER; cup_t is the logarithm of the CUP and ε_t is the stochastic error term. To investigate Granger causality, Equation (2) can be written as a bivariate model generated by a VAR(p) as follows:

$$y_t = \nu + A_1 y_{t-1} + \cdots + A_p y_{t-p} + u_t \tag{3}$$

where $y_t = (rer_t, cup_t)'$, $\nu = (\nu_1, \ldots, \nu_K)'$ is a $(Kx1)$ vector of intercept terms, the A_i are (KxK) coefficient matrices, and u_t is white noise with non-singular covariance matrix Σ_u. As mentioned before, to determine the short- and long-run relationship between CUP and RER, a VEC model should be estimated. Equation (3) can be rewritten as a VEC as follows:

$$\Delta y_t = \nu + \prod y_{t-1} + u_t = \nu + \alpha\beta' y_{t-1} + u_t \tag{4}$$

where $t = 1,2, \ldots, p$; Δ is the difference operator; $y_t = (rer_t, cup_t)'$; $\nu = (\nu_1, \ldots, \nu_K)'$ is a $(Kx1)$ vector of intercept terms; Π is a (KxK) matrix of rank $r, 0 < r < K$, α and β' are (Kxr) with rank r, and u_t is two-dimensional white noise with mean zero non-singular covariance matrix Σ_u. According to Giles (2016) if the two variables are cointegrated there must be Granger causality between them, either one-way or in both directions. However, the converse is not true.

6 Sources of data

Copper is mostly traded in three commodity exchanges: The London Metal Exchange (LME), the Commodity Exchange Division of the New York Mercantile Exchange (COMEX/NYMEX) and the Shanghai Futures Exchange (SHFE) (International Copper Study Group 2015). From FIGURE 3, it can be observed that until 2003, real copper price oscillated around 4,300 USD/Mt. However, in early 2004 there was a structural break in the price. From then, the real copper price has been in a strong upward trend, interrupted briefly by the GFC in 2008. Between the end of 2010 and almost all 2011, the nominal copper price averaged 9,400 USD/Mt, and it reached its maximum historical nominal value at 9,868 USD/Mt in February 2011. Nominal prices have been falling since then, and real prices have fallen from 2014 to the present.

INSERT FIGURE 3 HERE

All the series included in this study are monthly observations dated from October 1999 when Chile adopted the free-floating exchange rate regime, to September 2016 (204 observations). The CUP was estimated using the nominal London Metal Exchange (LME) copper price grade A (USD/Mt) deflated by the World Bank Commodity Price Index for Base Metals (excluding Iron Ore; nominal US dollars, 2010=100), both series obtained from World

Bank (2016). The RER is calculated by deflating the nominal CLP/USD exchange rate (Observed dollar monthly average) by the Real Exchange Rate index-TCR (index average 1986=100), both series obtained from the Central Bank of Chile (2016). The CLP/USD exchange rate represents the amount of Chilean peso per one USD.

FIGURE 4 plots monthly data from October 1999 (1999m10) to September 2016 (2016m09) for both series. After applying natural logarithms, the data were normalized such that 1999m10=0. As can be observed from FIGURE 4, an inverse relationship appears to exist between the CUP and the RER. However, the real nature of this relationship will be determined in a more formal way in further analysis in this study.

INSERT FIGURE 4 HERE

7 Empirical Results

7.1 Unit root and Stationary tests for CUP and RER:

Several tests are performed to determine the order of integration of the series. TABLE 1, summarizes ADF and PP tests results for unit root testing and KPSS test results for stationarity. As noted from TABLE 1, all tests show that the series are non-stationary at the level (at 5% level of significance) and that both series are stationary at first differences. Therefore, both data generating process are Integrated order 1, I(1) in levels. The maximum order of integration of the series is set $d_{max} = 1$.

INSERT TABLE 1 HERE

7.2 VAR model estimation

Next, a VAR model of order p (VAR (p)) is estimated. The optimal lag length (p) is calculated using the AIC, the SIC, and the HQ. From TABLE 2, it can be observed that the three mentioned criteria define a lag order 2 (p=2). Thus, we set up our VAR model to a VAR(2).

INSERT TABLE 2 HERE

7.3 Testing the stability of the VAR(p) model

Several additional tests are performed to ensure the correct specification of the VAR(p) model. TABLE 3 shows the results of the Residual Serial Correlation Lagrange Multiplier Tests. As noted, the test rejects the null hypothesis (No serial correlation exists at lag order h), when applied to a VAR(2) (TABLE 3, lags h=7 and h=8). Moreover, the test rejects the null in the VAR(8) (TABLE 3, lag h=9).Finally, the test fails to reject the null when applied to a VAR(9) model. The results of this test imply that the VAR model has to be re-specified. Thus, the preferred VAR model is augmented to order 9 (p=9).

INSERT TABLE 3 HERE

The Stability Condition Test showed that the VAR(9) model is stable because all the roots lie inside the unit circle. The results of the test are presented in TABLE 4.

INSERT TABLE 4 HERE

Finally, the residuals of the VAR(9) model are tested under the Jarque-Bera test, Skewness test, and Kurtosis to determine if they are normally distributed. The majority of the tests reject the null hypothesis of the normal distribution of the residuals. In a bivariate framework, these irregularities can be due to different reasons such as omitted variables or multicollinearity because the information set is limited to the variables involved in the model. The only exception is the skewness of the copper price. TABLE 5 shows the results of the normality tests.

INSERT TABLE 5 HERE

7.4 Cointegration tests in a bivariate model

Johansen Cointegration Tests (Trace and Maximum Eigenvalue) are performed to investigate the existence of cointegration between the CUP and the RER. The tests are applied to a VAR(2) and VAR(9) models. As noted from TABLE 6, both tests reject the null hypothesis of no cointegration of the VAR(2) model at rank r=0, at 5% level of significance. However, the test fails to reject the null at rank=1.When the cointegration tests are applied to a VAR(9) model, they fail to reject the null at all the rank levels. However, as exists cointegration of the series in the VAR(2) model, we can indicate that exists cointegration between CUP and RER, therefore, there may be a long-run relationship between them.

INSERT TABLE 6 HERE

7.5 Granger (non)causality test

After checking the stability of the VAR(9) model and determining the existence of a long-run relationship between CUP and RER, the Wald test for long-run Granger causality (weak exogeneity) can be performed. According to Toda and Yamamoto (1995), the Wald test statistics will be asymptotically chi-square distributed with $k + d_{max}$ degrees of freedom under the null hypothesis (Null: X does not Granger-cause Y). Therefore, we test our model at $k + d_{max}$ degrees of freedom; where k is the lag order of the model $(k = 9)$ and d_{max} is the maximum degree of integration of the variables $(d_{max} = 1)$. TABLE 7 shows the results.

INSERT TABLE 7 HERE

The Wald test rejects the null hypothesis of non-Granger causality of real CLP/USD exchange rate (RER) to real copper price (CUP) at 5% level of significance (p-value equals 0.0184). However, the test fails to reject the null of non-Granger causality of the real copper price (CUP) to real CLP/USD exchange rate (RER) at 5% level of significance (p-value equals

0.1459). In summary, from the empirical results, we can conclude that it exists reasonable evidence supporting Granger causality from RER to CUP in the long run, but not vice versa.

7.6 Estimation of the VEC model

A VEC model is built to understand the nature of the relationship between CUP and RER. From Equation (4) we can distinguish the main elements of the model which can be written as:

$$\Delta rer_t = c_1 + \sum_{i=1}^{p-1} \delta_{1i} \Delta rer_{t-1} + \sum_{j=1}^{p-1} \psi_{1j} \Delta cup_{t-j} + \alpha_{11} ecm_{t-1} + \varepsilon_t \qquad (5)$$

$$\Delta cup_t = c_2 + \sum_{i=1}^{p-1} \delta_{2i} \Delta rer_{t-1} + \sum_{j=1}^{p-1} \psi_{2j} \Delta cup_{t-j} + \alpha_{21} ecm_{t-1} + \varepsilon'_t \qquad (6)$$

where c_1 and c_2 are constant terms; δ and ψ are the short-run matrices of coefficients; α_{11} and α_{21} are the error correction terms, and ε_t and ε'_t are the serially uncorrelated disturbances. TABLE 8 shows the vector of intercepts terms and TABLE 9 shows the short-run matrices of coefficients.

INSERT TABLE 8 AND TABLE 9 HERE

As observed, in the short run RER can be explained mostly due to its lags (1^{st}) (TABLE 9/Line 1) and small explanation comes from the lags of CUP (7^{th}) (TABLE 9/Line 3). On the other hand, according to the model CUP is influenced by the lags of RER (1^{st} and 7^{th}) (TABLE 9/Line 2) and explained by its lags just in the very short-run (1st) (TABLE 9/Line 4).

TABLE 10 reports the Error Correction term of the model which explain the long-run dynamics between RER and CUP. In Equation 1, we impose a restriction on RER. The VEC model indicates that under this condition, the adjustment coefficients are $\alpha_{(11)} = -0.060243$ and $\alpha_{(21)} = -0.14768$ respectively, both statistically significative at 5% level. The coefficient $\alpha_{(11)}$ indicates that in Chile 6.02% of the long-run deviation of the RER due to innovations in CUP is eliminated in one month. In other words, the average half-life of the reversion (HLS)[1] is 11 months. The coefficient $\alpha_{(21)}$ indicates that CUP the eliminates 14.76% of its long-run deviation due to innovations in RER in one month. The average half-life of the shocks in the CUP is 5 months. Therefore, CUP's reversion speed more than doubles RER's speed of reversion. Finally, the negative sign of this coefficient confirms that the long-run relationship between CUP and RER is inverse.

INSERT TABLE 10 HERE

7.7 The Impulse–Response Function (IRF) and Forecast Error Variance Decomposition (FEVD)

The Impulse Response Function (IRF) describes the reaction of one of the variables of the model to a one-time innovation in the other variable (external shock) (Hamilton 1994).

[1] Average half-life of a shock (HLS) is the time (T) required to dissipate 50% percent of a shock. Is determined according to: $(1-\Theta)^T = (1-x)$ where Θ is the coefficient of the error-correction term and T is the required number of periods (months) (Cashin, Cespedes and Sahay 2003).

FIGURE 5 plots the impulse responses of CUP and RER to Cholesky one standard deviation innovations in a twenty-four months period.

The first chart (left) shows the response of CUP to innovations. As can be observed, the CUP responds positively to its innovations jumping in the first two months, decreasing slightly in the consecutive months (dotted line). The long-run effect never dies out. On the contrary, CUP responses negatively to innovations in RER decreasing until the fourth month when reaches a plateau. After the sixth month, the effect tends to stabilize (continued line).

The second chart (right) depicts the response of RER to innovations. RER responds positively in the short-run to its innovations and the reaction never dies out (continued line). However, the response of RER to innovations in CUP is negative as well as weak (dotted line). These charts confirm that the relationship between CUP and RER is inverse. Therefore, a positive shock on copper price induces a decreasing in the RER i.e. an appreciation of CLP. Conversely, a negative shock on copper price leads to an increase in the RER i.e. a depreciation of the CLP. Also, it can be said that the persistence of the effects in the long-run reflects the nonstationarity of the system since one-time impulse can have permanent effects (Lütkepohl 2005; Hamilton 1994).

INSERT FIGURE 5 HERE

Hamilton (1994) defines the Forecast Error Variance Decomposition (FEVD) as the portion of the total variance of a variable (*y*) that is due to a disturbance in the other variable (*x*) in the system. From FIGURE 6, it can be noted that in the long run (24 months) 49% of the variance of CUP is explained due to disturbances in RER. However, only 25% of the variance of RER can be explained due to disturbances in the CUP in the same period. Therefore, the effect of RER on CUP's variance doubles the effect of CUP on RER's variance.

INSERT FIGURE 6 HERE

8 Conclusion

This study examined the dynamics of the relationship between real copper price and the real CLP/USD exchange rate over the period 1999m10 to 2016m09. To understand the underlying dynamics behind these two variables we built and tested a VAR(9) model. We tested Granger causality using the Toda and Yamamoto (1995) approach. The tests demonstrated a unidirectional relationship between the two variables with strong evidence of Granger causality from real CLP/USD exchange rate to copper price, but not vice versa. This finding is in line with previous studies such as Chen and Rogoff (2002) Chen, Rogoff, and Rossi (2008) and Chen et al. (2014). Nonetheless, contradicts the findings of Wu (2013) who argues that copper price has a very strong power to explain short-run and long-run movements in real CLP/USD exchange rate. As a result, this study has reinforced the Chilean peso as a 'commodity currency.'

This study has also demonstrated the existence of a stable long-run relationship between real copper price and the real CLP/USD exchange rate. The VEC model shows that real copper price can be better predicted using lags of real CLP/USD exchange rate. Moreover, the model also indicates that the Chilean economy, through its exchange rate, eliminates shocks produced by copper price at 6.02% monthly, reverting 50% of the shocks in 11 months towards its long-run level of equilibrium.

Finally, the analysis of the impulse responses shows a smooth reaction of Chilean peso to shocks in the copper price. The study demonstrates that only 25% of the variance of the Chilean peso can be attributed to disturbances on copper price in the long-run. This finding is in line with De Gregorio and Labbé (2011) who argue that the Chilean economy has become resilient to shocks in the copper price.

In conclusion, the empirical results from this study constitute a freshly updated analysis of the dynamics between copper price and real CLP/USD exchange rate. Policy makers and the mining industry in Chile should take these results into account for long-term economic planning. It is recommendable to conduct future research in the same field using, for example, MGARCH models which take into account some time-varying effects that can be affecting the normal distribution of the model's residuals.

9 References

Cashin, P., L. Cespedes, and R. Sahay. 2003. "Commodity Currencies." *Finance & Development* 40 (1): 45-48.

Central Bank of Chile. 2016. Parities and Exchange Rates. Accessed October, 2016, http://si3.bcentral.cl/estadisticas/Principal1/excel/EC/PARIDADES/excel_EN.html.

Chen, S., J. Jackson, H. Kim, and P. Resiandini. 2014. "What Drives Commodity Prices?" *American Journal of Agricultural Economics*: aau014.

Chen, Y., and K. Rogoff. 2002. *Commodity Currencies and Empirical Exchange Rate Puzzles*. Edited by Yu-chin Chen: International Monetary Fund.

Chen, Y., K. Rogoff, and B. Rossi. 2008. *Can Exchange Rates Forecast Commodity Prices?*

Chilean Copper Commission. 2016. Accessed 10/October/2016, http://www.cochilco.cl/.

Chipili, J. 2016. "Copper Price and Exchange Rate Dynamics in Zambia."

Claro, S., and C. Soto. 2013. "Exchange Rate Policy and Exchange Rate Interventions: The Chilean Experience." *BIS Paper* (73g).

De Gregorio, J., and F. Labbé. 2011. *Copper, the Real Exchange Rate and Macroeconimic Fluctuations in Chile*: Central Bank of Chile.

Engle, R., and C. W. J. Granger. 1987. "Co-Integration and Error Correction: Representation, Estimation, and Testing." *Econometrica* 55 (2): 251-276. doi: 10.2307/1913236.

Giles, D. 2016. Testing for Granger Causality. http://davegiles.blogspot.com.au/.

Granger, C.W. J. 2004. "Time Series Analysis, Cointegration, and Applications." *American Economic Review*: 421-425.

Hamilton, J. 1994. *Time Series Analysis*. Vol. 2: Princeton university press Princeton.

Haque, Md A, E. Topal, and E. Lilford. 2015. "Iron Ore Prices and the Value of the Australian Dollar." *Mining Technology* 124 (2): 107-120.

International Copper Study Group. 2015. The World Copper Factbook 2015. Accessed June, 2016, http://www.icsg.org/index.php/component/jdownloads/viewdownload/170/2092.

Le Roux, C. 2012. "The Co-Movement between Copper Prices and the Exchange Rate of Five Major Commodity Currencies." University of Johannesburg.

Lewis, K. 1995. "Are Foreign Exchange Intervention and Monetary Policy Related, and Does It Really Matter?" *The Journal of Business* 68 (2): 185-214. http://www.jstor.org/stable/2353112.

Lütkepohl, H. 2005. *New Introduction to Multiple Time Series Analysis*: Springer Science & Business Media.

Toda, H., and T. Yamamoto. 1995. "Statistical Inference in Vector Autoregressions with Possibly Integrated Processes." *Journal of econometrics* 66 (1): 225-250.

U.S. Geological Service. 2016. Accessed 10/October/2016, http://minerals.usgs.gov/minerals/pubs/commodity/copper/mcs-2016-coppe.pdf.

World Bank. 2016. Commodity Price Data (the Pink Sheet). Accessed October, 2016, http://www.worldbank.org/en/research/commodity-markets.

Wu, Yi. 2013. "What Explains Movements in the Peso/Dollar Exchange Rate?" *IDEAS Working Paper Series from RePEc*.

Zhou, Su. 1995. "The Response of Real Exchange Rates to Various Economic Shocks." *Southern Economic Journal* 61 (4): 936-954. doi: 10.2307/1060733.

10 Figures

Country	2014*	2015*
Chile	5,750	5,764
Peru	1,380	1,705
China	1,632	1,669
USA	1,383	1,373
Congo DR	996	1,039
Australia	965	957
Zambia	756	754
Russia	720	720
Canada	696	697
Indonesia	366	580
Others	3,835	4,008
Total world	18,479	19,266

* Thousand metric tonnes

Figure 1 Top 10 Countries, World Copper Producers.
Source: Chilean Copper Commission (COCHILCO)

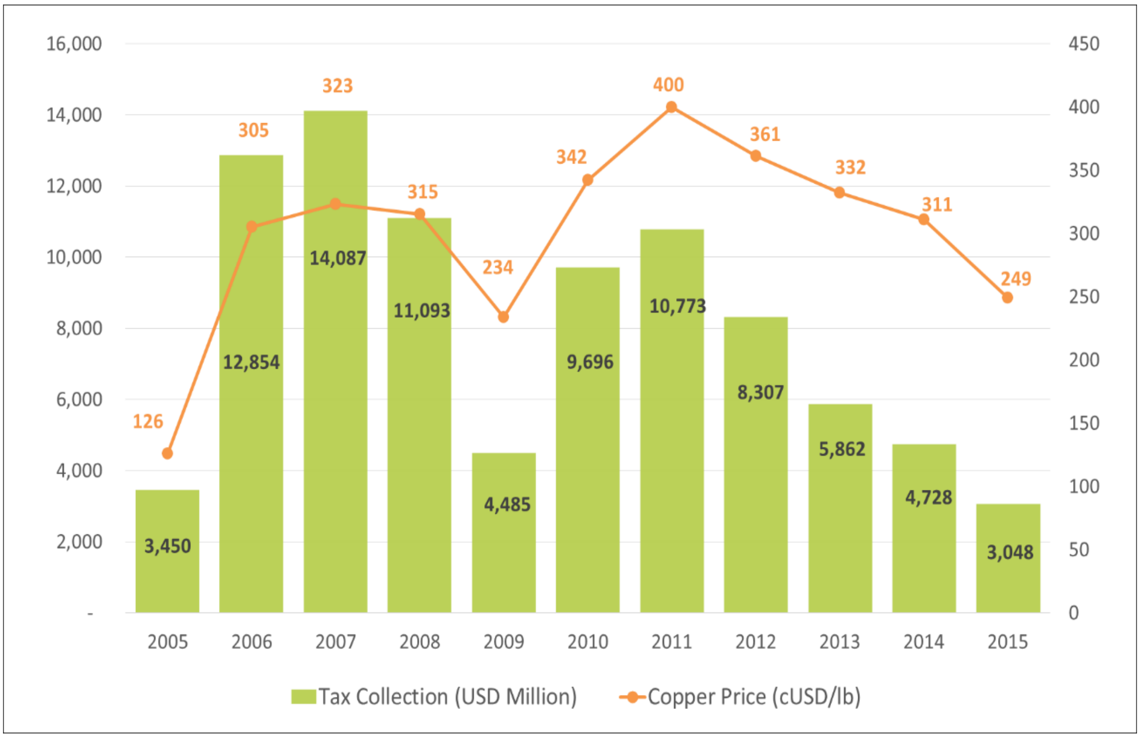

Figure 2 Tax collection in Chile. Period 2005-2015.
Source: Chilean Copper Commission (COCHILCO)

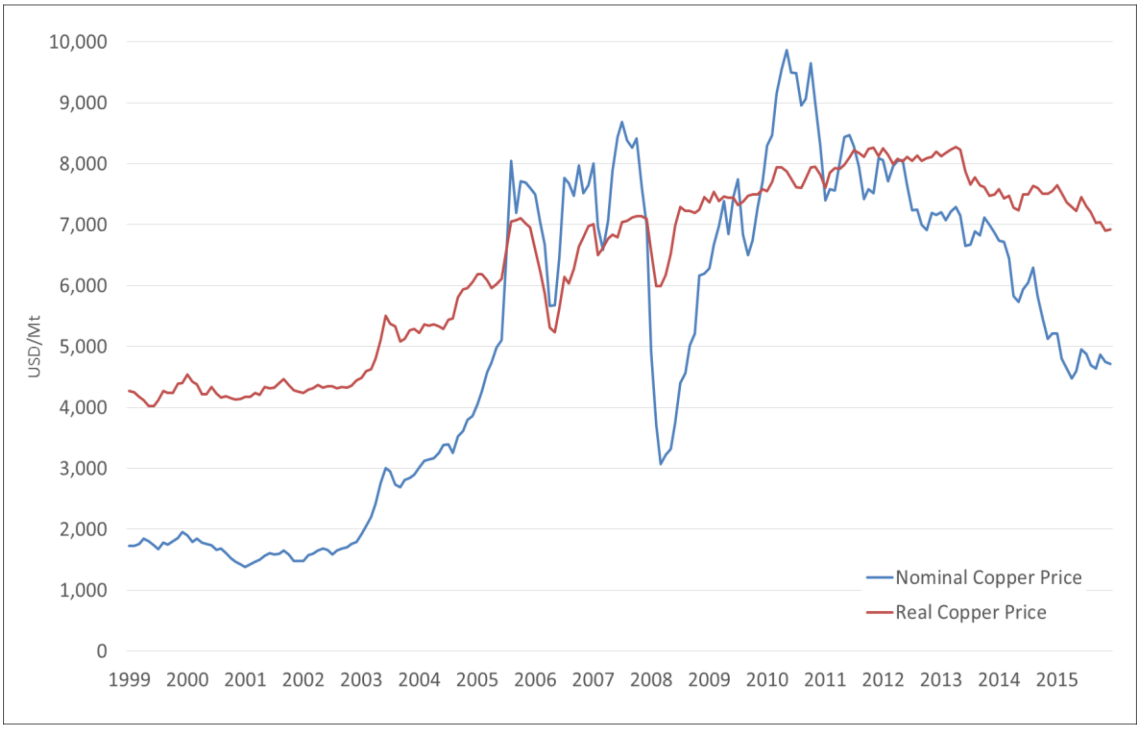

Figure 3 Nominal and real copper price (USD/Mt).
Period 1999m10–2015m09.
Source: World Bank (The Pink Sheet), 2016.

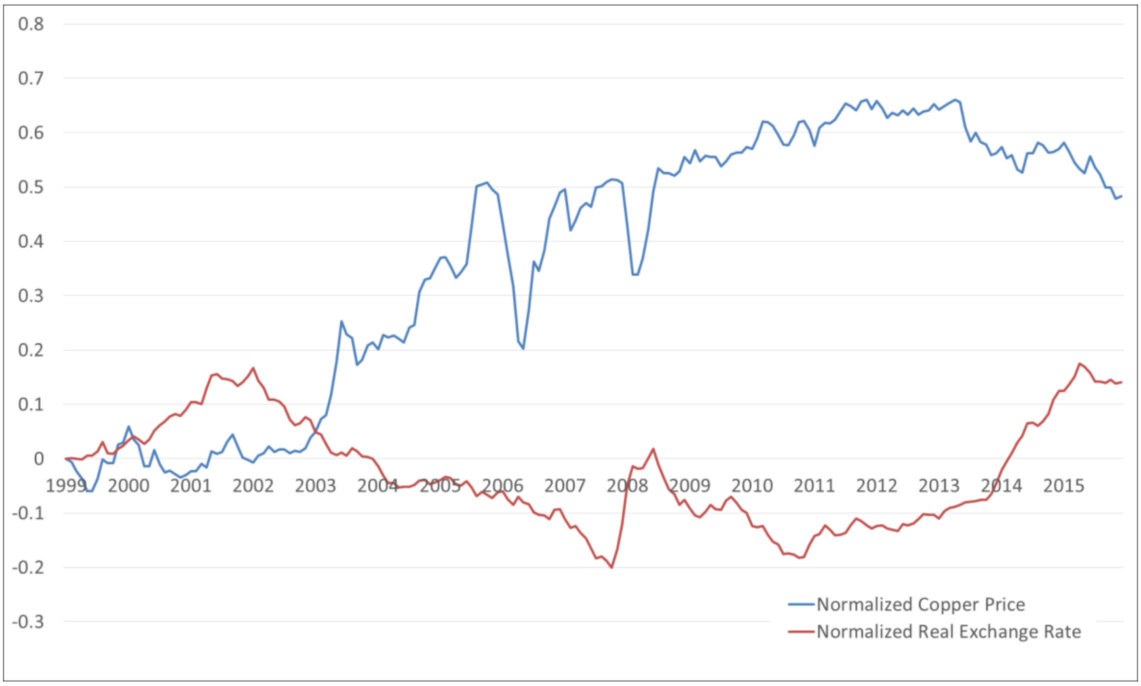

Figure 4 Normalized natural logarithm of copper price and real CLP/USD exchange rate.
Period 1999m10–2015m09.
Source: Author. Data from World Bank (The Pink Sheet), 2016.

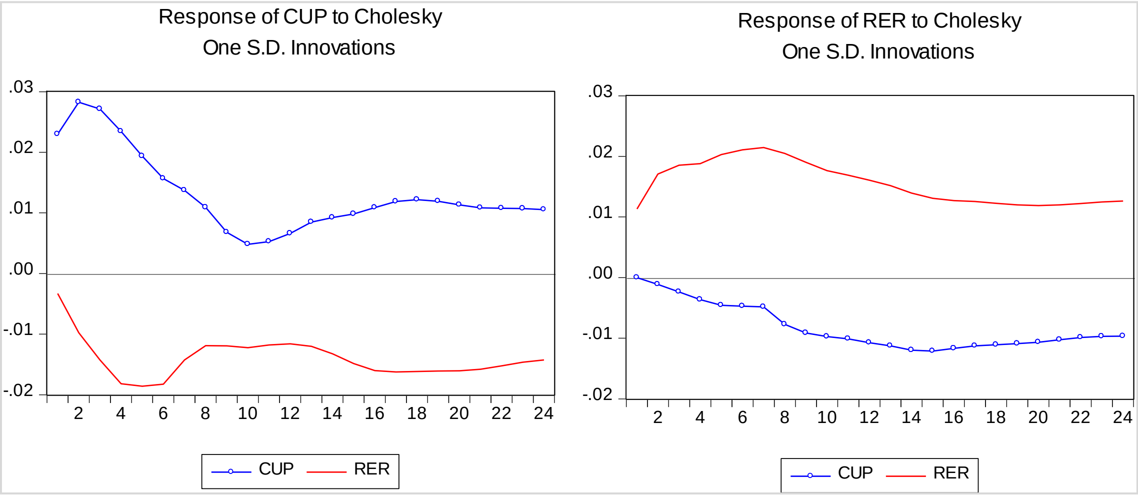

Figure 5 Impulse Responses to innovations (24 months).
Source: Author from Eviews.

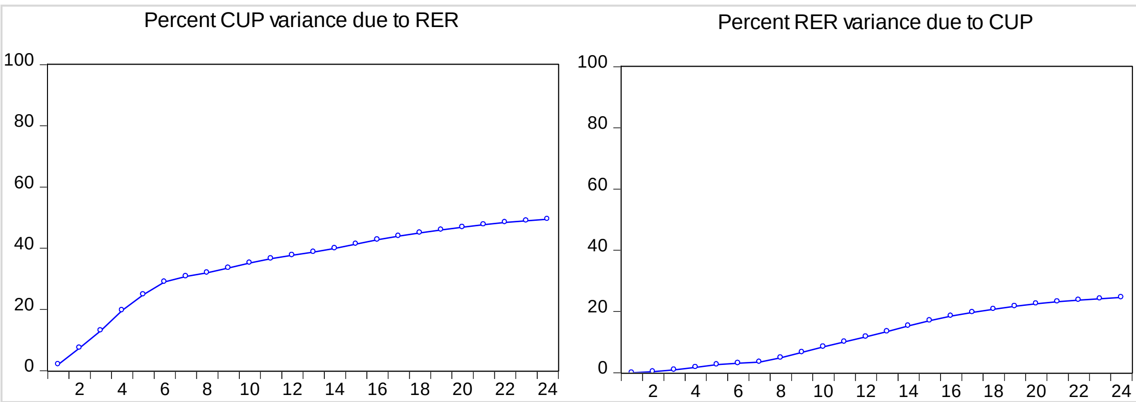

Figure 6 Variance Decompositions (24 months).
Source: Author from Eviews.

11 Tables

Table 1 Unit Root Tests and Stationarity Tests

In Levels-Unit Root & Stationarity Tests

		t-statistics							
		H_0: Series has a unit root						H_0: Series is stationary	
		ADF Tests (AIC)			PP Tests			KPSS Tests	
		None	Intercept	Intercept and trend	None	Intercept	Intercept and trend	Intercept	Intercept and trend
Series: CUP	Test statistic	1.8232	-1.7053	-2.0409	1.0099	-1.4937	-1.4690	1.6026	0.3478
Test critical values:	1% level	-2.5769	-3.4639	-4.0041	-2.5764	-3.4626	-4.0039	0.7390	0.2160
	5% level	-1.9425	-2.8762	-3.4322	-1.9424	-2.8756	-3.4321	0.4630	0.1460
	10% level	-1.6156	-2.5747	-3.1399	-1.6157	-2.5743	-3.1398	0.3470	0.1190
	Decision (5%)	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary
Series: RER	Test statistic	0.3510	-1.4440	-1.1396	0.4634	-1.0466	-0.6684	0.4750	0.2934
Test critical values:	1% level	-2.5766	-3.4632	-4.0048	-2.5764	-3.4626	-4.0039	0.7390	0.2160
	5% level	-1.9424	-2.8759	-3.4326	-1.9424	-2.8756	-3.4321	0.4630	0.1460
	10% level	-1.6156	-2.5745	-3.1401	-1.6157	-2.5743	-3.1398	0.3470	0.1190
	Decision (5%)	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary	Non Stationary

In First Differences-Unit Root & Stationarity Tests

		t-statistics							
		H_0: Series has a unit root						H_0: Series is stationary	
		ADF Tests (AIC)			PP Tests			KPSS Tests	
		None	Intercept	Intercept and trend	None	Intercept	Intercept and trend	Intercept	Intercept and trend
Series: CUP	Test statistic	-9.6328	-7.2150	-7.4932	-8.9637	-8.9877	-9.0313	0.1608	0.0616
Test critical values:	1% level	-2.5765	-3.4639	-4.0058	-2.5765	-3.4627	-4.0041	0.7390	0.2160
	5% level	-1.9424	-2.8762	-3.4330	-1.9424	-2.8757	-3.4322	0.4630	0.1460
	10% level	-1.6157	-2.5747	-3.1403	-1.6157	-2.5744	-3.1399	0.3470	0.1190
	Decision (5%)	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary
Series: RER	Test statistic	-5.1092	-5.1115	-8.0159	-8.2767	-8.2709	-8.3423	0.2618	0.1197
Test critical values:	1% level	-2.5766	-3.4632	-4.0044	-2.5765	-3.4627	-4.0041	0.7390	0.2160
	5% level	-1.9424	-2.8759	-3.4323	-1.9424	-2.8757	-3.4322	0.4630	0.1460
	10% level	-1.6156	-2.5745	-3.1399	-1.6157	-2.5744	-3.1399	0.3470	0.1190
	Decision (5%)	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary

Table 2 VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	226.1328	NA	0.000332	-2.334716	-2.300784	-2.320973
1	985.6544	1495.308	1.27E-07	-10.20473	-10.10294	-10.1635
2	1026.076	78.73724	**8.68E-08 ***	**-10.58412 ***	**-10.41446 ***	**-10.51541 ***
3	1028.028	3.762265	8.87E-08	-10.56279	-10.32527	-10.46659
4	1030.839	5.358771	8.98E-08	-10.55041	-10.24502	-10.42672
5	1034.821	7.507969	8.98E-08	-10.55022	-10.17697	-10.39905
6	1036.637	3.385634	9.19E-08	-10.52747	-10.08635	-10.34881
7	1040.025	6.247498	9.25E-08	-10.5211	-10.01211	-10.31496
8	1047.301	**13.26293 ***	8.94E-08	-10.55522	-9.978372	-10.32159
9	1052.017	8.497781	8.88E-08	-10.56267	-9.917961	-10.30156
10	1056.238	7.519808	8.86E-08	-10.56498	-9.852405	-10.27638
11	1056.679	0.775274	9.20E-08	-10.5279	-9.747462	-10.21182
12	1059.581	5.04921	9.31E-08	-10.51647	-9.668165	-10.1729

* indicates lag order selected by the criterion

LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

Table 3 VAR Residual Serial Correlation Lagrange Multiplier Tests

Lags	VAR(2)			VAR(8)			VAR(9)	
	LM-Stat	Prob		LM-Stat	Prob		LM-Stat	Prob
1	3.6047	0.4621		7.2994	0.1209		7.8670	0.0966
2	4.4221	0.3519		2.5051	0.6437		2.3084	0.6792
3	3.2510	0.5167		1.1316	0.8892		4.7038	0.3191
4	5.0680	0.2804		6.0369	0.1964		6.0363	0.1965
5	2.6970	0.6097		6.1036	0.1915		1.4228	0.8402
6	8.5001	0.0749		3.5288	0.4735		2.3817	0.6659
7	**12.2201**	**0.0158**	*	5.2679	0.2609		5.5684	0.2338
8	**10.1741**	**0.0376**	*	7.3092	0.1204		3.0748	0.5454
9	4.3968	0.3550		**9.5876**	**0.0480**	*	7.7757	0.1001
10	3.5514	0.4701		1.9228	0.7500		3.0035	0.5572
11	6.5330	0.1627		4.3329	0.3628		4.9400	0.2935
12	2.7864	0.5942		3.0057	0.5569		4.5000	0.3425

Null Hypothesis: No serial correlation at lag order h

* denotes rejection of the null hypothesis at 5% of significance level.

Table 4 Roots of Characteristic Polynomial

Root	Modulus
0.989013 - 0.011081i	0.989075
0.989013 + 0.011081i	0.989075
0.327711 + 0.828217i	0.890696
0.327711 - 0.828217i	0.890696
0.769857 - 0.407719i	0.871157
0.769857 + 0.407719i	0.871157
0.807434 - 0.268584i	0.850933
0.807434 + 0.268584i	0.850933
-0.376996 - 0.735933i	0.826876
-0.376996 + 0.735933i	0.826876
-0.673564 - 0.339339i	0.754214
-0.673564 + 0.339339i	0.754214
-0.143740 - 0.734213i	0.748151
-0.143740 + 0.734213i	0.748151
-0.746994	0.746994
0.330216 + 0.623332i	0.705398
0.330216 - 0.623332i	0.705398
-0.529148	0.529148

No root lies outside the unit circle.

VAR satisfies the stability condition.

Table 5 Residual Tests
Multivariate Normality Tests

Jarque-Bera test

Component		χ^2	df	Prob.
reer		40.34774	2	0.0000
cup		16.63641	2	0.0002
Joint		56.98416	4	0.0000

Skewness test

Component	Skewness	χ^2	df	Prob.
reer	0.46919	7.15452	1	0.0075
cup	- 0.24953	2.02356	1	0.1549
Joint		9.17807	2	0.0102

Kurtosis test

Component	Kurtosis	χ^2	df	Prob.
reer	5.02122	33.19322	1	0.0000
cup	4.34108	14.61286	1	0.0001
Joint		47.80608	2	0.0000

Notes for normality tests:

Orthogonalization: Cholesky (Lutkepohl)

Null Hypothesis: residuals are multivariate normal

Table 6 Unrestricted Cointegration Rank Tests

Lags	Rank	Eigenvalue	Trace			Maximum Eigenvalue		
			Trace Statistic	Critical Value (5%)	Prob.**	Max-Eigen Statistic	Critical Value (5%)	Prob.**
2	r=0	0.116285	26.88168	25.87211	**0.0374***	24.84766	19.38704	**0.0072***
	r=1	0.010068	2.034021	12.51798	0.9666	2.034021	12.51798	0.9666
9	r=0	0.067643	16.72171	25.87211	0.4360	13.58775	19.38704	0.2829
	r=1	0.016025	3.133962	12.51798	0.8602	3.133962	12.51798	0.8602

Indicates 1 cointegrating eqn(s) at the 5% level

* denotes rejection of the hypothesis at the 5% level

**MacKinnon-Haug-Michelis (1999) p-values

Table 7 VAR Granger Causality/Block Exogeneity Wald Tests

Null hypothesis	χ^2	Prob.
H_0: Real copper price (CUP) does NOT Granger cause real CLP/USD exchange rate (RER)	13.38687	0.1459
H_0: Real CLP/USD exchange rate (RER) does NOT Granger cause real copper price (CUP)	19.91585	**0.0184** *

* denotes rejection of the null hyphotesis at 5% of significance level.

Table 8 Vector of Intercept Terms Vector Error Correction Model

	Intercept
Δrer	-0.000163 [-0.17754]
Δcup	0.001915 [1.01701]

* t-statistics are reported in [ ]

Table 9 Short–run Matrices of Coefficients Vector Error Correction Model

	Line	Δrer(t-1)	Δrer(t-2)	Δrer(t-3)	Δrer(t-4)	Δrer(t-5)	Δrer(t-6)	Δrer(t-7)	Δrer(t-8)
Δrer	1	0.554803 **[7.55967]****	-0.0969 [-1.20095]	0.058382 [0.71979]	0.153235 [1.88229]	-0.015694 [-0.19148]	0.079991 [0.97518]	-0.073926 [-0.89666]	-0.034936 [-0.46416]
Δcup	2	-0.357965 **[-2.38098]****	0.105068 [0.63566]	-0.138983 [-0.83645]	0.172468 [1.03416]	0.04362 [0.25979]	0.358404 **[2.13291]****	0.020127 [0.11917]	-0.106446 [-0.69035]

	Line	Δcup(t-1)	Δcup(t-2)	Δcup(t-3)	Δcup(t-4)	Δcup(t-5)	Δcup(t-6)	Δcup(t-7)	Δcup(t-8)
Δrer	3	0.005542 [0.14847]	0.038445 [0.98980]	0.019183 [0.49699]	0.034974 [0.91351]	0.054436 [1.43940]	0.031745 [0.84475]	-0.078071 **[-2.08232]****	0.060187 [1.65268]
Δcup	4	0.366026 **[4.78669]****	0.008854 [0.11127]	-0.013453 [-0.17014]	-0.022377 [-0.28532]	-0.012 [-0.15489]	0.042924 [0.55758]	-0.032116 [-0.41815]	-0.133564 [-1.79031]

* t-statistics are reported in [ ]

** denotes statistical significance at 5% level

Table 10 Vector Error Correction Terms

Vector Error Correction Model

Equation 1	Adjustment Coefficients	rer(t-1)	cup(t-1)	@TREND(99M10)	Intercept
Δrer	$\alpha_{(11)}$: -0.060243 **[-2.43095]****	1	0.91962 **[9.47980]****	-0.002909 **[-6.86070]****	-14.12840
Δcup	$\alpha_{(21)}$: -0.14768 **[-2.90898]****				

* t-statistics are reported in [ ]

** denotes statistical significance at 5% level