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ARE THERE DIGITAL TECH BUBBLES IN CHINA?

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Abstract. This exploration employs the generalized supremum augmented Dickey-Fuller (GSADF) approach to explore whether there are digital tech bubbles in China. The empirical results suggest the existence of multiple digital tech bubbles, which are mostly accompanied by an excessive rise. However, the appearance of digital tech bubbles is curbed since 2016, mainly due to the increasing mature regulations in relevant fields. Besides, bubbles in different digital technologies are similar during the same period, which could be attributed to the close relationships among them. Additionally, we further investigate the factors influencing the explosive behaviours, and find that the Chinese stock market positively affects digital tech bubbles, while economic policy uncertainties and situations negatively influence such explosive behaviors. In the context of the new round of scientific and technological revolution and industrial transformation, these conclusions provide valuable implications to achieve the target of constructing a "Digital China" by becoming moderately cautious about potential bubbles in the digital tech industry.

Keywords: digital technology, explosive bubbles, generalized supremum ADF, China.

JEL Classification: C22, E31, G12.

Introduction

The analysis purposes to investigate if there are digital tech bubbles in China and further identify the influencing factors that cause such bubbles. Digital technology refers to the application of modern computer technology to convert the traditional forms of various information resources into binary coding digits that computers can recognize (Liu et al., 2022; Wang et al., 2022b). This is a collection of various digital technologies, including big data, cloud

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computing, the Internet of Things, artificial intelligence, blockchain, 5G, etc. (Sestino et al., 2020; Lyu & Liu, 2021). Like the internet bubble of the mid-1990s (Chan, 2014; Chang et al., 2019), a digital tech bubble could be formed if there is an excess investment in digital tech assets (e.g., stocks), resulting in their prices being self-perpetuated and soaring far beyond fundamental values. Against the new round of scientific and technological revolution and industrial transformation (Su et al., 2020b), countries or regions worldwide have paid great attention to digital tech development. As an emerging field (Sestino et al., 2020), the relevant policies lead investors to deeply understand that digital technology is an essential direction for the future and guide them to invest in its assets (Vernim et al., 2021). Without solid regulation in digital technology, it may trigger an "investment fever", resulting in a speculative bubble. Although digital tech investment could fund the growth of relevant enterprises (Lin et al., 2022; Wu & Huang, 2022), a severe bubble would hinder the stable development of the digital economy in countries or regions. As a result, exploring digital tech bubbles and their influencing factors is an essential and meaningful investigation that has not been discussed in previous studies. Through probing this question, countries could identify the causes of digital tech bubbles and prevent them in advance, and monitor the stages of bubbles and accordingly implement policy interventions to develop the world's leading digital tech and to globally compete in the digital economy.

China has attached significant importance to the progress of digital technology and emphasizes that it is a key engine for high-quality economic development in the digital economy era (Sestino et al., 2020; Su et al., 2022c; Liu et al., 2022; Wang et al., 2022a). Therefore, the Chinese government has implemented national policies that support digital technology development. For instance, big data, cloud computing, the Internet of Things, artificial intelligence, blockchain and 5G have been successively listed as national strategies in the Five-Year Plans. As the barometer of national policies, the Five-Year Plans clarify future directions (Teixeira et al., 2022), promoting investors to increase their focus on related fields and injecting funds into digital tech assets. For instance, the investment and financing amount in the global artificial intelligence industry was 71.47 billion dollars in 2021, and China (20.02 billion dollars) contributed nearly 30%. The increase in investment inevitably promotes the development of the digital tech industry (Lin et al., 2022; Wu & Huang, 2022), but if there is significant overinvestment, a speculative bubble may be formed. Moreover, the business models of digital tech-related enterprises, such as Alibaba, Tencent and Baidu, could achieve rapid growth, which has gradually won favor by the capital markets and raised investor enthusiasm. If investors lose their minds and speculate wildly, it could inevitably lead to "irrational prosperity" in digital tech fields, which would be similar to the internet bubble (Chan, 2014). Therefore, under the background of vigorously building "Digital China", a digital tech bubble may appear. If the bubble becomes increasingly serious and even bursts, it dramatically weakens investor confidence and then hinders the construction of "Digital China"; thus, it is significant to identify digital tech bubbles.

However, the occurrences and reasons of digital tech bubbles in China have not been comprehensively explored in the existing efforts. First, the previous analyses mainly focus on the internet bubble (Campello & Graham, 2013; Chan, 2014; Chang et al., 2019) and the tech bubble (Kassouri et al., 2021; Haddad et al., 2022), as well as a bubble of products based on digital technology (e.g., cryptocurrencies), but no study has probed digital tech bubbles. Second, the previous efforts of a bubble have only proven its existence but provided no empirical evidence on the underlying causes (Li et al., 2020; Wang et al., 2020; Nguyen & Waters, 2022). Third, the SADF and GSADF approaches provide a complete understanding of the occurrence of bubbles (Phillips et al., 2012, 2013), which is a limitation in traditional approaches and has been ignored by the extant literature. Thereupon, this paper will fill these gaps, and answer two research questions: Whether there are digital tech bubbles in China? What factors influence these explosive behaviours?

There are several marginal contributions in this investigation. To begin with, the analysis is a pioneering work to probe if digital tech bubbles exist in China. In addition, we consider various digital technologies, including big data, cloud computing, the Internet of Things, artificial intelligence, blockchain and 5G, which are also innovative in the existing studies. Secondly, this paper not only detects the occurrence of digital tech bubbles but also identifies the influencing factors that cause such bubbles. The result is supported by the bubble model (Gürkaynak, 2008), pointing out that there are digital tech bubbles in China, but these bubbles mainly existed before the 13th Five-Year Plan period. While discussing each period that has samples, the occurrence of bubbles in different technologies is generally the same. In addition, the Chinese stock market has a positive effect on digital tech bubbles, while economic policy uncertainty and the situation show negative influences. We could put forward insightful implications from these results: the Chinese government should take measures (e.g., macroprudential policy) to prevent investment from overheating while vigorously urging funds into digital technologies. Simultaneously, the government should also take a moderate attitude to guard against potential bubbles to prevent excessive regulation from backfiring. Digital tech enterprises ought to integrate relevant products into manufacturing and service industries to avoid bubbles caused by stock market speculation divorced from actual production. In addition, investors must rely on the contribution to productivity to assess the value of digital innovations rather than market enthusiasm and then they must invest rationally to avert huge losses from the bubble burst. Thirdly, since the GSADF test outperforms the SADF approach in recognising multiple booms and busts (Li et al., 2020; Wang et al., 2020; Khan et al., 2021; Li et al., 2022b; Qin et al., 2022). Thus, this paper employs a more advanced technique, namely, the GSADF approach, to identify the digital tech bubbles in China.

The construction of this paper can be described as follows: Section 1 reviews the related literature. Sections 2 and 3 present the theoretical and empirical models. Section 4 introduces the data. Section 5 discusses the empirical results. Finally, the summary and corresponding suggestions are presented.

1. Literature review

1.1. The internet or tech bubble

Compared with digital tech bubbles, the existing research pays more attention to the internet or tech bubble. Griffin et al. (2011) underline that as tech stocks rose more than fivefold from 1997 to March 2000, institutional investors bought more novel tech supplies than individuals, while the bubble burst, and was accompanied by a wide sell-off from institutions. Singh (2013) states that all types of institutions have been herded with great intensity into internet stocks during the internet bubble, and positive abnormal returns were consistent with institutional herding, while negative abnormal returns occurred at the point that herding ceased. Leone and de Medeiros (2015) evidence the existence of the internet bubble with its start and end dates and identify an unexpected negative bubble that ranges from the beginning of the 1970s to the start of the 1990s. Sargen (2016) notes that the internet bubble initially occurred because of substantial corporate profits, while the price-earnings ratio climbed to record levels for tech stocks by the 1990s. Kassouri et al. (2021) emphasize that there are explosive bubbles in high-tech stock prices, which present close relations with clean energy and oil prices. Özdurak and Alcan (2021) reveal that the U.S. should be cautious about the second internet bubble since 26% of Standard & Poor's (S&P) 500 market cap is driven by Facebook, Apple, Amazon, Netflix, Alphabet and Microsoft stocks, which are all tech stocks. Haddad et al. (2022) suggest that booming tech innovation usually coincides with intense speculation in financial markets; specifically, a tech innovation boosts the share price of its creator by 40%.

1.2. The bubble of products based on digital technology

The bubble of products based on digital technology (e.g., cryptocurrencies) has attracted much attention in recent years. Cheah and Fry (2015) point out that Bitcoin prices include a considerable speculative component, are susceptible to bubbles, and their fundamental value is zero. Corbet et al. (2018) prove that there are periods with obvious bubble behavior in Bitcoin and Ethereum, and Bitcoin is almost certainly in a bubble phase. Geuder et al. (2019) highlight that bubble behavior is a common and reoccurring feature of Bitcoin prices, and a critical time point is December 6, 2017. However, Chaim and Laurini (2019) have a different opinion from the above, as they find the occurrence of a bubble in Bitcoin prices from early 2013 to mid-2014 but not in late 2017. Li et al. (2019) suggest that most explosive bubbles occur in the period of considerable surges in Bitcoin prices, and Bitcoin can be used as an asset to hedge against market-specific risk. Enoksen et al. (2020) state that there are multiple bubbles for Bitcoin, Ethereum, Ripple, Litecoin, Monero, Dash coin, Nem coin and Dogecoin, especially in 2017 and early 2018, which have positive relations with volatility, trading volume and transactions, as well as economic policy uncertainty. Kyriazis et al. (2020) reveal that Bitcoin has been in a bubble phase since June 2015, while Ethereum, Nem coin, Stellar, Ripple, Litecoin and Dash coin have been denoted as possessing bubble-like features since September 2015, but the latter group has presented no bubbles since early 2018. Caferra et al. (2021) show a close affinity between the Bitcoin bubble in 2017 and the internet bubble in 2000. Cross et al. (2021) evidence that Litecoin and Ripple incurred a risk premium by investors during the boom in 2017, and the adverse news effect was a significant driver of the cryptocurrency (including Bitcoin, Ethereum, Litecoin and Ripple) crash in 2018. Yao and Li (2021) suggest that there are two evident boom and bust episodes in Bitcoin prices: the first lasted from November 25, 2017, to December 21, 2017, caused by considerable expansion of initial coin offerings, and the second lasted from June 22 to June 29, 2019, affected by the release of Libra. Li et al. (2022a) indicate that media coverage could act as a driver of Bitcoin returns during bubbles, further making the Bitcoin bubble more serious. Maouchi et al. (2022) emphasize that decentralized finance (DeFi) and nonfungible tokens (NFTs) bubbles are less recurrent but have higher magnitudes than that of cryptocurrency, and that the coronavirus disease 2019 (COVID-19) could exacerbate bubbles (Su et al., 2022b).

1.3. Influencing factors of the tech stock price in China

Previous studies from the perspective of China mainly discuss this topic through the influencing factors of the tech stock price. Meng et al. (2015) indicate that the influence of research and development (R&D) investment on market value is insignificant in China's growth enterprise market (GEM), which is mainly due to the weak protection for minority investors and lax regulation of information disclosure. Zhang and Du (2017) show that high-tech stock prices have close relations with new energy companies, and the analyses of stochastic volatilities and dynamic correlations could explain the Chinese stock market turbulence in 2015. Gu et al. (2021) reveal that Sino-US trade and nontrade disputes mainly affect the stock prices of related tech industries, such as media, computer applications, computers and electronic equipment. Gui et al. (2022) suggest that China's GEM is susceptible to stock market sentiment; that is, investor sentiment in online reviews has a significant effect on GEM index returns.

1.4. Summary of the extant literature

Most extant efforts pay attention to the internet bubble, tech bubble and bubble of products based on digital technology (e.g., cryptocurrencies). Nevertheless, no investigation has explored digital tech bubbles. Therefore, the analysis employs a new bubble detection method, the GSADF technique, to study if digital tech bubbles exist in China. Additionally, there are no studies that consider different digital technologies, so this exploration considers various digital technologies, such as big data, cloud computing, the Internet of Things, artificial intelligence, blockchain and 5G. Additionally, several studies explore the influencing factors of the internet or tech stock price from the perspective of China but neglect the factors that contribute to bubbles. Thus, this study provides empirical evidence on the underlying causes of digital tech bubbles.

2. Theoretical mechanism

The occurrences of digital tech bubble are the economic imbalance phenomena, it can be described as the nonstationary rise in a price level relative to a theoretical price affected by economic situation. Precisely recognising and forecasting cyclical boom and bust times in the digital tech market is important for policy-makers to take precautions. After that, the analysis employs the asset pricing model to carry on the theoretical discussion to recognise the digital tech bubble from market fundamentals (Lucas, 1978). On the basis of theory introduced by Tirole (1982, 1985) and Shiller (1984), we believe that minor explosion behavior (such as speculation) might cause asset price to deviate from the fundamental value. Thereafter, based on Gürkaynak (2008), the fundamental prices of digital tech assets can increase from the nonarbitrage condition, and it starts with the following formula.

$$P_t = \frac{E_t\left(\zeta_{t+1} + U_{t+1}\right)}{1 + r_f}, \tag{1}$$

where P_t and E_t refer to the price and conditional expectation of digital tech assets. r_f points out the risk-free rate. ζ_{t+1} and U_{t+1} reveal the return and invisible component. Through forward iteration, the above formula could be expressed as:

$$P_t^f = \sum_{i=0}^{\infty} \frac{E_t\left(\zeta_{t+i} + U_{t+i}\right)}{\left(1 + r_f\right)^i},\ i = 0, 1, 2, ..., n, \tag{2}$$

where P_t^f means the fundamental price of digital tech assets. After that, the above formula indicates the determining factors of fundamental values without digital tech bubbles. Thus, we consider the condition of existing bubble, and any random sequences conforming to the homogeneous expectation equation are written as:

$$B_t = \frac{E_t\left(B_{t+1}\right)}{1 + r_f}. \tag{3}$$

Through incorporating the above formulas, Eq. (1) can be rewritten as:

$$P_t = P_t^f + B_t, \tag{4}$$

where the price of digital tech assets (P_t) is split into two constituent parts, containing the fundamental price $\left(P_t^f\right)$ and bubble (B_t). This formula constricts the motion law of the nonfundamental component (B_t) of the asset price, signifying multiple ways for every value of the initial bubble. If $B_t = 0$, no digital tech bubble exists in the overall period, but there exist boom and bust periods if $B_t \neq 0$. Thus, we could put forward an assumption from this theoretical analysis: there are expectations and intangibles in digital tech asset price's formation, which might result in digital tech bubbles.

3. Empirical techniques

Based on the explosive features of bubble, Diba and Grossman (1988) introduce the stationarity test for asset price. The conditional techniques for testing stationarity are the ADF (Dickey & Fuller, 1981) and PP (Phillips & Perron, 1988) methods, and they possess the alternative assumption of explosive features. These techniques are written as follows:

$$\Delta P_t = \alpha + \beta P_{t-1} + \sum_{i=1}^{k} \chi_i \Delta P_{t-i} + \varepsilon_i, \tag{5}$$

where P_{t-1} points out the price of digital tech assets and k is an optimal lag order selected through the significance test. The alternative assumption is $\beta > 1$, underlining that there is an explosive root in P_{t-1} and ΔP_t is unstable, but the original assumption ($\beta = 1$) refers to P_{t-1} being a unit root process and ΔP_t being stationary. However, traditional techniques might not possess the ideal effect in capturing bubble if periodic crash behaviors exist in the sequences (Evans, 1991). In addition, Phillips and Yu (2011) demonstrate the limitations of traditional techniques, mainly due to their sensitivity to alternating from unit root to mild explosive one or alternating in different directions. This method is more sensitive than the left-tail unit root tests of constant substitution, and it cannot fully understand the periodic bursting of digital tech bubbles.

To cope with these difficulties, Phillips and Yu (2011) further introduce the supremum ADF (SADF) technique, meaning the ADF technique is repeated to estimate the forward expansion sample sequences and the upper limits of the corresponding ADF statistical sequences. Additionally, the repeated estimations are according to the window width r_w. The SADF technique can be expressed as follows:

$$\mathrm{SADF}(r_0) = \sup_{r_2 \in (r_0, 1)} \{\mathrm{ADF}_{r_2}\}. \tag{6}$$

Although this technique is more efficient if there is only one bubble in the entire series, in general, this is not always the case. When multiple digital tech bubbles exist, the utilization of the SADF technique is unreasonable (Phillips et al., 2012, 2013), particularly in long-sample times or rapidly altering market. To cope with this difficulty efficiently, Phillips et al. (2013) introduce the generalized SADF (GSADF) technique, and this method is relatively advanced in capturing multiple bubbles. There is a changeable window width in the GSADF technique, varying its end point and changing its original one (ranging from 0 to $r_2 - r_0$). Subsequently, the GSADF technique can be expressed as Eq. (7).

$$\mathrm{GSADF}(r_0) = \sup_{r_2 \in (r_0, 1), r_1 \in (0, r_2 - r_0)} \{\mathrm{ADF}_{r_1}^{r_2}\}. \tag{7}$$

If GSADF(r_0) exceeds the critical value, we could ascertain that there are bubbles in the whole sequence. When the regression model has an intercept, which is also accompanied by the original assumption of random walk, the GSADF(r_0)' limited distribution is expressed as follows:

$$\sup_{r_2 \in (r_0, 1), r_1 \in (0, r_2 - r_0)} \left\{ \frac{(1/2) r_w \left[w(r_2)^2 - w(r_1)^2 - r_w \right] - \int_{r_1}^{r_2} w(r) dr \left[w(r_2) - w(r_1) \right]}{r_w^{1/2} \left\{ r_w \int_{r_1}^{r_2} w(r)^2 dr - \left[\int_{r_1}^{r_2} w(r) dr \right]^2 \right\}^{1/2}} \right\}. \tag{8}$$

where $r_w = r_2 - r_1$ obeys a standard Wiener process. In addition, the bootstrap technique is employed to count the limited sample distribution, and the asymptotic critical value can be obtained through numerical simulation (Pavlidis et al., 2012; Phillips et al., 2012, 2015).

Based on bubble identification, this investigation also employs the backward SADF (BSADF) technique, and it was introduced by Phillips et al. (2015), to offer a consistent and novel method for tracking the initial and end of digital tech bubble. The BSADF technique is expressed as Eq. (9).

$$\mathrm{BSADF}(r_0) = \sup_{r_1 \in (0, r_2 - r_0)} \{\mathrm{ADF}_{r_1}^{r_2}\}. \tag{9}$$

Based on the BSADF technique, the start and end are r_{ni} and r_{ne} for the n-th bubble, and these are denoted as:

$$\tilde{r}_{ni} = \inf_{r_2 \in [r_0, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) > cv_{r_2}^{\beta_T} \right\}; \tag{10}$$

$$\tilde{r}_{ne} = \inf_{r_2 \in [\tilde{r}_{ni} + \zeta \log(T)/T, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) < cv_{r_2}^{\beta_T} \right\}. \tag{11}$$

From Eqs (10) and (11), we observe that if the statistic exceeds the critical value $\left(cv_{r_2}^{\beta_T}\right)$, a digital tech bubble appears; when the statistic is less than the critical value, this bubble terminates.

4. Data

To answer whether there are digital tech bubbles in China, this analysis chooses the monthly sequences of related assets to probe the cyclical boom and bust periods in them (see Table 1). Since 2010, the third wave of information technology has been ushered with the popularity of big data, cloud computing and the Internet of Things (Chen et al., 2022; Viana et al., 2022). Then, we select the monthly time series of the Wind Big Data Concept Index (BDI), Cloud Computing Concept Index (CCI) and Internet of Things Concept Index (IOTI) to reflect the general performance of enterprises related to these three digital tech industries. BDI, CCI and IOTI are obtained by assigning equal weights to 61, 62 and 60 constituent stocks, respectively, which cover the period from January 2010 to September 2022. In 2013, China surpassed the U.S. in the number of highly cited papers in the field of artificial intelligence to become the world's largest[1], indicating that this field has received significant attention. Since then, this digital technology has been proliferating in China (Lundvall & Rikap, 2022), and this paper chooses the monthly variable of the Wind Artificial Intelligence Concept Index (AII) to reflect its macro trends in asset markets. AII is acquired by assigning equal weight to 66 constituent stocks, covering the period from January 2013 to September 2022. In 2014, the People's Bank of China (PBC) set up a special research group to demonstrate the feasibility of issuing fiat digital currency, which is an essential step for China in the blockchain field (Shen & Hou, 2021). Subsequently, China not only issued digital currency, the electronic Chinese Yuan (e-CNY) but also possessed an increasing blockchain market scale. We consider monthly data of the Wind Block Chain Concept Index (BCI) from January 2014 to September 2022 to represent the blockchain market, which is made of 96 constituent stocks with equal weight. In 2016, China fully launched 5G technology trials, divided into three phases: 5G key technology trials, technical scheme verification and system verification. This is the first time China has tested and verified the new generation mobile communication technology simultaneously with the international standards organization. Since then, China's 5G has been possessing more significant potential (Lee & Yu, 2022), and this paper selects the monthly variable of the Wind 5G Network Concept Index (5GI) from January 2016 to September 2022 to reflect its performance, which consists of 127 equally weighted constituent stocks. Therefore, we could recognise digital tech bubbles in China through proving the cyclical boom and bust periods in BDI, CCI, IOTI, AII, BCI and 5GI.

[1] The data is obtained from China Artificial Intelligence Development Report 2018.

Table 1. Selection of data (source: authors' calculations)

Data	Abbreviation	Sample period	Source
Big Data Concept Index	BDI	2010:M01 to 2022:M09	Wind Database
Cloud Computing Concept Index	CCI		
Internet of Things Concept Index	IOTI		
Artificial Intelligence Concept Index	AII	2013:M01 to 2022:M09	
Block Chain Concept Index	BCI	2014:M01 to 2022:M09	
5G Network Concept Index	5GI	2016:M01 to 2022:M09	

The trends of these six variables are revealed in Figure 1. From Figure 1, we can observe that the trends of BDI, CCI, IOTI, AII, BCI and 5GI are roughly similar, and that there are drastic fluctuations in these six time series, which may lead to periodical collapse behaviors. BDI, CCI and IOTI changed steadily from 2010 to 2012, showing an obvious upward trend (in addition to AII and BCI) since 2013. Driven by the growing appeal and attention of digital technologies, as well as the rising investor sentiment in the Chinese stock market, these variables (except 5GI) boomed in 2015. Among them, BDI increased sharply from 9308 points in January 2015 to 25350 points in June 2015, which grew by 170%, and CCI, IOTI, AII and BCI also increased by 145%, 138%, 139% and 166%, respectively, during the same period. Subsequently, these five-time series fell sharply, but they soared again in the fourth quarter of 2015. With investor sentiment apparently cooling, BDI, CCI, IOTI, AII and BCI began to decrease in fluctuation and basically returned to preboom and bust levels (in late 2014 or early 2015) in the first half of 2018. From the second half of 2018, BDI, CCI, IOTI, AII, BCI and 5GI have risen amid volatility, that is, although the overall trend is upward, there have been downturns in these six variables several times. For instance, the outbreak of COVID-19 hindered the development of digital technologies, making these six sequences decline in the second half of 2020. Additionally, the bear stock market in China from the second half of 2021 to the first half of 2022 led to a sharp decline in BDI, CCI, IOTI, AII, BCI and 5GI. Moreover, these six variables present various characteristics at different stages,

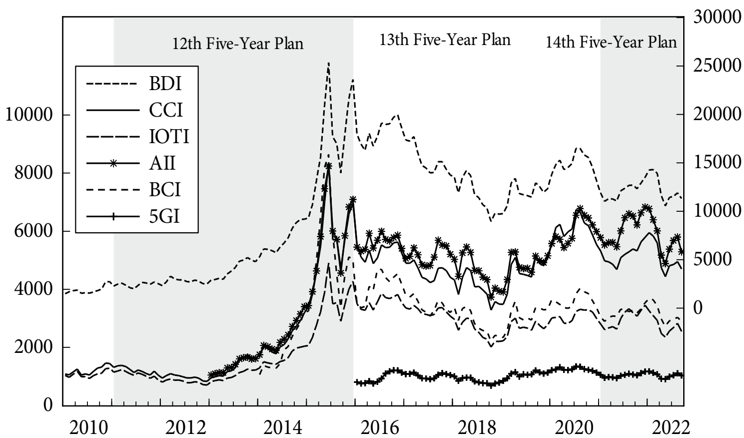


Figure 1. The trends of BDI, CCI, IOTI, AII, BCI and 5GI (source: authors' calculations)

mainly reflected in their fluctuations during the 12th Five-Year Plan period being more dramatic than those of the 13th and 14th Five-Year Plans. Thus, the fluctuations in BDI, CCI, IOTI, AII, BCI and 5GI indicate that digital tech bubbles might exist. In addition, multiple bubbles related to long-sample periods and promptly altering market cannot be precisely recognised by the SADF approach, but the GSADF one is more reasonable.

Table 2 shows the descriptive statistics of BDI, CCI, IOTI, AII, BCI and 5GI. The averages of the above six time series are concentrated at 10100.40, 3633.624, 2294.945, 4746.767, 3420.241 and 1040.328, respectively. The maximum and minimum of BDI, CCI, IOTI, AII, BCI and 5GI vary considerably, meaning that these six variables are highly volatile, which increases the possibility of bubbles. The skewness is positive in BDI and BCI, which indicates that these two variables satisfy the right-skewed distributions, while CCI, IOTI, AII and 5GI obey the left-skewed distributions. The kurtosis of BDI, CCI, IOTI, AII and 5GI is less than 3, satisfying the platykurtic distribution, while BCI has a fat-tail feature. In addition, the Jarque-Bera method shows that CCI, IOTI, AII and BCI do not follow the normal distribution at a 1% level, and BDI could reject the null hypothesis at a 5% level, while 5GI could accept it.

Table 2. Descriptive statistics for BDI, CCI, IOTI, AII, BCI and 5GI (source: authors' calculations)

	BDI	CCI	IOTI	AII	BCI	5GI
Observations	153	153	153	117	105	81
Mean	10100.40	3633.624	2294.945	4746.767	3420.241	1040.328
Median	11423.98	4410.917	2608.272	5279.643	3327.776	1062.829
Maximum	25350.28	8368.295	4908.577	8244.060	8653.426	1356.511
Minimum	1477.345	832.567	706.489	1048.479	1067.486	692.139
Standard Deviation	5924.835	1955.398	1033.982	1662.483	1124.161	154.612
Skewness	0.037	–0.131	–0.101	–0.844	1.686	–0.231
Kurtosis	1.968	1.637	1.722	2.829	9.593	2.359
Jarque-Bera	6.820**	12.288***	10.667***	14.016***	239.913***	2.112
Probability	0.033	0.002	0.005	0.001	0.000	0.348

Notes: ** and *** denote significance at 5% and 1% levels.

5. Empirical result and discussion

To determine if there exist bubbles, the analysis employs the SADF and the relatively advanced GSADF techniques to recognise the BDI, CCI, IOTI, AII, BCI and 5GI. Through choosing the iteration as 10000, the statistic and critical value of these two techniques can be obtained, these are denoted in Table 3. We could observe that the statistics of BDI, CCI, IOTI, AII and BCI are larger than the critical values at the 1% level, which rejects the original assumption that there exists no bubble. However, the statistical value of 5GI is less than the critical value, meaning that there is no bubble in this sequence. Additionally, the critical value of the GSADF technique is more obvious than another one, and thus the former could recognise bubbles more keenly. Therefore, we could confirm that BDI, CCI, IOTI, AII, and BCI have periodic booms and busts. Further, we should the concrete times and reasons of bubbles according to this result.

Table 3. The outcomes of SADF and GSADF tests (source: authors' calculations)

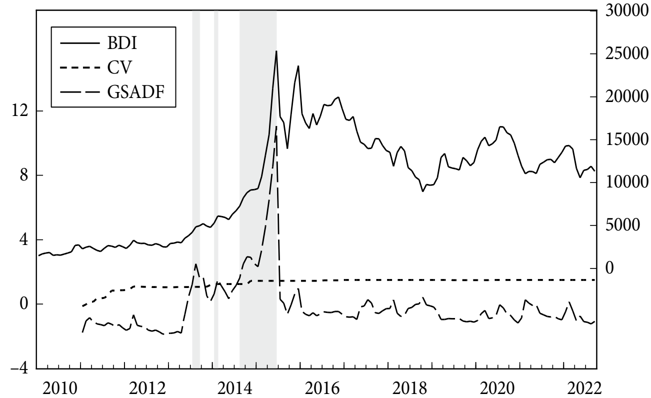
		Statistics	Critical Values		
			90%	95%	99%
SADF	BDI	10.857***	1.332	1.580	1.756
	CCI	14.867***	1.332	1.580	1.756
	IOTI	10.822***	1.332	1.580	1.756
	AII	8.393***	1.318	1.559	2.090
	BCI	7.257***	1.120	1.268	1.904
	5GI	–0.734	1.111	1.488	1.646
GSADF	BDI	11.069***	2.164	2.475	3.111
	CCI	14.870***	2.164	2.475	3.111
	IOTI	11.000***	2.164	2.475	3.111
	AII	8.584***	1.923	2.227	2.967
	BCI	7.326***	1.927	2.104	2.950
	5GI	0.514	1.772	2.086	2.336

Notes: Critical values are acquired from Monte Carlo simulations with 10000 replications. *** denotes significance at 1% level.

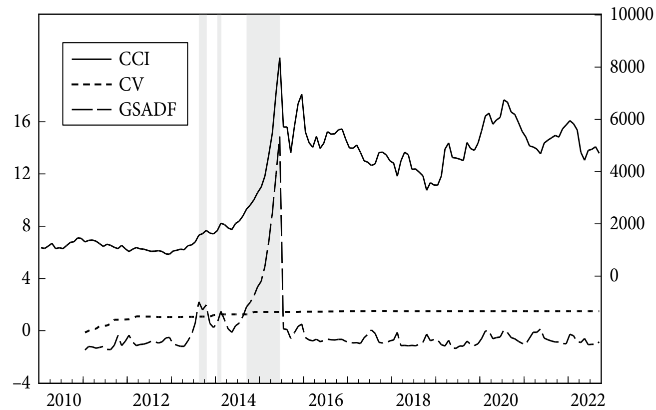
On the basis of the GSADF technique, we could position bubbles, as revealed in Figures 2–6, which graph the initial (top), statistical (bottom), and 95% critical (middle) values of BDI, CCI, IOTI, AII and BCI, respectively. Then, the analysis denotes the bubble periods as parts where GSADF statistic is more than critical value. These figures suggest that bubbles mainly occur from the second half of 2013 to the first half of 2015, indicating that digital tech bubbles exist in China. The result is supported by the bubble model (Gürkaynak, 2008), underlining there exist expectations and invisible components in the formation of asset prices.

To perceive the periodic boom and bust episodes more intuitively, Figure 7 further compares bubbles in BDI, CCI, IOTI, AII, BCI and 5GI. BDI, CCI and IOTI have three bubbles, all of which are concentrated in the period of the second half of 2013 to the first half of 2015. AII has two bubbles appearing from January 2014 to February 2014 and September 2014 to June 2015. BCI has only one bubble, which occurs from January 2015 to June 2015, but there is no bubble in 5GI during its sample interval. Although bubbles differ in the above sequences, because essentially the sample lengths in BDI (2010–2022), CCI (2010–2022), IOTI (2010–2022), AII (2012–2022), BCI (2013–2022) and 5GI (2015–2022) are different. When we analyze each stage containing samples, the occurrence of bubbles is basically the same. The close relations can explain this phenomenon among big data, cloud computing, the Internet of Things, artificial intelligence, blockchain and 5G, which is pictured in Figure 8. These complicated and intimate interactions lead to strong correlations amid BDI, CCI, IOTI, AII, BCI and 5GI, resulting in similar results for bubbles.

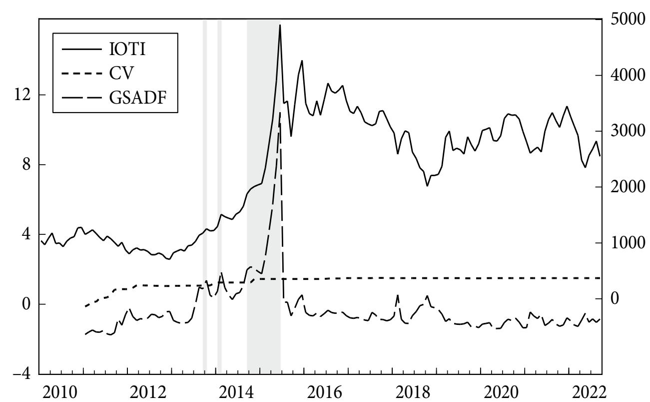
Furthermore, we construct the regression model to identify the influencing factors that contribute to bubbles in BDI, CCI, IOTI, AII and BCI, and the explained variable is defined as 1 (with bubble) and 0 (no bubble). The explanatory variables are: First, the 13th and 14th Five-Year Plans create a more favorable policy environment for the sound and ordered development of digital technology in China, which may decrease the possibility of related bubbles.



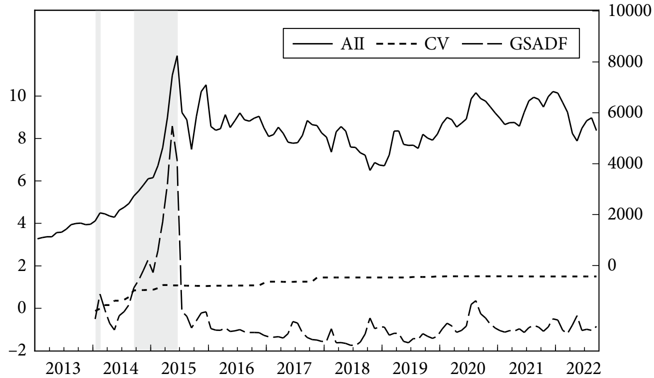
Notes: The shadows indicate sub-periods with bubbles.
Figure 2. GSADF test of Big Data Index (source: authors' calculations)



Notes: The shadows indicate sub-periods with bubbles.
Figure 3. GSADF test of Cloud Computing Index (source: authors' calculations)

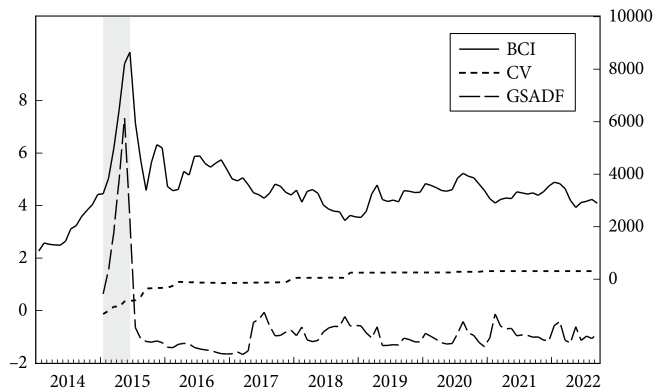


Notes: The shadows indicate sub-periods with bubbles.
Figure 4. GSADF test of Internet of Things Index (source: authors' calculations)



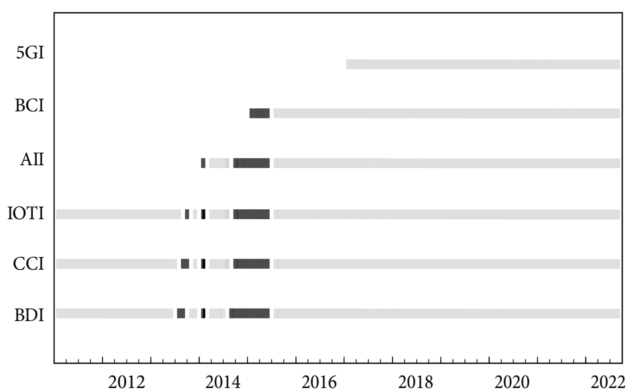
Notes: The shadows indicate sub-periods with bubbles.

Figure 5. GSADF test of Artificial Intelligence Index (source: authors' calculations)



Notes: The shadows indicate sub-periods with bubbles.

Figure 6. GSADF test of Block Chain Index (source: authors' calculations)



Notes: Black sections indicate the presence of bubbles, and gray sections mean that there are no bubbles.

Figure 7. The comparison of bubbles in BDI, CCI, IOTI, AII, BCI and 5GI (source: authors' calculations)

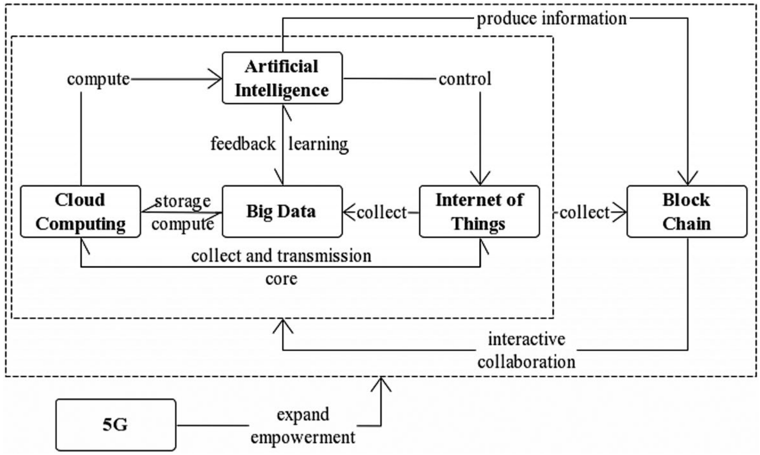


Figure 8. The framework of digital tech (source: authors' calculations)

For instance, one chapter of the 13th Five-Year Plan is to expand the cyberspace economic space (e.g., implementing the national big data strategy), and the 14th Five-Year Plan calls for accelerating the development of digitalization and building a "Digital China". Then, we select a dummy variable denoted as POLICY, where 1 refers to the 13th and 14th Five-Year Plans period and 0 refers to the other periods representing the policy factor. Second, BDI, CCI, IOTI, AII and BCI are all stock indices, inevitably affected by the fluctuations of the Chinese stock market. This paper chooses the Shanghai Securities Composite Index (SSCI)[2] to reflect the stock market in China (Wang et al., 2021), and it could also reflect investor sentiment (Dai et al., 2022). Third, the uncertainties in economic policies may affect the Chinese stock market (Wang et al., 2022c), and high uncertainty may decrease investments and lead to a downturn in relevant stock indices (e.g., BDI, CCI, IOTI, AII and BCI). We choose the Economic Policy Uncertainty Index for China (EPU)[3] to reflect it, which was developed by Baker et al. (2013, 2016). Fourth, the economic situation is also closely related to BDI, CCI, IOTI, AII and BCI; its development might cause more investment, while its recession accompanied by high stock prices may be more likely to cause bubbles (Pan & Mishra, 2018). This paper selects the Macro-Economic Prosperity Index (MPI)[4] to reflect the economic situation in China. The regression results are shown in Table 4.

From Table 4, we discover that POLICY has negative effects on BDI, CCI, IOTI, AII and BCI, which are statistically significant. This phenomenon implies that the Chinese government has strengthened the regulations and gradually unified technical standards while vigorously developing the digital economy during the 13th and 14th Five-Year Plans period, creating a sustainable environment that is less prone to digital tech bubbles. However, before these stages, although the Chinese government supports the development of digital technologies (e.g., launching cloud computing trials), the proposition of new concepts is challenging

[2] The Shanghai Securities Composite Index is obtained from Wind Database.

[3] The Economic Policy Uncertainty Index for China is obtained from Economic Policy Uncertainty Database.

[4] The Macro-Economic Prosperity Index is obtained from National Bureau of Statistics in China.

Table 4. The regression results on the influencing factors of bubbles (source: authors' calculations)

Variables	BDI	CCI	IOTI	AII	BCI
POLICY	−0.179** (−2.302)	−0.151** (−2.025)	−0.135* (−1.847)	−0.410*** (−4.689)	−0.409*** (−5.705)
SSCI	1.369*** (3.251)	1.357*** (3.362)	1.260*** (3.183)	1.062*** (2.648)	0.782** (2.439)
EPU	−0.082* (−1.712)	−0.077* (−1.682)	−0.077* (−1.706)	−0.052 (−1.008)	−0.079* (−1.943)
MPI	−1.010 (−0.585)	−1.053 (−0.636)	−1.145 (−0.705)	−1.430 (−0.987)	−1.204 (−1.107)
Intercept	0.689*** (2.861)	0.632*** (2.734)	0.613*** (2.706)	0.735*** (2.819)	0.900*** (4.220)
R-squared	0.265	0.246	0.230	0.481	0.525
F-statistics	11.890	10.759	9.833	22.490	23.516
Probability	0.000	0.000	0.000	0.000	0.000

Notes: The values in parentheses point out t-statistics. *, ** and *** denote significance at 10%, 5% and 1% levels.

to immediately form intense supervision, which might trigger an "investment fever" and increase the possibility of bubbles (Chiang et al., 2011; Choi et al., 2015). SSCI has significantly positive effects on BDI, CCI, IOTI, AII and BCI, which can be explained by two main reasons. On the one hand, digital tech stocks are part of the Chinese stock market; thus, a bull market can boost BDI, CCI, IOTI, AII and BCI, and vice versa. On the other hand, the stock market can reflect investor sentiment; a bull market means that investors are enthusiastic, which tends to generate digital tech bubbles, while a bear market lowers the likelihood of these bubbles (Dai et al., 2022). Moreover, the adverse influences of EPU on BDI, CCI, IOTI and BCI are statistically significant. We can explain this by stating that high EPU makes investors more inclined to seek hedging assets or safe havens (e.g., gold) to avoid uncertainties (Qin et al., 2020a, 2020b, 2021, 2023; Su et al., 2020a, 2022a), and such investors are less willing to invest in the Chinese stock market (including digital tech stocks), which makes it difficult to generate bubbles (Wang et al., 2022a, 2022b, 2022c) and vice versa. Although the effect of EPU on AII is not significant, it still has certain economic significance, as explained above. Additionally, MPI has no significant influences on BDI, CCI, IOTI, AII and BCI, but these negative effects also possess economic significance; that is, the buoyant stock market accompanied by an economic downturn can lead to the so-called existence of "irrational prosperity" and bubbles (Pan & Mishra, 2018).

Next, we particular focus on the concrete causes behind every bubble and relate them to the above influencing factors. The first bubble exists in BDI, CCI and IOTI, and is concentrated in the period from July 2013 to October 2013. We can interpret this bubble in several ways. First, the National Medium- and Long-term Plan for Major Scientific and Technological Infrastructure Construction (2012–2030) was released in 2013, covering cloud computing services, Internet of Things applications, and data accumulation and processing. This national plan may guide investors and then trigger an "investment fever" in the fields of big data, cloud computing, and the Internet of Things, causing BDI, CCI and IOTI to increase.

Second, under the background of an upward environment and gradual release of reform dividends, A-shares' earnings expectations transform from extreme pessimism to cautious optimism in the third quarter. SSCI has risen from 1979.21 points in June 2013 to 2141.61 points in October 2013, and thus has grown by more than 8%. The upturn in the Chinese stock market and the accompanying upsurge in investor sentiment (Dai et al., 2022; Le & Luong, 2022) have boosted BDI, CCI and IOTI. Third, EPU is at a relatively low level during this period (Baker et al., 2016), leading investors not to invest in safe-haven assets to hedge uncertainties (Qin et al., 2020c, 2021). Then, they are more confident in investing in the stock market (including digital tech stocks), which exacerbates the explosive behavior and causes overinvestment. Fourth, MPI continues to decline during this time, which is always below 100, indicating that the economy is in recession and progressing in an unfavorable direction. The rise in BDI, CCI and IOTI in a depressed economy causes "irrational prosperity" (Pan & Mishra, 2018), urging the formation of a bubble. In addition, the internet giants in China have made noticeable progress in big data, cloud computing and the Internet of Things during this period. For instance, Alibaba has launched Yu Ebao, which is supported by big data, Tencent has fully opened its Cloud, and Baidu has introduced Exchange Servers (BES). These strategies of internet giants have increased investors' confidence in the future development of related fields, causing them to overinvest in digital tech assets, further pushing BDI, CCI and IOTI far beyond their fundamental values. As the investment boom in digital tech assets dissipates, BDI, CCI and IOTI show a downward trend, followed by the burst of this speculative bubble.

The second bubble occurs from January 2014 to February 2014, which exists in BDI, CCI, IOTI and AII. The following sides could interpret this appearance: in terms of relevant policy, there are national policies that could facilitate the development of digital technologies, such as the State Council holding a national teleconference on the Internet of Things to strengthen policy support for it in February 2014. In addition, local policies also had promotion effects on digital technology development; for example, the Guizhou Provincial Government issued the Big Data Industry Development and Application Planning Outline (2014–2020) in February 2014. These national and local policies spur investors to become more bullish on digital tech assets, resulting in an "investment fever" in related fields, followed by a bubble in BDI, CCI, IOTI and AII. Additionally, according to Figure 8, the policies of a certain digital technology not only promote its development but also facilitate the progress of other relevant digital technologies, further attracting investors and exacerbating explosive behaviors. In terms of the Chinese stock market, although the global stock market is depressed and even continued to decline in 2014, A-shares show a rising independent market. Then, this phenomenon would boost sentiment toward the Chinese stock market (including digital tech stocks) among Chinese and foreign investors (Dai et al., 2022; Le & Luong, 2022), driving BDI, CCI, IOTI and AII to grow beyond their fundamental values. In terms of uncertainties, EPU is still at a relatively low level from January 2014 to February 2014 (Baker et al., 2016), leading investors to be more willing to invest in the stock market (including digital tech stocks) rather than hedging assets (Su et al., 2020a, 2022a), which accelerates the formation of a bubble in BDI, CCI, IOTI and AII. In terms of the economic situation, MPI in January and February 2014 was 97.9 and 97.6, respectively, which is below 100, indicating a recession in the national economy. Subsequently, the rise in BDI, CCI, IOTI and AII with an economic downturn significantly increases the probability of a bubble (Pan & Mishra, 2018). However, since the overinvestment in digital tech assets is corrected gradually and the market shows moderate investment, BDI, CCI, IOTI, and AII appear to decrease, resulting in the collapse of this bubble.

The third bubble is concentrated in the period from the second half of 2014 to the first half of 2015, which exists in BDI (from August 2014 to June 2015), CCI (from September 2014 to June 2015), IOTI (from September 2014 to June 2015), AII (from September 2014 to June 2015) and BCI (from January 2015 to June 2015). The major cause behind this bubble is the bull stock market in China (Shu & Zhu, 2020; Zhao et al., 2021). SSCI increased from 2217.2 points in August 2014 to 4277.22 points in June 2015, an increase of more than 90%. As part of the Chinese stock market, digital tech stocks or indices have also presented a similar boom. In addition, the profitability of emerging enterprises represented by GEM is significantly better than that of traditional enterprises during this bull market period (Gui et al., 2022). Since some digital tech enterprises are listed on the GEM, their excellent performance attracts extensive investment, further aggravating speculative bubble generation in BDI, CCI, IOTI, AII and BCI. Simultaneously, this bull market could boost investor sentiment, exacerbating explosive behaviors (Chen et al., 2019; Dai et al., 2022) and causing the Chinese stock market (including digital tech stocks) to continue to boom. Although this bull stock market existed during this time, the economy was extremely depressed, mainly due to excess capacity and insufficient demand. MPI is not only below 100 but also on a downward trend, and has decreased from 97 in July 2014 to 94.55 in June 2015. Then, this phenomenon might have led to "irrational prosperity", followed by bubbles in BDI, CCI, IOTI, AII and BCI. Moreover, policy factors (including digital tech policy and EPU) are also significant reasons behind this bubble. On the one hand, the Report on the Work of the Government first put forward the "Internet Plus" plan in 2015, which promotes the integration of mobile internet, cloud computing, big data and the Internet of Things with modern manufacturing. In addition, "Made in China 2025" mentioned intelligent manufacturing for the first time, and PBC has also been actively developing platforms for trading fiat digital currencies during this time. These national policies or plans allow investors to clarify the future directions in China and then cause them to overinvest in digital tech assets, making BDI, CCI, IOTI, AII and BCI rise farther than their fundamental values. On the other hand, the relatively high degree of economic policy certainty (Baker et al., 2016) makes investors more inclined to invest in riskier but higher return assets (e.g., stocks), urging the formation of a bubble in BDI, CCI, IOTI, AII and BCI. However, the Chinese stock market has plummeted since July 2015 (Zhao et al., 2021), and EPU has also risen significantly (Davis et al., 2019), resulting in low investor confidence in digital tech stocks and subsequent bubble bursts. Additionally, the Guideline on Actively Promoting the "Internet Plus" Initiative issued by the State Council in July 2015 and the subsequent 13th Five-Year Plan have strengthened the regulation and supervision of digital technologies, which is conducive to bringing BDI, CCI, IOTI, AII and BCI back to normal levels.

Overall, the SADF and GSADF statistics show that BDI, CCI, IOTI, AII and BCI have multiple bubbles, while 5GI has no bubbles during the sample period. Additionally, the critical values and relevant results reveal that performing the GSADF technique is reasonable to effectually capture multiple periodic booms and busts. The conclusion points out that the occurrence of bubbles mainly take place during the period from July 2013 to October 2013, January 2014 to February 2014, and the second half of 2014 to the first half of 2015, which is mainly accompanied by the excessive rise in BDI, CCI, IOTI, AII and BCI. This conclusion corresponds to the bubble model, proposing that the asset price has expectations and intangible parts. Although bubbles differ in above sequences, the essential reason is that the sample lengths are various. When discussing each period containing samples, the appearance of bubbles is generally similar due to the intimate interactions amid BDI, CCI, IOTI, AII, BCI and 5GI. Additionally, this analysis explores the influencing factors that cause multiple bubbles and discover that the relevant policies during the 13th and 14th Five-Year Plans period could reduce the possibility of digital tech bubbles. Additionally, the Chinese stock market exerts positive effects on digital tech bubbles, while economic policy uncertainties and situations negatively influence explosive behaviors.

Conclusions and policy implications

Theoretical contributions

This investigation primarily addresses two research questions, which also have advantages to the extant literature. First, previous studies primarily provide proof of the existence of the internet or tech bubble, as well as a bubble of products based on digital technology, but there is no existing study that directly explores digital tech bubbles. Thus, the analysis is a groundbreaking work to probe if digital tech bubbles exist in China, and we also consider various digital technologies. In addition, we employ the more advanced GSADF technique to probe the multiple digital tech bubbles in China, which is also a marginal contribution to the extant literature. The empirical results reveal that bubbles occur mainly during the period from the second half of 2013 to the first half of 2015, coinciding with bubble theory, which suggests that expectations and intangibles exist in the formation of asset price. Because of the close relations among different digital technologies (including big data, cloud computing, the Internet of Things, artificial intelligence, blockchain and 5G), the occurrence of bubbles is basically similar when considering each period that contains samples.

The existing efforts mainly focus on the influencing factors (e.g., trade disputes and stock market sentiment) of the internet or tech stock prices from the perspective of China but ignore the factors that contribute to bubbles. Therefore, we innovatively provide empirical evidence on the underlying causes of digital tech bubbles and find that the relatively mature regulations and unified technical standards in the 13th and 14th Five-Year Plans curb the occurrence of digital tech bubbles. The Chinese stock market has positive effects on digital tech bubbles, mainly because digital tech stocks are part of the Chinese stock market, and the latter could also reflect investor sentiment. At the same time, economic policy uncertainty could adversely affect explosive behaviors in the digital tech market since investors are more inclined to seek hedging assets or safe havens (e.g., previously metals) to avoid uncertainties. Moreover, the economic situation also exerts negative influences on digital tech bubbles because the buoyant stock market accompanied by an economic downturn may be more prone to "irrational prosperity". By this analysis, it can be claimed that there are digital tech bubbles in China, but they existed mainly before the 13th Five-Year Plan period.

Policy significance

On the basis of the conclusion, we can put forward significant insights for China to promote the sustainable development of digital technology and the digital economy. First, although the probability of digital tech bubbles has dropped significantly since 2016, China should still guard against it. The government should vigorously encourage funds into digital technologies while taking precautions to prevent investment from overheating, such as adopting macroprudential policies that reliably monitor the existence of bubbles, judge their stages, and accordingly implement policy interventions. Additionally, relevant authorities ought to innovate the approaches to regulating digital technologies and establish a complete government regulation system to prevent speculative and even explosive behaviors. Particularly, they should be warier of Chinese stock market booms during periods with economic downturns and low policy uncertainties, which may lead to severe bubbles. However, since the digital tech industry is emerging, it can allow reasonable bubbles to exist through reform and innovation to play their role in promoting the industry. Subsequently, the government should be moderately cautious about potential bubbles in the digital tech sector to prevent excessive regulation from backfiring. Second, digital tech enterprises should rely on innovation to build their core competitiveness and try to squeeze out bubbles. They must be closely integrated with manufacturing and service industries, as well as shouldering the responsibility of economic transformation and upgrading to avoid the risk of bubble accumulation caused by stock market speculation divorced from actual production. Additionally, these related enterprises ought to explore digital tech products and services with more market value, pay attention to the simultaneous development of quality and speed, and then guide the digital tech industry to grow soundly and steadily within a reasonable bubble range. Third, investors cannot rely solely on market enthusiasm to assess the value of digital innovations but on their contribution to the productivity of traditional industries to avert "herd behavior" from driving asset prices far above their fundamental values. Additionally, investors should invest rationally and accurately identify arbitrage in the market to avoid huge losses from the burst of digital tech bubbles. In addition, maintaining a roughly stable development of the Chinese stock market al.o dampens digital tech bubbles.

Limitations and future research directions

The limitations of this investigation are reflected in two aspects. On the one hand, this paper only explores digital tech bubbles and their influencing factors in China, but we do not consider the development of digital technology and the digital economy in other countries or regions. On the other hand, this study has not yet predicted the direction or intensity of asset price movements in the digital tech market. In future exploration, we will analyze the existence of digital tech bubbles from the perspectives of other countries or regions and even the whole world. In addition, we will conduct a similar investigation with an interval of one year and compare the conclusions obtained. Additionally, the occurrence of the next digital tech bubble should be further predicted.

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