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Non-linearities in financial bubbles: Theory and Bayesian evidence from S&P500☆

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ABSTRACT

The modeling process of bubbles, using advanced mathematical and econometric techniques, is a young field of research. In this context, significant model misspecification could result from ignoring potential non-linearities. More precisely, the present paper attempts to detect and date non-linear bubble episodes. To do so, we use Neural Networks to capture the neglected non-linearities. Also, we provide a recursive dating procedure for bubble episodes. When using data on stock price-dividend ratio S&P500 (1871.1–2014.6), employing Bayesian techniques, the proposed approach identifies more episodes than other bubble tests in the literature, while the common episodes are, in general, found to have a longer duration, which is evidence of an early warning mechanism (EWM) that could have important policy implications.

1. Introduction

In August 2015, the Chinese stock market lost over 30% of its stock value, experiencing one of the worst stock market crashes in recent financial history. Despite the efforts made by the Chinese Government and the Chinese Central Bank to prevent the crash by implementing a strict legislatory framework on short selling as well as by providing huge cash injections to brokers so as to stimulate stock demand, the Shanghai Stock Exchange experienced an unprecedented crash. As a result, on the 24th of August, the Shanghai Stock Exchange experienced an overall devaluation of approximately 8% in stock prices, the so-called "Black Monday" of the Chinese Stock Market (The New York Times, 25 August 2015).

Despite the fact that in the long history of financial bubbles the Chinese case is not the first and certainly not the last one, only limited attention has been paid by the scientific community to creating a rigorous and robust framework for the detection of bubble formation based on a credible early warning mechanism (EWM). In general, EWMs are essential components of time-varying macroprudential policies that can help reduce the high losses associated with both banking and country specific crises. In this context, the EWMs employed should not only have sound statistical forecasting power, but also need to satisfy several additional requirements.

Analytically, the importance of bubble dating lies on the appropriate timing, which is a crucial requirement for EWMs. In this context, macroprudential policies need time before they become effective (Basel III, 2010 and, hence, signals should need to arrive at a relatively early stage in order to prevent policy measures from being costly (Caruana, 2010). The stability of the signal is a second, largely overlooked, requirement. More precisely, policy makers tend to base decisions on trends rather than reacting to changes in signaling variables immediately (Bernanke, 2004). Meanwhile, the gradual implementation of policy measures may also allow policy makers to affect market expectations more efficiently and deal with uncertainties in the transmission mechanism (CGFS, 2012). Finally, a last requirement is that EWM signals should be easy to interpret, as any signals that do not "make sense" are likely to be ignored by

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policy makers (Önkal et al., 2002; Lawrence et al., 2006). In sum, well designed EWIs, in terms of timing and signal processing, can reduce uncertainty and allow for more decisive policy action.

Thus far, one of the main reasons behind the inability of most models to capture the formation of bubbles, at a relatively early stage, is the fact that bubble formation has inherent non-linear characteristics, which are difficult to capture using standard linear models. This, clearly, implies that any econometric test that aims at capturing the formation of bubbles, especially at an early stage, should be able to capture their non-linear character.

Additionally, another equally important challenge for the econometric detection of bubbles is their dating, in the sense that an econometric test should be able to accurately date the bubble periods detected in the sample. Of course, early detection and accurate dating of financial bubbles could have important policy implications, especially for central bankers and policy makers since it could assist in the implementation of relevant policy actions that could potentially ease the consequences of bubbles. More specifically, the importance of early identification lies in the timing of specific countermeasures that could potentially prevent: (a) the magnitude of a potential collapse through regulatory interventions in the financial markets; (b) the potential downturn effects of bubble collapse in the economy through appropriate inflation targeting; and (c) the devastating spillover effects in the global economy through interest rate and/or exchange rate setting.

Due to the fact that, according to the recent financial history of bubbles, more than one bubble could occur in the same sample period (Ferguson, 2008), any econometric test for bubble detection should be structured upon flexible backward and/or forward recursive estimation techniques. However, relatively limited research has been done in the literature using recursive estimation techniques for dating multiple bubble episodes. See Phillips and Yu (2011) and Phillips et al. (2011a, 2011b, 2013, 2014, 2015a) and Phillips et al. (2015b)[hereafter PSY].

Meanwhile, non-linear economic models have become quite popular lately, because economic data exhibit significant non-linearities. To this end, in this paper, we propose a rigorous and robust mathematical and econometric framework for the detection of bubbles, which is structured upon Artificial Neural Networks (ANN), that are perfectly capable of capturing any neglected non-linearity. In fact, this is the first paper in the relevant literature, to the best of our knowledge, which employs ANNs, to capture neglected non-linearities in bubbles.

After all, according to PSY, the use of computationally efficient dating methods "over long historical periods presents a more serious econometric challenge due to the complexity of the *non-linear* structure and break mechanisms that are inherent in multiple-bubble phenomena within the same sample period". Finally, our approach provides a recursive algorithm for the accurate detection of bubbles, which serves as an EWM that could be used in order to guide a policy decision in an uncertain environment, without the need of taking into consideration the policy maker's preferences (e.g. Pesaran and Skouras, 2002; Granger and Machina, 2006; Baxa et al., 2013).

In brief, the present paper contributes to the literature in the following ways: (a) It establishes a rigorous framework, based on ANNs, under which bubble detection could be achieved, while emphasizing on the presence of non-linearities; (b) It provides a new algorithm for the accurate and early detection of bubble formation, as well as for the identification of potential explosive behaviors; (c) It illustrates the proposed test by early detecting and capturing accurately the bubble episodes that are present in the S&P500 index for the time period 1871 (M1)–2014 (M6), and by identifying more episodes compared to a competitive methodology in the literature.

This paper is structured as follows: in Section 2, a review of the literature takes place; Section 3 presents the theoretical model; Section 4 sets out the proposed non-linear test; Section 5 presents the empirical analysis; finally, Section 6 concludes.

2. Related literature

According to Kindleberger and Aliber (2005) a bubble is defined as "an upward price movement over an extended range that then implodes". Brunnermeier (2009) argued that bubbles "are typically associated with dramatic asset price increases followed by a collapse", whereas Garber (2000) defined a bubble as the part of the price movement that cannot be explained by fundamentals. Also, Barlevy (2007) described a bubble as "a situation where an asset's price exceeds the fundamental value of the asset". In brief, a bubble occurs when the market value is higher than the fundamental (Diba and Grossman, 1988a, 1988b). Some researchers (e.g. Wu, 1997) define bubbles as the difference between the fundamental value and the market price allowing, thus, for negative bubbles.

Reasons for the occurrence of bubbles include, among other things, greed (Kindleberger and Aliber, 2005), introduction of breakthrough technologies or financial innovations (e.g. Pérez, 2009); existence of rational and irrational traders (Dufwenberg et al., 2005; Hong et al., 2006); institutional restrictions on short selling (Haruvy and Noussair, 2006); herding (DeMarzo et al., 2008), speculating investors (Greenwood and Nagel, 2009; Scheinkman and Xiong, 2002), and "bubble riding" (Abreu and Brunnermeier, 2003; Temin and Voth, 2004).

Despite the fact that several approaches, even seminal ones (e.g. Fama, 1965), have denied the possibility of bubbles in financial markets, the phenomenon has made its appearance long ago (e.g. Dutch Tulipmania [1634–1637], Mississippi Bubble [1719–1720]) and has often led to generalized and deep economic recessions. As a result, Fama's *Efficient Market Hypothesis* and other similar theories have not always found so much support. After all, probably the most prominent economist, who considered the existence of bubbles in financial markets, was John Maynard Keynes (1936).

Following the related literature on financial bubble detection, Shiller (1981) and LeRoy and Porter (1981) were probably the first to develop variance bound tests for equity prices. Despite the fact that Shiller's (1981) variance bound test was not initially developed for bubble detection, the works of Blanchard and Watson (1982) and Tirole (1982) suggested that violation of variance bounds could be attributed to the presence of bubbles. Nevertheless, the variance bound tests were heavily criticized by a number of authors like Flavin (1983), Marsh and Merton (1986), Mankiw et al. (1985), Kleidon (1986) and Flood and Hodrick (1986, 1990), due to the fact that the variance bound tests could fail, not only if bubbles exist but also if any of the assumptions of the present value model is violated.

In a different approach, West (1987) developed a two-step test for the identification of bubbles in equity prices based on Euler's equation of no arbitrage process and the autoregressive process of dividends that governs the market fundamental stock price. Despite the fact that West's (1987) test was more attractive than the variance bound test as it explicitly incorporated the null hypothesis of no bubbles, once again Dezbakhsh and Demirguc-Kunt (1990), as well as Flood and Hodrick (1986, 1990), criticized the econometric procedure of the test because it exhibited significant size distortions in small samples.

Another popular approach for bubble detection was the one proposed by Diba and Grossman (1987, 1988a, 1988b), who tried to exploit the theoretical properties of bubbles. Their test allowed for unobserved fundamentals in the market fundamental price and a bubble would exist if the dividends and stock prices did not have