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Testing for multiple bubbles in the copper price: Periodically collapsing behavior

Chi-Wei Su\textsuperscript{a}, Xiao-Qing Wang\textsuperscript{b,*}, Haotian Zhu\textsuperscript{c}, Ran Tao\textsuperscript{d}, Nicoleta-Claudia Moldovan\textsuperscript{e}, Oana-Ramona Lobont\textsuperscript{e}

\textsuperscript{a} School of Economics, Qingdao University, Qingdao, China
\textsuperscript{b} Department of Finance, Ocean University of China, Qingdao, China
\textsuperscript{c} School of Engineering and Applied Science, University of Pennsylvania, USA
\textsuperscript{d} Qingdao Municipal Center for Disease Control & Prevention, China
\textsuperscript{e} Department of Finance, West University of Timisoara, Romania

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\section*{ABSTRACT}

This study investigates whether multiple bubbles exist in the copper price on the basis of the Generalized Supremum Augmented Dickey-Fuller (GSADF) approach (Phillips et al., 2013). This technique delivers date-stamping strategies for the emergence as well as collapse of explosive bubble episodes and is best suited for practical application to time series. The results reveal that four explosive bubbles are detected over the period of 1980–2019 when copper price deviates from fundamental value. Besides, this finding is in accordance with the asset pricing model (Gürkaynak, 2008), which generally considers both fundamental and bubble components in the presence of asset prices. Based on the empirical results, the multiple emergence and collapse of multiple price bubbles are attributed to speculation, depreciation of the U.S. dollar, an imbalance between supply and demand, and financial crises. Policymakers should actively recognize bubble episodes and monitor their evolution, which could be conducive to achieving the effective stabilization of the international copper price. To reduce excess price fluctuations and explosive copper bubbles, authorities should impose restrictions on excessive speculative behavior under extreme market conditions.

\section{Introduction}

This study explores the mildly explosive behavior in copper prices and detects the origination and termination of bubble episodes. As one of the most widely used metals, copper plays a critical role in many industries, including electrical wiring, building construction and machinery manufacturing (Wu and Hu, 2016). Over recent decades, global copper prices have undergone drastic fluctuations with general characteristics of extreme upward and downward movements (Chen, 2010). Copper also serves as one of the major metal commodities in physical futures exchanges, including the London Metal Exchange (LME), the New York Commodity Exchange (COMEX), and the Shanghai Futures Exchange (SHFE) (Lasheras et al., 2015). With the move to exchange-based pricing, nonferrous metals, such as copper and aluminum, have been increasingly perceived as an investable asset class and are widely included in investment portfolio allocation, which triggers concerns about volatile price fluctuations and bubble-type patterns (Todorova, 2015).

Given the strategic nature of this resource, which is extensively used in various fields of the worldwide economy, the copper price can be considered a crucial indicator of global economic performance (Buncic and Moretto, 2015). Excessive fluctuations and bubbles in the copper price may cause significant negative welfare effects among market participants (Cochran et al., 2012). Specifically, copper-importing countries are potentially subject to balance-of-payment problems and endure negative inflationary and growth pressure (Todorova et al., 2014). Copper-exporting countries suffer from adverse implications for tax revenues and reduce incentives for investments in copper production, further weakening economic confidence (Bova, 2012). Furthermore, developing countries whose domestic economies rely principally on copper productions, including Chile and Zambia, have successively given its price movements a national strategic status (Lasheras et al., 2015). In Zambia, copper exports contribute to over 70% of total export earnings and approximately 70% of total foreign exchange, according to

\begin{itemize}
\item \textsuperscript{*} Corresponding author. Department of Finance, Ocean University of China, 238, Songling Rd., Qingdao, Shandong, China.
\item E-mail address: awxiaqing@163.com (X.-Q. Wang).
\end{itemize}

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Bova (2012). Volatile and cyclical prices may heavily deteriorate economic stability and spark political unrest, which highlights the necessity of exploring the features of copper price movements and explosive bubbles (Watkins and McAleen, 2004; Liu et al., 2017).

Bubbles are observable economic phenomena that are routinely considered to be economic cycles characterized by a rapid expansion followed by a contraction. According to Brunnermeier and Nagel (2004), bubbles are typically accompanied by a drastic rise in prices followed by a collapse. Based on rational expectation theory, if market participants buy a range of assets purely in expectation that they can sell at higher prices, market prices will far exceed fundamental values, fostering speculative bubbles (Stiglitz, 1990). Following Gürkaynak (2008), bubbles are described as a dramatic increase in prices, with the initial rise that generates the expectation of further rises and attracts new buyers by a process usually referred to as irrational exuberance. According to Flood and Garber (1980), price bubbles may exist when prices are propelled by arbitrary and self-fulfilling elements in expectations. As proven by Irwin and Sanders (2011), bubble episodes are typically related to negative welfare effects for various agents, which highlight the importance of monitoring multiple bubbles in the copper price.

With the rise of the financial attribute of commodities, copper is no longer merely perceived as a pivotal manufacturing input but is also viewed as a profitable investment asset possessing enormous speculative space (Büyükşahin and Robe, 2014). Following Tadesse et al. (2014), it is widely accepted that economic recessions tend to be preceded by asset bubbles. If the existence of copper price bubbles is identified, the price dynamics will not reflect the efficient operation of the market. The distorted price signals have considerable detrimental implications for industrial production as well as portfolio strategies and risk management, intensely aggravating instability and uncertainty for manufacturers and investors (Mayer, 2012). Furthermore, copper price overshooting induced by speculation may provoke excessive hoarding behaviors and trigger resource misallocation, which dramatically reduces the allocation efficiency of the market (Irandon, 2017). Finally, once copper bubbles burst, price maladjustment could drastically deteriorate the trade balance, exposing market participants to serious welfare losses (Bova, 2012; Liu et al., 2017). Therefore, in view of the possibility of bubble behavior affecting real allocation in the economy, tracking the evolution of copper price bubbles is of great importance and impact for policymakers and academics. Deriving the relevant policy implications has become a high-priority issue in informing the appropriate global institutional arrangements to prevent market failures (Kriebhaumer et al., 2014).

The paper proceeds as follows: Section 2 reviews the related literature. Section 3 outlines the asset pricing model and presents the adopted methodology. Section 4 describes the corresponding data. Section 5 discusses the empirical results. Section 6 concludes.

2. Literature review

A number of previous studies have endeavored to determine the main drivers of the value of the copper commodity as well as the reasons behind price bubbles, since dramatic fluctuations in the copper price have an appreciable impact on the overall economic situation (Atienza and Modrego, 2019). Following standard microeconomic theory, the supply and demand situation ultimately results in price fluctuation, influencing the fundamental values of nonferrous metals (Boschi and Pieroni, 2009). Figueiredo-Ferretti et al. (2015) and Fernandez (2019) assert that the recent copper super cycle ensued upon an unexpected surge in demand that could not be satisfied by existing production capacity. Considering the low price elasticities of demand and supply of copper, relatively minor shocks may induce sharp spikes and high volatility (Buncic and Moretto, 2015). Under the condition of abundant reserves, copper supply shocks, which are usually associated with price upsurges, are primarily driven by labor disputes, low inventory levels and political unrest (Todorova et al., 2014).

From the demand perspective, accompanying the advent of accelerated industrialization and urbanization, explosive demand growth in emerging countries like China has drastically boosted price for copper, which is used as a pivotal input in manufacturing (Jerrett and Cuddington, 2008; Irandon, 2017). Nevertheless, in the context of the commodity financialization, the key role of excessive speculation in pushing price above the level justified by market fundamentals has been highlighted in the copper market (Behm and Manera, 2015). In addition, the U.S. dollar has been a contributing factor to additional volatility since the international copper price is typically denominated in it (Buncic and Moretto, 2015). Dutta (2018) indicates that oil shocks significantly impacts metal price fluctuations and that market returns exhibit jump dynamic behavior, which may be a sign of possible crashes. As illustrated by Shao et al. (2013), the supply and demand fundamentals of copper might be incapable of explaining the drastic price movements, while the non-fundamental factors, such as speculation and appreciation/depreciation in U.S. dollar, also induce excessive fluctuations. Multiple bubble episodes may come into existence in case global copper price is deviated from the fundamentals (Mayer et al., 2017).

The important role of speculation is increasingly highlighted in promoting bubble behaviors since copper commodities are regarded as investable assets (Figueroa-Ferretti and Mccrorie, 2016). Commodities are broadly included in investment strategies, for the superiority of low correlations with equities and bonds, diversification benefits of portfolios and effective hedging properties against inflation (Hammoudeh et al., 2013). Chen et al. (2019) confirm that the financial property of copper is increasingly prominent and its price volatility can be fully explained by financial factors. Considering the special merit of recyclability and suitability for storage, copper is increasingly included in the investment portfolio as a substitute for precious metals during times of uncertainty (Buncic and Moretto, 2015; Mayer et al., 2017). Zhou and He (2011) provide evidence that copper price contains a substantial speculative component which that potentially indicates explosive bubbles. Babalos and Stavroyiannis (2015) illustrate that metal prices are susceptible to information spillovers from financial markets stemming from speculative actions and facilitating excessive volatility and price bubbles. Caporin et al. (2015) assert that spikes in the international copper market are amplified by speculative behaviors, leading to complex and nonlinear price movements with a significant level of risk perceived. Additionally, Chen et al. (2019) confirm the finding that the price movements of copper present the characteristics of structure dissimulation and nonlinearity. Adams and Glick (2015) consider that sharp increases in noncommercial long positions turn a commodity investment into a self-fulfilling success, promoting the explosiveness of price bubbles. Mastroeni et al. (2018) demonstrate that the copper price time series presents a typical pattern of intermittency, indicating the possible existence of bubble-related value. Additionally, the copper price distortion may further spillover to other metal markets, which contributes to joint and persistent bubbles (Sensoy, 2013; Tweneboah, 2019). According to Gorton and Rouwenhorst (2006), as a new type of market participants with the development of financialization, commodity index traders (CITs) achieve the goals in regard to reducing portfolio risk and capturing risk premiums by utilizing long-only commodity index funds. Shao et al. (2013) confirm that CITs provide strong incentives for accentuating explosive price bubbles in the international copper market, triggering concerns about price-manipulating behaviors. Furthermore, in the presence of capital controls and financial frictions, metal commodities, including copper, are pledged as collateral for financing to capture high expected returns in importing countries, inducing transitory explosive bubbles (Tang and Zhu, 2016).

Bubble detection has been explored in depth owing to the disastrous consequences of its explosive process. Commonly used econometric detection techniques include the two-step test (West, 1987) and cointegration-based test (Diba and Grossman, 1988). Nevertheless, the empirical validity of these methods has been questioned (Brenner and
Kroner, 1995). Yiu et al. (2013) argue that the bubble component detected by the variance bounds test could be ruled out by other reasonable factors. Due to the dependence on the strength of underlying equilibrium models, the rejection of the no-bubble hypothesis indicated by the two-step test may be caused by model misspecification rather than mildly explosive bubble episodes. Phillips and Yu (2011) reveal the defect of unit root and cointegration tests in examining explosive property given that the Dickey-Fuller statistics diverge to minus infinity when obtained from the full sample. Moreover, conventional cointegration approaches are demonstrated to have limited power in examining explosive behaviors that collapse periodically. The reason for their low power is that if the probability of collapse cannot be negligible, the periodic process is proven to manifest as a stationary linear autoregressive or I(1) process (Evans, 1991). Therefore, more effective techniques should be applied to detect the existence of multiple copper bubble episodes considering the high volatility and frequent explosive behaviors.

This paper contributes to existing literature with regard to price behavior of copper in several respects. First, by obtaining accurate recognition for multiple bubbles, this study not only has significant implications on the formation as well as nature of copper bubble behaviors but also explores the driving forces behind copper bubbles, which has not been covered in the existing literature but is of vital importance to policymakers in implementing precautionary policies. Todorova (2015) and Chen et al. (2019) illustrate the course of realized volatility in nonferrous metal markets, but they do not refer to explosive bubble behaviors in the copper market. Figuerola-Ferretti et al. (2015) observe explosivity in metal markets, but the influencing factors behind bubbles are not explained. Our findings highlight the crucial role of financial factors such as depreciation of the U.S. dollar and excessive speculation in explaining multiple bubble episodes of emergence and collapse. In particular, we provide an innovative assessment of whether multiple collapsing behaviors exist in the international copper market. In addition, we elaborate the implementation of other techniques to investigate existence of multiple bubble behaviors.

3. Methodology

This paper utilizes the asset pricing model (Lucas, 1978) to conduct the theoretical analysis of identifying multiple bubbles from market fundamentals. In line with the theory developed by Tirole (1985), the conception that commodity prices may deviate from market fundamental values due to mildly explosive behaviors is widely accepted. As indicated by Gürkaynak (2008), fundamental prices of the copper commodity are derived from the no-arbitrage condition:

$$P_t = (1 + r_t)^{-1} E_t[\delta_{t+1} + U_{t+1}]$$  \hspace{1cm} (1)

where $P_t$ and $E_t$ indicate the copper price and expectation in period $t$, $r_t$ is the free-risk rate, and $\delta_{t+1}$ and $U_{t+1}$ indicate returns and the invisible component in period $t + 1$. By forward iteration, the equation is expressed as:

$$P_t = \left(1 + r_t\right)^{-1} E_t[B_{t+1}]$$  \hspace{1cm} (2)

where $P_t$ represents the fundamental price of copper and $\delta_{t+1}$ represents the returns in period $t + i$. Equation (2) states the determinants in fundamental value. In turn,

$$B_t = \left(1 + r_t\right)^{-1} E_t[B_{t+1}]$$  \hspace{1cm} (3)

which is any sequence of random variables that generally satisfies the homogeneous expectation equation. As a result, Equation (1) is expressed as:

$$P_t = P'_t + B_t$$  \hspace{1cm} (4)

Equation (4) decomposes the copper price into the market fundamental component, $P'_t$, and the bubble component, $B_t$. Prices may exceed market fundamentals as a result of the expectation that agents could sell at higher prices. It should be noted that the path of bubbles is not unique. Equation (4) indicates a different path for each possible value of the original bubble level, since it restricts the law of motion for nonfundamental component in commodity prices. When $B_t = 0$, the equation indicates that explosive behaviors do not exist. Otherwise, in the case of $B_t$ with a nonzero value, bubble episodes do not terminate until explosion due to expectations. Accurate recognition and prediction of multiple bubbles is of vital importance to policymakers in implementing precautionary policies.

On the basis of the theoretical analysis of identifying multiple bubbles from market fundamentals, this study further implement the SADF and GSADF techniques to investigate existence of multiple bubble behaviors in the international copper market. In addition, we elaborate the Backward Sup Augmented Dickey-Fuller (BSADF) statistic sequence that is utilized to locate the origination and termination of each bubble. Finally, we further explore the role of macroeconomic determinants of copper bubble behaviors and confirm the relative importance of each factor.

Evans (1991) has proven that when periodically collapsing behaviors exist in time series, traditional approaches are not effective in examining bubble episodes. The stationarity tests with an explosive alternative hypothesis are based upon standard ADF and Phillips-Perron tests. In the model

$$\Delta P_t = \alpha + \beta P_{t-1} + \sum_{i=0}^{k} \gamma_i \Delta P_{t-i} + \epsilon_t \sim NID(0, \sigma^2)$$  \hspace{1cm} (5)

where $P_{t-1}$ represents the logarithmic copper price, $k$ represents the number of lags, and $NID$ indicates an independent and normal distribution. The null hypothesis is $\hat{\beta} = 1$, implying $P_{t-1}$ is unit root process, while the alternatives $\hat{\beta} > 1$ signify the presence of mildly explosive behaviors. Nevertheless, according to Evans (1991), traditional tests
possess limited power in exploring periodically collapsing bubbles. Phillips and Yu (2011) propose utilizing the supremum value of ADF T-statistics, which are recursively determined to address the drawback. The SADF test estimates the ADF model repeatedly on a forward-expanding sample sequence. The window size \( r_w \) ranges from \( r_0 \) to 1. The starting point \( r_1 \) is fixed at 0, and then the ending point \( r_2 \) equals \( r_w \), which changes from \( r_0 \) to \( r_1 \). The SADF statistics can be expressed as

\[
\text{SADF}(r_w) = \sup_{r_2, r_1 \in (r_0, r_1)} \{ADF_{r_1}^w\}
\]

(6)

Moreover, the GSADF method further utilizes flexible window widths, given the weakness of the SADF technique in dealing with the origin and collapse of multiple bubbles. The GSADF method not only varies the ending point from \( r_0 \) to 1 but also alters its starting point \( r_1 \) from 0 to \( r_2 - r_0 \). The GSADF statistic is denoted by GSADF\((r_w)\). That is,

\[
\text{GSADF}(r_w) = \sup_{r_2, r_1 \in (r_0, r_1)} \{ADF_{r_1}^w\}
\]

(7)

The existence of bubbles can be confirmed when the GSADF statistic is greater than the critical value obtained from Monte Carlo simulations. When the model includes an intercept and the null hypothesis is a random walk, the limit distribution of the GSADF statistic is:

\[
\sup_{r_2, r_1 \in (r_0, r_1)} \left\{ \frac{1}{2} r_w \left[ \frac{w(r_2)^2}{w(r_1)^2} - w(r_1)^2 - r_w - \int_{r_1}^{r_2} w(r) dr \right] \right\}^{1/2}
\]

(8)

where \( r_w = r_2 - r_1 \). We acquire the asymptotic critical values by numerical simulations and calculate the finite sample distributions by bootstrap methodology. This technique is not affected by a possible explosive root of the determinants of the copper price, and it provides a date-stamping strategy.

Moreover, the BSADF statistic sequence is obtained by implementing the right-tailed ADF test on backward-expanding sample sequences to locate the emergence and termination of each bubble. BSADF statistic is defined as:

\[
\text{BSADF}(r_w) = \sup_{r_2, r_1 \in (r_0, r_1)} \{ADF_{r_1}^w\}
\]

(9)

Based on the obtained BSADF statistic, the starting and ending dates for the \( k \)-th bubble (i.e., \( r_w \), and \( r_1 \)) are, respectively, defined as:

\[
\tilde{r}_w = \inf_{r_2, r_1 \in (r_0, r_1)} \left\{ r_2 : \text{BSADF}_{r_1}^w(r_0) > \text{CS}_{r_1}^w \right\}
\]

(10)

\[
\tilde{r}_1 = \inf_{r_2, r_1 \in (r_0, r_1)} \left\{ r_2 : \text{BSADF}_{r_1}^w(r_0) < \text{CS}_{r_1}^w \right\}
\]

(11)

where \( \text{CS}_{r_1}^w \) is the 100(1-\( \beta_1 \))\% critical value of the sup ADF statistic based on \( T_{R_2} \) observations from Monte Carlo simulations and \( \delta \) depends on data frequency.

Utilizing the date-stamping procedure developed above, this study detects the existence of multiple bubbles and estimates the origination and termination of each explosive episode. Based on the timeline of exuberance in the international copper market, this paper further investigates the role of macroeconomic determinants in copper bubbles. Following Li et al. (2017), to represent the bubble testing results for the copper commodity, we define \( R_t \) as:

\[
R_t = \begin{cases} 
0, & \text{if } \text{BSADF}_{r_0}(t) < \text{CS}_{r_0}^w \\
1, & \text{if } \text{BSADF}_{r_0}(t) > \text{CS}_{r_0}^w 
\end{cases}
\]

(12)

where \( t = 1, 2, \ldots, T \). According to Equation (12), \( R_t \) equals 1 when a bubble is detected on the \( t \)-th date and 0 otherwise.

Using the bubble variable \( R_t \) as the dependent variable, we next employ a standard probit model to explore the influences of driving forces on bubble formations in international copper market. Based on relevant studies, the formation of bubbles is determined by supply and demand fundamentals and influenced by financial factors such as speculation and the U.S. dollar index (Bosch and Pradkhan, 2015; Chen et al., 2019). Therefore, the basic model specification is expressed as:

\[
R_t = X_t \beta + \mu_t
\]

where the vector \( X_t \) represents macroeconomic factors that affect bubble behaviors in the international copper market, including copper supply (CS), copper demand (CD), the interest rate (IR), the U.S. dollar index (USD), and speculation (FS). Therefore, the probit model is described by:

\[
P(R_t = 1|X_t) = \Phi(X_t \beta)
\]

(14)

where \( \Phi(\cdot) \) is the standard normal cumulative distribution function. The parameters are estimated by maximizing the full-sample log likelihood function:

\[
\ln L = \sum_{t=1}^{T} [\ln \Phi(X_t \beta)] + \sum_{t=1}^{T} (1 - R_t) \ln [1 - \Phi(X_t \beta)]
\]

(15)

In a probit model, a parameter estimate only provides information on the direction of the effect through its sign. The marginal effect for variable \( X_t \) is further calculated based on the following formula:

\[
\frac{\partial P(R_t = 1|X_t)}{\partial X_j} = \phi(X_t \beta) \beta_j
\]

(16)

where \( \phi(X_t \beta) \) is the standard normal density. Based on marginal effects, we can confirm the extent of the impact of macroeconomic determinants on bubble occurrences in the international copper market.

4. Data

This paper applies LME copper spot prices covering the period from January 1980 to May 2019 to explore the formation of multiple mildly explosive episodes in the copper market. The data used in our tests are obtained from the International Monetary Fund database, which has been available to the public since January 1980. The LME copper price is widely recognized as the major international benchmark for the copper pricing mechanism, which reflects supply and demand conditions worldwide (Watkins and McAleer, 2004; Lasheras et al., 2015). As for macroeconomic factors, copper supply, copper demand, the interest rate and dollar movements are represented by global refined copper production, global refined copper consumption, the federal funds rate and the U.S. dollar index, respectively. According to Chen et al. (2019), changes in global copper supply and demand can be reflected by global refined copper production and global refined copper consumption, which are obtained from the International Copper Study Group. The federal funds rate and the U.S. dollar index data are obtained from the Wind database. Following Bosch and Pradkhan (2015), we use the noncommercial net long position to measure speculative activity (FS), which is calculated as follows:

\[
FS_t = \frac{NC\text{L}_{t} - NCS_{t}}{\text{TOL}_t}
\]

(17)
countries, in conjunction with rapid industrialization and urbanization in Asia, caused a continuous, strong upsurge in the international copper price (Pauliuk et al., 2013; Rossen, 2015). Moreover, the global financial crisis in 2008 and the European sovereign debt crisis in 2011 triggered panics of collapse in the worldwide economy because of financial contagion, contributing to a sharp price crash in the global copper market. The low interest rates and quantitative easing policies implemented by the Federal Reserve after the economic recession in 2008 generated upward pressure on the copper price (Baffes and Savescu, 2014). In addition, the emergence of new financial market participants such as index-based investment funds and speculators has also amplified the variability of the global copper price (Humphreys, 2010). All these changes may lead to furious price fluctuations, implying the possible existence of copper bubbles.

As displayed by Fig. 1, the copper price has experienced significant fluctuations since the 1980s. After decreasing steadily but slowly from 1980 to 1986, the copper price rose sharply to peak at almost $3500 per ton in 1988 and then fell back due to increased supply. Subsequently, it fluctuated moderately until the end of 2003 within a range of $1377 to $3076 per ton. By 2004, the copper price started on a dramatic upward trend, ultimately rising to a primary peak in May 2006 and to a secondary peak in July 2007. After a temporary decline, it rose sharply again to a record high of $8714 per ton in April 2008, increasing over 250%. Then, as the global financial crisis unfolded, the international copper price plunged substantially to as low as $3105 per ton at the end of 2008. With the re-emergence of sharp upward tendency, copper price skyrocketed to an even higher peak at nearly $9900 per ton in February 2011, which exceeded the level reached in 2008. Subsequently, the copper price returned to a continuous decreasing process again with the characteristic of high volatility. Given the violent fluctuations, it is considered that the copper price is likely to contain multiple bubble episodes.

5. Empirical results

The SADF and GSADF techniques are applied in this paper to test the existence of multiple copper bubbles. The SADF and GSADF statistics, with the respective sample critical values, are recorded in Table 1. The statistics of both tests are 5.959 and 8.524, which exceed their 1% right-tailed critical values, respectively. According to the results, the null hypothesis is rejected at the 1% significance level, which reveals that there are multiple episodes of explosive behavior in the copper price. On the basis of SADF and GSADF techniques, we conclude that exuberance exists in the international copper market, which allows us to investigate the possible existence of bubble episodes.

According to the results of the BSADF test, we graph the estimate of the copper price with 95% confidence intervals in Fig. 2 to locate multiple bubble episodes. The upper curve presents the international copper price. The middle curve presents the 95% critical value. The bottom curve represents the BSADF statistics. The starting point of a bubble is defined as the first observation at which the BSADF statistic is greater than the critical value obtained from Monte Carlo simulations, while the ending point is the first observation after the starting date at which the BSADF statistic is smaller than the critical value. We focus on the origination and collapse of explosive behaviors and detect four copper price bubble episodes during the sample period. The technique exhibits greater window flexibility since it covers more subsamples. According to this argument, we can provide evidence for multiple bubbles in the international copper market and explore possible reasons behind them.

Table 2 offers further information with regard to the length and magnitude of four bubble episodes examined in the international copper price. In terms of bubble length, the bubble behaviors that occurred in 1987, 2004, and 2011 proved to be short-lived, with respective durations of 7, 4, and 4 months. The bubble episode that occurred in 2008 covers the longest period, lasting 41 months. In addition, it is concluded that the four bubble periods occurred when the copper market experienced dramatic price variations. In particular, the starting point of the longest bubble episode coincides with a price change

![Fig. 1. LME copper spot price, January 1980 to May 2019.](image)

![Fig. 2. BSADF test of the copper price. Note: the shadows are sub-periods with bubbles.](image)

| Bubble periods | Length (Months) | Δ?? start to peak (%) | Δ?? peak to end (%) |
|----------------|-----------------|-----------------------|--------------------|
| 1987M10-1988M04| 7               | 45.740                | -20.308            |
| 2004M01-2004M04| 4               | 23.903                | -2.443             |
| 2005M03-2005M07| 41              | 138.515               | -12.398            |
| 2011M01-2011M04| 4               | 3.648                 | -4.030             |

Note: Bubble length is identified by the BSADF test with 95% critical values from a recursive bootstrap procedure.
magnitude of 138.515%. Moreover, copper bubbles generally occur when the price soars and burst when the price drops sharply.

We further apply the probit model to explore how macroeconomic determinants affect bubble behavior and the relative importance of each contributing factor. Specifically, copper supply, copper demand, the interest rate, dollar movements and speculation are represented by global refined copper production, global refined copper consumption, the federal funds rate, the U.S. dollar index and the noncommercial net long position, respectively. According to Table 3, the absolute value of the log likelihood statistic exceeds the 5% critical value, indicating strong explanatory power of the variables. Consequently, we further illustrate the impact of each variable in details.

First, the coefficient of copper supply is confirmed to be negative and statistically significant, suggesting that copper supply has a negative regulatory effect on the occurrence of bubbles. The marginal effect suggests that the likelihood of a price bubble increases by 4.8% for a unit decrease in copper supply. When physical supply decreases and is even lower than demand, the insufficient supply puts upward pressure on the copper price, raising the likelihood of bubble occurrence. Second, we find that an increase in copper demand raises the likelihood of price bubbles, complementing similar findings in commodity market (Figuerola-Ferretti et al., 2015; Li et al., 2017). Specifically, the expansion of copper demand by 1% increases the likelihood of a price bubble by approximately 10.3%. Considering short-term copper productions are inelastic, increased demand might contribute to large movements in the copper price, which supports explosive behavior (Bosch and Pradkhan, 2015). Third, the interest rate is confirmed to negatively affect bubble occurrence. Nevertheless, the impact of the interest rate is statistically insignificant. Fourth, the result suggests bubble behavior is more likely to occur when the dollar depreciates. Since the international copper price is typically denominated in U.S. dollars, changes in the dollar’s value inevitably result in fluctuations in the copper price and promote mildly explosive price behavior (Chen et al., 2019). Moreover, the depreciation of the U.S. dollar prompts investors to seek alternative approaches to asset allocation, including commodities, contributing to the rapid influx of funds into the commodity market (Hammoudeh et al., 2013). The rapid increase of trading capital leads to a surge in the copper price, which promotes the formation of price bubbles. Finally, speculation is demonstrated to exert a positive effect on bubble occurrences. With the financialization of commodity markets, increasingly more financial speculators participate in commodity futures markets. Financial speculators affect price fluctuations and bubble behaviors via noncommercial positions (Chen et al., 2019). In the case of the expectation of further rises, speculators buy a range of copper futures, leading to increases in noncommercial net long positions (Mayer et al., 2017). In this context, speculators destabilize market prices by triggering positive feedback trading among trend followers who ignore fundamental information and buy futures as prices rise, which pushes up the international copper price and raises the likelihood of price bubbles (Bosch and Pradkhan, 2015).

Table 3

| Variable | Coefficient | Std. error | Z-Statistic | Marginal effect |
|----------|-------------|------------|-------------|----------------|
| CS | -0.120* | 0.065 | -1.78 | -0.048 |
| CD | 0.306** | 0.128 | 2.39 | 0.103 |
| IR | -0.164 | 0.133 | -1.23 | -0.063 |
| USD | -0.167** | 0.077 | -2.15 | -0.065 |
| FS | 0.368** | 0.160 | 2.30 | 0.143 |
| Intercept | -0.863 | 0.763 | -1.13 | |

LR statistic 57.53
Log likelihood -312.416
Prob > Chi-Square 0.000

Note: * and ** denote significance at the 10% and 5% significance levels, respectively.

On the basis of the date-stamp bubbles in the international copper market, this paper further links the four bubble episodes to macroeconomic determinants. The first bubble originated in October 1987 and collapsed in April 1988, lasting nearly seven months. The price bubble was driven more by supply than by demand, in consideration of the massive supply disruptions and capacity constraints in major copper-producing countries. As reported by the U.S. Geological Survey (USGS, 1932–2011), Chile has the largest reserves of potentially realizable copper (28%), followed by Peru (13%), Australia (12.5%) and the United States (5%). Since 1987, the copper output of key producing countries such as Peru, Chile and Zambia has experienced a continuous decline due to a series of episodes of political unrest or mine depletion (Todorova et al., 2014). In addition, the U.S. copper industry cut production capacity by 15%, implying potential supply shocks. By the end of 1987, a nationwide strike by Peru’s largest labor federation sharply reduced export supply and drove the massive price surge (Crowson, 1988). Therefore, worldwide inventory level fell drastically from 1987 to 1988, which resulted in the emergence of a supply shortfall of approximately 170,000 tons in 1988 (Humphreys, 1988). Moreover, along with the weakening of the U.S. dollar since 1987, metal costs at the margin rose strongly in dollar terms and further generated upward pressure on the copper price, contributing to the substantial increase to peak at almost $2900 per ton in December 1988 (Crowson, 1988). In general, supply disruptions limit production responses from keeping pace with growing demand, ultimately driving the copper price from its fundamental value and fostering the occurrence of bubbles. In pace with the continuing growth of global supply, facilitated by the reactivation of idle capacity and new investments in production, the copper price gradually decreased, followed by the bursting of the bubble.

The second bubble arose in January 2004 and crashed in April. As illustrated by Lasheras et al. (2015), commodity booms are regularly concomitant with positive market fundamentals and worldwide economy development. After the trough of the cyclical recession in 2001–2002, the accelerated process of global economic recovery and sustained industrial expansion from 2003 gave strong impetus to robust demand in the international copper market (Irandoust, 2017). Specifically, with the implementation of a series of easy policies (low interest rates and tax cuts), U.S. gross domestic product (GDP) grew sharply by 4.4% in the first quarter of 2004, which substantially stimulated copper demand in industrial manufacturing. The Japanese economic recovery was also unexpectedly strong, with growth of 3.7% in 2004, the highest level since 1991, which enlarged the effective need for commodities including copper. Following the recovery from the severe acute respiratory syndrome (SARS) outbreak in late 2003, Chinese GDP grew by 9.8% in the first quarter of 2004, mainly supported by strong investment growth, dramatically fostering the increase in domestic copper consumption. Meanwhile, global copper inventories experienced a sharp decline as a result of capacity constraints, which led to insufficient supply to meet expanding consumption demand (Figuerola-Ferretti et al., 2015). Overall, the imbalance between rigid supply and explosive demand gave an impetus to the surge in the copper price during this phase. Furthermore, abundant global liquidity associated with low interest rates triggered massive capital inflows to the copper market, further driving the price upswing above fundamental value and fueling the bubble-type pattern (Baffes and Savescu, 2014). Until the second quarter of 2004, higher prices and projections of a continued shortfall in production gradually encouraged reactivations of idle capacity and investment in the mining industry, easing the tight supply situation. In addition, the growing expectation of soaring U.S. interest rates contributed to declining investor participation in the copper market, resulting in the bubble’s burst.

The third bubble is observed to begin in March 2005 and crash in July 2008. This episode lasted over three years, which is proved to be the longest bubble period. From 2005, the international copper price experienced a continued, substantial surge from $3168 per ton to over $8000 per ton, followed by a high and volatile trend. The copper price...
subsequently plummeted by almost 65% within just half a year after the global financial crisis. This bubble-type trend is largely attributable to huge demand shocks, given the sharp rise in demand for industrial metals, particularly in emerging economies. The drastic demand growth of copper in developing regions, including developing Asia, Latin America and Africa, has exerted tremendous force on the explosive price surge as they pass through the industrialization and urbanization stages (Jerrett and Cuddington, 2008). Given that growth in industrializing countries tends to be highly metal intensive, demand for copper also increases substantially, even exceeding the economic growth rate (Humphreys, 2010). In the case of China, due to growing demand from large infrastructure projects, it has become one of the world’s largest consumers of copper, accounting for approximately two-fifths of global consumption and playing a significant role in the global copper boom (Northey et al., 2014). In 2006, the Chinese government announced the 11th national Five-Year Plan for accelerating urbanization and revitalizing the manufacturing industry and invested RMB800 billion for the construction of a power grid, contributing to enormous copper demand and driving the price up. Against this background of tight supply and demand situations, the sustained depreciation of the dollar in 2007 induced huge capital inflows into the copper market and exacerbated the substantial rising trend to take the international copper price to its peak, triggering the occurrence of a bubble (Bunicic and Moretto, 2015). Moreover, copper commodity futures allow market participants to hedge against increased uncertainty and diversify portfolio risk through alternative investment tools, which induces an exponential increase in fund inflows and price deviations from fundamentals (Demiray and Ulusoy, 2014). Speculators and financial arbitrageurs gravitate toward commodity assets including copper for their low correlations with equities, thereby heavily amplifying the variability and uncertainty in the international copper market (Sensoy, 2013). In general, the financialization of commodities may distort price signals and contribute to persistent and significant bubbles (Boschi and Pieroni, 2009). The copper price then dramatically plummeted, mainly affected by substantial downward revisions in global growth forecasts as a result of the economic crisis; this price decline ultimately contributed to the bursting of the bubble.

The last bubble appeared in January 2011 and collapsed in April. The copper price dramatically rose again to an almost 30-year-record high in February 2011, which exceeded the level reached in 2008. The sharp price surge is primarily attributed to the depreciation of the U.S. dollar and financialization of commodity markets. In early November 2010, the second round of quantitative easing policy led to the substantial depreciation of the U.S. dollar, providing enormous impetus for the international copper market to ascend to a price peak (Figueroa-Ferretti and Mccrorie, 2016). Given that the U.S. interest rate was maintained at an extremely low level, large amounts of funds flowed into commodity markets, moving the prices of commodities including copper out of line with fundamentals (Baffes and Savescu, 2014). Furthermore, as an alternative hedging instrument against the declining dollar, the copper market prominently attracted the participation of long-only commodity index investments. According to Humphreys (2010), metals account for almost 12% of total holdings on the S&P Goldman Sachs Commodity Index and approximately 30% of total holdings on the Dow-Jones AIG Commodity Index. According to the Commodity Futures Trading Commission, total investments in commodity index funds increased from only $8 billion in 2002 to almost $200 billion by the end of 2011. This unprecedented purchasing pressure from CITS is considered to greatly exacerbate the explosiveness of speculative bubbles (Mayer et al., 2017). Meanwhile, metal commodities are increasingly utilized as collateral for financing to capture higher expected returns in importing countries (Bunicic and Moretto, 2015). In China, one of the world’s largest consumers of copper, copper-based financing has become critical in the shadow-banking sector, mainly because of superior suitability of copper for storage and high value-to-bulk ratio (Tang and Zhu, 2016). This continuously growing collateral demand for copper drastically pushed up its price, fostering the explosive bubble. With the subsequent aggravation of the European sovereign debt crisis, the international copper price dropped substantially due to slowing demand triggered by investors’ negative expectations concerning the economic situation. Finally, the resulting bubble burst with the drastic recession in the global economy.

Overall, we draw the following conclusions by summarizing the similarities among the episodes of explosive bubble behavior. First, four explosive bubble-type episodes in the international copper price have been confirmed, which is in accordance with the asset pricing model that indicates there exists expectation as well as invisible components in asset prices. Second, copper bubbles basically occur during periods of excess price volatility. Specifically, the formation of bubbles is typically accompanied by a drastic rise in price, and bubbles generally collapse when the copper price dramatically plummets. Third, the excessive copper price movements and resulting bubbles are partially attributable to the imbalance between supply and demand engendered by supply disruptions in key copper-producing countries and growing demand in developing countries, particularly in China. Fourth, the crucial role of nonfundamental factors, such as depreciation of the U.S. dollar and excessive speculation, has also been highlighted in explaining multiple bubble episodes of exuberance and collapse. Furthermore, the growing demand triggered by rapid industrialization and urbanization in emerging countries provides strong grounds for a massive surge in the copper price, given the basic commonality that bulk commodities tend to follow economic cycles. Nevertheless, bubbles are susceptible to collapse with the restoration of the copper price to the equilibrium trend in the short and medium run (Humphreys, 2010). Supply disruptions are demonstrated to foster transient bubbles but have no long-run impact on copper price volatility, since the balance between demand and supply quickly resumes in the wake of the reactivations of idle capacity and new investments in the mining industry (Figueroa-Ferretti et al., 2015). Turning to the financial perspective, the drastic price decline and speculative bubble collapse could be partly attributed to the global recessionary effect triggered by the economic crisis, proving an intensive integration between financial and commodity markets. It seems that the speculation component contributes to a longer-term bubble. The speculative boom with the expectation of a higher future copper price and U.S. dollar depreciation further facilitates an excessive price surge and aggravates explosive bubbles in the copper market (Shao et al., 2013). Furthermore, the bubble component could be amplified by the considerable buying pressure from CITS and growing collateral demand for copper (Bunicic and Moretto, 2015). It is of great importance for policymakers to know the potential reasons behind the periodically collapsing behavior and adopt precautionary policies to forestall potential adverse consequences. To reduce excess price fluctuations and bubble episodes, authorities should prevent excessive speculation in copper markets through the formulation of trading restrictions as well as the supervision of long-only index investments in extreme cases.

6. Conclusion

This study applies the GSADF technique developed by Phillips et al. (2013) to examine exuberance and the collapse of explosive bubble-type behaviors in the international copper market. The empirical results indicate the presence of four bubble episodes in the international copper market—in 1987, 2004, 2005–2008 and 2011—which is consistent with the asset pricing model, in which there are expectation as well as invisible components in the formation of asset prices. In general, we find that copper bubbles basically occur during periods of excess price volatility as a result of faster demand growth triggered by rapid industrialization and urbanization in emerging countries and supply disruptions, as well as nonfundamental reasons such as depreciation in the U.S. dollar, speculation, and financial crises. Specifically, copper demand is demonstrated to have a positive effect on bubble occurrence, while copper supply and the U.S. dollar index exert a negative influence on the
formation of bubbles. Moreover, excessive speculation is particularly identified as a significant driving force in amplifying the explosiveness of multiple bubbles in the copper price over the past decade (Cochran et al., 2012; Buncic and Moretto, 2015). Locating the starting and collapsing points of bubble episodes that have occurred is quite conducive to identifying the crucial variables promoting the formation of multiple copper price bubble episodes.

Through the corresponding analysis, several policy implications are offered. First, with the expansion of the futures market and the increasing prominence of the financial property of copper, the copper spot price has gradually become linked to futures pricing. Therefore, the international copper pricing mechanism should not only be established based on demand and supply fundamentals but also take financial factors into account. Second, given the development of financialization in the copper market, policymakers should construct a pre-warning mechanism for the copper spot price to effectively identify the adverse effects of financial shocks on the international copper market. Third, countries that are greatly affected by the copper price should improve their strategic reserve systems to curb excessive fluctuations of market prices, reduce the negative influence on their national economies. Moreover, governments should promote the diversification of import/export channels and actively seek international cooperation. Additionally, governments should develop and improve the copper futures market to limit copper price risk more efficiently and make the copper market more stable. Fourth, considering the effect of the U.S. dollar on copper bubble-type behaviors, market participants should focus on copper price fluctuations, which can help alleviate the negative influence of dollar depreciation. Finally, given the potential negative consequences of explosive bubbles, policymakers should supervise long-only index investments and frame restrictions on excessive speculative behaviors in extreme market cases to reduce excess price fluctuations and explosive bubble episodes.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2020.101587.

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