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Impact of Cryptocurrency Market Capitalization on Open Source Software Participation

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Abstract: Open source software (OSS) has become indispensable to our society. The success of OSS depends on the participation of a large number of developers or maintainers (contributors). Shedding light on the mechanisms of their participation has been an important academic and practical matter. One aspect to decide participation is the future prospects of a project. However, the causal mechanism behind participation has yet to be studied exhaustively and remains unclear. In this study, we used cryptocurrency projects, many of them were developed on GitHub, to better understand this mechanism. Both GitHub and cryptocurrencies are highly transparent, i.e., information is fully disclosed; we can analyze relevant information on a project, such as the contributors' activities, financial information, and development status. We adopted market capitalization as the substitution index of future prospects and the number of contributors and analyzed the relationship using time series analysis techniques, such as the Granger causality test and regression. We found that the number of contributors increases two months after market capitalization increases. This quantifies the impact of the future prospects of the project, i.e., of the market capitalization of a cryptocurrency, on the participation of contributors.

Keywords: cryptocurrency, open source software, mining software repositories, GitHub

1. Introduction

Open source software (OSS) has been adopted not just for consumer software products but for the core systems of companies and public institutions as well. It has become a staple of today's society. To develop and sustain OSS, it is necessary to gather stakeholders, especially developers and maintainers (contributors) from outside the project in addition to the initial core members. OSS projects have frequently failed due to insufficient volunteer participation [1]. We can say the number of developers involved in a project is a potential indicator of success [2]. Thus, better understanding the dynamics of the contributors' participation to the project has been an important academic and practical topic of interest.

Recently, a considerable amount of OSS has been developed on GitHub, which is a code hosting, internet-based service aiming at supporting collaborative software development. Artifacts, such as source code and documents on it, are open to the public in principle. Any individual can not just refer to them but modify them as well as a contributor. This service has grown rapidly since its launch in April 2008. As of April 2017, it has over 20 million users and 57 million projects [3]. Major OSS projects such as Bootstrap, jQuery, and Docker use GitHub for the development and maintenance of their artifacts.

Many cryptocurrencies are developed and continue to be developed as OSS, including the first cryptocurrency, Bitcoin. Bitcoin was invented by an unknown person or a group under the name Satoshi Nakamoto. The anonymous creator published a paper on the cryptocurrency in 2008 [4] and released the initial OSS in 2009. Interestingly, not only can everyone view the source code, but they can also branch out and start their own cryptocurrency projects. Since Bitcoin, cryptocurrencies with several different schemes have been invented. Nearly 600 listed projects have been reported, and many of them are managed on GitHub [*1].

In general, cryptocurrencies have a high level of transparency. Firstly, the source code, documents, and the activity history of a cryptocurrency project developed on GitHub can be publicly viewed. Secondly, a cryptocurrency uses the blockchain technology, which discloses all transaction records to the public. Finally, in the case of a listed cryptocurrency, anyone can acquire market information such as market price, volume, and market capitalization as time series data. In other words, the activities of all stakeholders such as developers, users, miners, traders, and project managers are disclosed. Using the information, we can analyze OSS from a different perspective.

We adopted market capitalization as an indicator of future prospects. In stock markets, market capitalization is equal to the share price multiplied by the number of shares outstanding. As market capitalization reflects all available information at any time [5], it is often used as an indicator of public opinion of a company's net worth and is a determining factor in some forms of stock valuation [6], [7] [*2]. The market capitalization of cryptocurrency is equal to the market price of each coin multiplied

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*1 http://coinmarketcap.com (accessed 2018-02-18)
*2 https://en.wikipedia.org/wiki/Market_capitalization (accessed 2019-10-04)

by the total circulating supply [*3]. If the market capitalization of a cryptocurrency increases, one can consider the cryptocurrency promising. If people are motivated by it, the participation increases.

In this study, we adopt the number of contributors of cryptocurrency projects on GitHub as an index of participation along with their market capitalization and proposed the following research question:

(RQ) Are "future prospects" an important factor in determining the participation of the contributors in an OSS project? In other words, does market capitalization, allegedly an indicator of future prospects, affect the participation of contributors?

We conducted time series analysis and examined the existence of a causal relationship using the Granger causality test [8] for every cryptocurrency project we extracted from GitHub.

The structure of this paper is as follows. In Section 2, we review studies related to the participation in OSS projects. In Section 3, we explain how to acquire and clean cryptocurrency information. The characteristics of the cryptocurrency projects on GitHub are described in detail in Section 4; in Section 5, we present the results/solutions answering the research question posed above. We conclude and discuss future work in Section 6.

2. Related Work

In this study, we attempted to analyze the relationships between the number of contributors and the market capitalization quantitatively. Our goal was to confirm "future prospects" is an important factor in determining the contributors' participation in an OSS project.

The participation in OSS projects has been studied for many years. Krogh et al. [9] investigated past studies and classified the various motivations for participating into three groups: intrinsic, internalized extrinsic, and extrinsic. Intrinsic motivations include ideology, altruism, kinship, enjoyment, and fun. Internalized extrinsic motivations include reputation, reciprocity, learning, and use-value. Pure extrinsic motivations include careers and pay. Krogh concluded, "Figuring out what moves people, we should start with the assertion that people's pursuit of visible carrots is at times interrupted by the larger quest for the invisible gold at the end of the rainbow."

What motivation lies beneath the participation? Robert et al. [10] studied the relation between motivation and participation. They used three major OSS projects under the umbrella of the Apache Software Foundation and revealed that developers' paid participation and motivation linked to status lead to above-average contribution levels, but use-value motivation leads to below-average contribution levels, and there is no significant relationship between intrinsic motivation and participation. They also found that status motivation enhances intrinsic motivation. Cerasoli et al. showed that intrinsic motivation was less important to performance when incentives were directly tied to performance [11]. For some users, payment has a direct positive effect on overall motivation [12].

Dabbish et al. [13] discovered through an interview that the user decided on which project to participate in based on speculation around which projects would thrive in the long run. Users combine these inferences into effective strategies for coordinating work, advancing technical skills and managing their reputation.

Previous studies insisted that users tend to choose a project that satisfies pure extrinsic motivations such as status, reputation and pay. Considering the cryptocurrency projects, there are two hypotheses. 1) Status: rising market capitalization means that the cryptocurrency is gathering attention, and the project is expected to be well-known accordingly. Participating in high-profile projects leads to the participant's reputation. 2) Pay: some projects might provide participants with the cryptocurrency or a user may decide to invest while participating in the project. In this case, users select a promising project. Thus, the future of a project is considered an important factor for the contributors when deciding their participation.

In this study, we attempt to present a new quantitative approach that examines the results of previous works and measures the impact of perception on the project future on participation.

To analyze the causal relationship quantitatively, research using a time lag is practical [8]. There have been several studies over time [14], [15]. Stewart et al. [16] investigated the impacts of organizational sponsorship and license restrictiveness on developers over time and concluded that the cues regarding the future of a project can be picked up from the available information. For example, they found that the projects that are sponsored by nonmarket organizations employ nonrestrictive licenses. However, to the best of our knowledge there has not been any time series analysis to date. In this study, we used time series analysis techniques, such as the Granger causality test [8] and regression for this purpose.

3. Overview of the Dataset

3.1 Projects Used to Date

The OSS projects used in the analysis changed with time. The first studies on well-known projects such as Apache and Linux have been popular, but such studies peaked in 2003 and dropped sharply thereafter [17]. Indeed, there were no other options for these projects at that time. Studies were conducted either on specific projects or the entire community under the same governance. These projects tend to adopt a traditional OSS development such as developer hierarchies [18] and only qualified individuals can modify the code. Even if people are motivated, they are not always able to participate in the project.

Source coding services such as SourceForge and GitHub have made possible the analysis of a large number of projects bundled together. In addition, a GitHub user can modify a repository without being part of the development team because of a novelty idea of decoupling of the development effort from the decision to incorporate the results of the development in the code base [19]. Studies on participation were conducted frequently using GitHub since around 2010.

*3 https://blockgeeks.com/guides/cryptocurrency-market-cap/ (accessed 2019-10-04)

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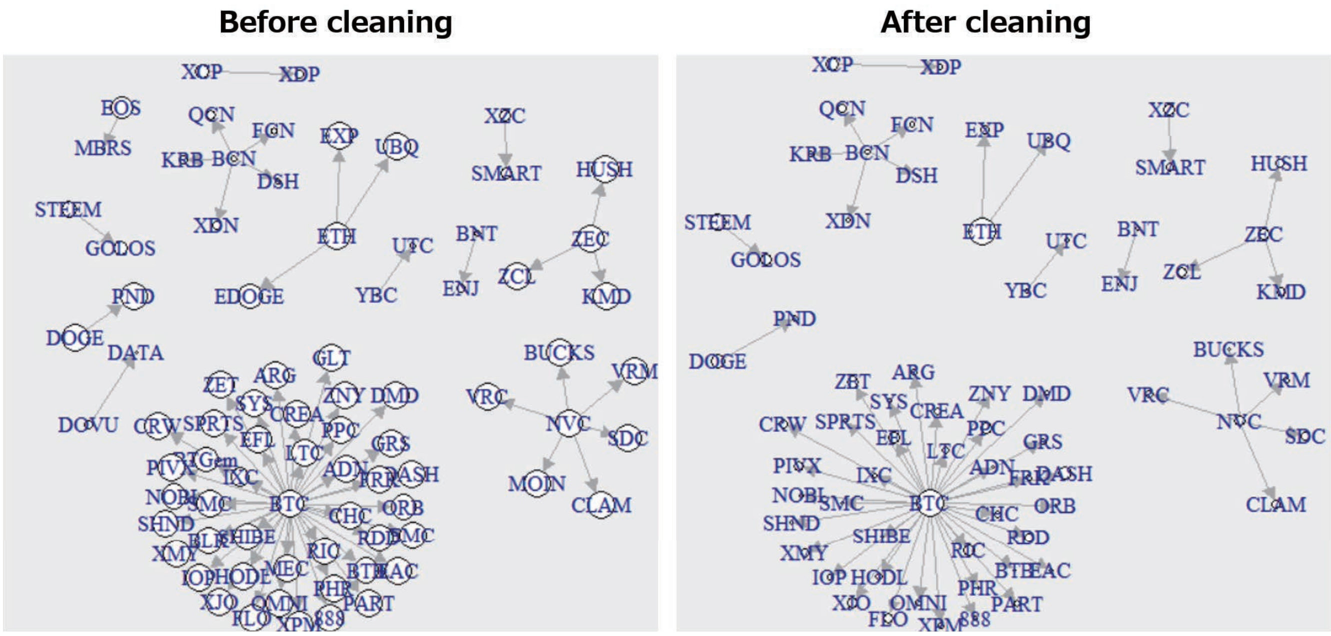


Fig. 1 The cleaning process of forked projects (only projects with fork relationships are shown). The size of the circle indicates the number of contributors. The source and destination projects have a nearly identical number of contributors (left) before cleaning. After cleaning, it is apparent that the number of contributors in the destination project decreases significantly (right). (The data was obtained on 2018-02-12)

3.2 Project Selection Challenges

As GitHub includes a considerable number of projects, it is impossible to analyze them all. Researchers have to use a subset of the data; thus the extraction criteria for the projects is essential. Previous studies used popular [20], active [21], etc. In these cases, each project is independent and there is no relationship between projects, which may distort the results.

Here, we attempt to maintain the relationship between projects by using the projects belonging to the same domain as cryptocurrency.

3.3 Obtain the Dataset

As mentioned in the introduction, we chose two variables of market capitalization and the number of contributors for each cryptocurrency project. We acquired them as time series data using the following procedures.

First, we obtained the list of cryptocurrencies from a market ranking chart website [*4]. This site provides the market capitalization in USD from April 2013 and the URLs of the development site. Major cryptocurrencies (See Section A.1), i.e., cryptocurrencies with the top 30 market capitalization, use GitHub as a development site. We obtained 584 URLs on GitHub.

GitHub provides an application programming interface (API), which allows us to obtain information of each project. We created the activity data of a contributor (a user who committed to the project at least once) based on the information acquired using the API. We accessed each URL using the API. Although some URLs did not exist, data pertaining to a total of 554 projects was collected. Here, the maximum number of contributors that can be acquired using the API is 100 for each project. The number of contributors has increased sharply since March 2017; however, from the data up to June 2017 used in this analysis, we can confirm there were no projects exceeding 100 contributors. Therefore, we used the data acquired with the API as is.

3.4 Clean the Data

We cleaned the data in the following way.

(1) Several projects are created by forking or reusing major cryptocurrency source code such as Bitcoin. In these cases, the project also inherits the history of activity in the original project; i.e., the activity is recorded in duplicate. This duplicate data must be deleted. We examined derived projects and deleted the duplicate contributors and their activity records (**Fig. 1**).
(2) Some contributors have multiple user IDs [22]. We cleaned the data using the tool [*5] that matches users with their information recorded in GitHub (e.g., login name, actual name, email address, and location). We examined the 2444 contributors of the projects and concluded that 10 were duplicates. We then merged the duplicate IDs and bringing the total number of contributors down to 2434 as a result.
(3) We excluded the projects with no contributors; these are presumed to be used simply as source code locations. In the end, 457 projects remained.

4. Characteristics of the Cryptocurrency Projects on GitHub

We believe that having an accurate understanding of the characteristics of the cryptocurrency projects hosted on GitHub, is vi-

*4 https://www.coingecko.com (accessed 2018-02-12)

*5 https://github.com/bvasiles/ght_unmasking_aliases (accessed 2018-05-13)

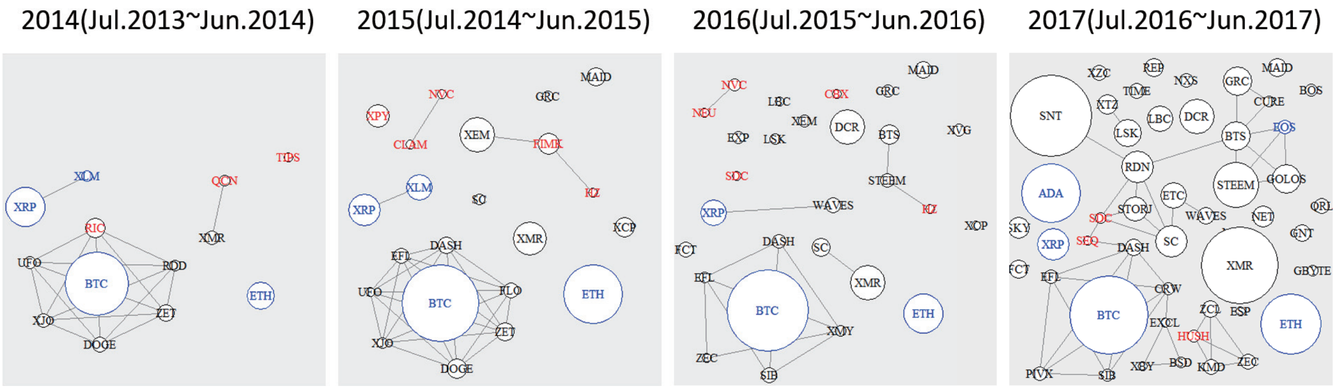


Fig. 2 Network structures of cryptocurrency projects. Projects with more than six contributors during the indicated period are displayed. Red letters indicate "dead" projects, and blue letters indicate projects with market capitalization within the top 10.

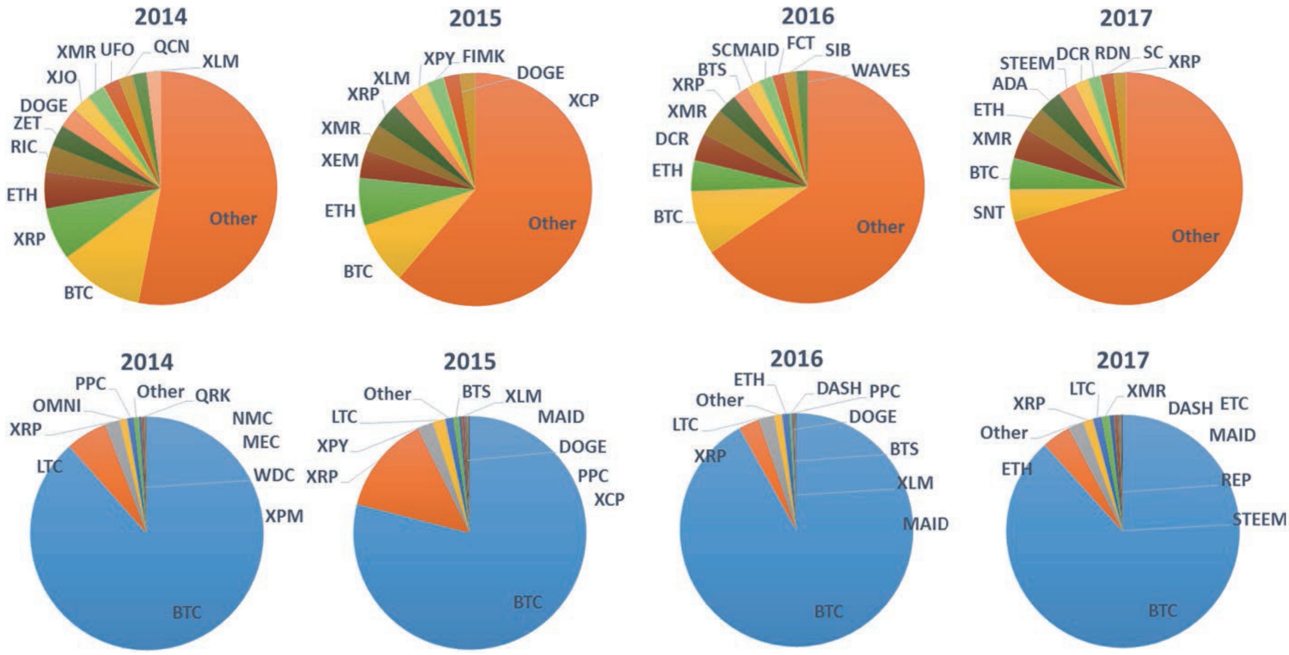


Fig. 3 Percentage of the contributors (upper) and the market capitalization (lower) of the cryptocurrency for each year.

tal in this study. This section describes the descriptive statistics, structure and temporal change of these projects.

As mentioned before, the number of projects is 457, each of which has more than a single contributor. For 202 projects, there had been no activity history for over half a year (i.e., they are dead). The average project life expectancy was 287 days as of February 2018. The number of contributors is 2434. According to the activity data, approximately 20% of them (504) have committed only once. This percentage is much lower than the 48.98% obtained in previous research [21].

Contributors participate in multiple projects. Approximately 10% of the contributors (254) participated in multiple projects. **Figure 2** shows the network structure of the cryptocurrency over four years. The projects that a contributor participated in the same period are connected by an edge. The size of a circle is proportional to the number of contributors. It has been observed that Bitcoin and its forked projects have accounted for a large proportion of OSS projects. Other projects have grown each year with contributors switching actively between projects.

Figure 3 shows the ratio of the number of contributors (upper) and the market capitalization (lower) of the projects each year. In terms of contributors, the percentage of the top 10 projects has declined gradually; however, no extreme changes are visible over the years. Bitcoin accounts for an overwhelming proportion in market capitalization for all periods. The second and subsequent rankings change every year. However, no significant change is observed on a per year basis.

The market capitalization of the cryptocurrency has not increased monotonically. The same is true for the number of contributors supporting the projects. **Figure 4** shows the time series of the total market capitalization for all the projects (shown as MC) and the sum of the unique contributors for all the projects each week (shown as WUC). The trend changed as a result of several events. In December 2013, Bitcoin price, which accounts for a large share of the cryptocurrency market capitalization, plummeted owing to the Chinese government's regulation on financial institutions (Fig. 4 {1}). The price had been sluggish over the long term since then. Moreover, when the European Court

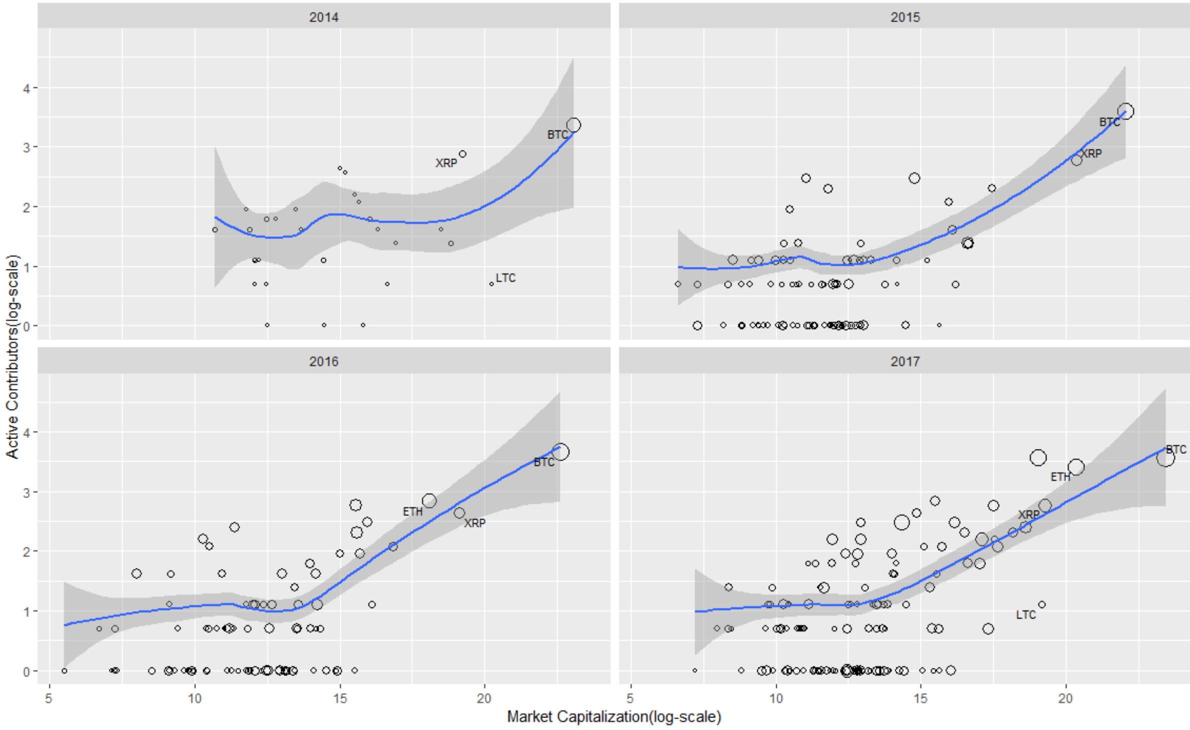


Fig. 5 Relationship between active contributors and the market capitalization in log-scale with loss curve. The size of a circle indicates the sum of contributors over the whole period.

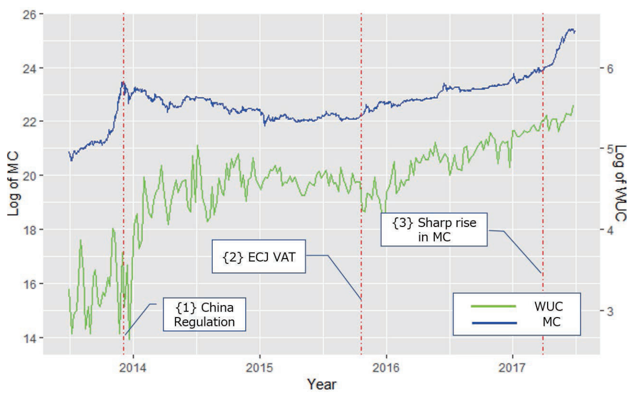


Fig. 4 Time series of the sum of market capitalization (MC) and weekly unique contributors (WUC) of all cryptocurrency projects. Social events are indicated in red dotted lines.

of Justice ruled that Bitcoin was not subject to VAT taxation (Fig. 4 {2}), market capitalization started to rise around October 2015. A sudden rise in market capitalization occurred in March 2017 (Fig. 4 {3}).

5. Analyzing Market Capitalization and Project Contributors

5.1 Relationship between Market Capitalization and Participation

Before analyzing the time series, we looked broadly at the relationship between market capitalization and contributors for individual cryptocurrencies each year. **Figure 5** depicts the relationship between the market capitalization at the beginning of the year and the number of contributors with records of activity (active contributor) after half a year. Both datasets were converted to natural log-scale to approximate a normal distribution. Large circles denote big projects with a large number of participants across the whole period. We can see that both market capitalization and active contributors of the projects are increasing gradually every year. The tendency for a cryptocurrency project with a larger market capitalization to have more contributors appears clearly.

5.2 Granger Causality Test

Will market capitalization affect contributors' behavior? What impact will it have and when will it occur? To answer these questions, we performed time series analysis, the Granger causality test and regression analysis, on the cryptocurrency information, namely, the sum of market capitalization (represented as MC), and sum of unique contributors each week (represented as WUC) for all projects. Here, MC and WUC were both converted to natural log-scale to approximate a normal distribution.

The equations involved in time series analysis are:

$$WUC_t = c_1 + \delta_1 t + \phi_{1,1}^{(1)} MC_{t-1} + \phi_{2,1}^{(1)} WUC_{t-1} + \cdots + \phi_{1,p}^{(1)} MC_{t-p} + \phi_{2,p}^{(1)} WUC_{t-p} + \varepsilon_{1,t} \quad (1)$$

$$MC_t = c_2 + \delta_2 t + \phi_{1,1}^{(2)} MC_{t-1} + \phi_{2,1}^{(2)} WUC_{t-1} + \cdots + \phi_{1,p}^{(2)} MC_{t-p} + \phi_{2,p}^{(2)} WUC_{t-p} + \varepsilon_{2,t} \quad (2)$$

$$WUC_t = c'_1 + \delta'_1 t + \phi_{2,1}^{(3)} WUC_{t-1} + \cdots + \phi_{2,p}^{(3)} WUC_{t-p} + \varepsilon'_{1,t} \quad (3)$$

$$MC_t = c'_2 + \delta'_2 t + \phi_{1,1}^{(4)} MC_{t-1} + \cdots + \phi_{1,p}^{(4)} MC_{t-p} + \varepsilon'_{2,t} \quad (4)$$

Here, c_i is a constant and δ_i is a trend term. Each parameter (δ and ϕ) in the model can be estimated by OLS (ordinary least squares).

We first conducted the Granger causality test [8] to examine the existence of a causal relationship from MC to WUC. According

Table 1 Result of the Granger causality test.

Case	Null signif.	Value	Result
1	$MC \longrightarrow WUC$	F statistic	5.276
		p value	0.0002***
2	$WUC \longrightarrow MC$	F statistic	1.597
		p value	0.165

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1

Table 2 Result of regression analysis.

Case 1 $MC \longrightarrow WUC$: Eq. (1)			Case2 $WUC \longrightarrow MC$: Eq. (2)		
Coefficient	Estimate	$P(>\|t\|)$	Coefficient	Estimate	$P(>\|t\|)$
$\phi^{(1)}_{1,1}$	−0.195	0.066+	$\phi^{(2)}_{1,1}$	1.592	$8.55e-13$***
$\phi^{(1)}_{2,1}$	0.292	0.077+	$\phi^{(2)}_{2,1}$	−0.215	0.369
$\phi^{(1)}_{1,2}$	0.587	0.002**	$\phi^{(2)}_{1,2}$	−1.093	$1.21e-4$***
$\phi^{(1)}_{2,2}$	0.218	0.118	$\phi^{(2)}_{2,2}$	−0.260	0.203
$\phi^{(1)}_{1,3}$	−0.161	0.262	$\phi^{(2)}_{1,3}$	0.575	0.009**
$\phi^{(1)}_{2,3}$	0.063	0.59	$\phi^{(2)}_{2,3}$	0.050	0.774
C_1	−3.331	0.005**	C_2	−0.036	0.982
δ_1	0.004	0.209	δ_2	0.013	0.011*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1

to Ref. [8], if the time series X is useful in forecasting the time series Y, the time series X is said to Granger-cause Y. Specifically, we compared the prediction of future Y based only on the current and past values of Y and the prediction of future Y based on the current and past values of Y and X. If the latter mean squared error (MSE) is smaller, then there exists a Granger causality from X to Y.

As tests of causal significance require stationary time series, we also performed preliminary analysis to check for stationarity and created stationary time series by using first differencing.

We then calculated the variance for the residual of the model [23]. The optimum order of $p = \{1, \ldots, 3\}$ was determined according to the minimum value of AIC (Akaike's Information Criterion).

Next, let SSR0 be the residual sum of squares of Eq. (1) and SSR1 be the residual sum of squares of Eq. (3), we can calculate the value of F statistic using Eq. (5) where T is the sample size.

$$F statistic = \frac{(\mathrm{SSR0} - \mathrm{SSR1})/2}{\mathrm{SSR1}/(T - 2p - 1)} \tag{5}$$

Comparing the resulting F statistic with the 95% point of the F distribution, we can statistically test the hypothesis of Granger causality from MC to WUC. This also applies to the test from WUC to MC with Eqs. (2) and (4). **Table 1** shows the results of the Granger causality test. In case 1 from MC to WUC, the result was 0.1% significant; however, in case 2 in the opposite direction, it was not significant. Thus, MC is said to Granger-cause WUC. Conversely, WUC does not Granger-cause MC.

5.3 Duration between Changes in MC and WUC

Equations (1) and (2) enable further analysis. **Table 2** summarizes the results of regression analysis. In case 1, from MC to WUC, the coefficient $\phi^{(1)}_{1,2}$ (MC before two months) was 1% significant with a positive value. This implies that a change in WUC tends to lag a change in MC by two months. In case 2 from WUC to MC, past coefficients of MC were significant; however, none of the past WUC coefficients were significant. In other words, the past WUC values have no impact on the future MC value.

6. Conclusion and Future Works

We interpret the above results as follows:

- From Table 1, the results of the Granger causality test indicate that 1) there is a possibility of having a causal relationship from market capitalization to the number of contributors and 2) no causal relationship exists from the number of contributors to market capitalization.
- As a result of the regression analysis (Table 2 case 1), the number of contributors increased (decreased) two months after the market capitalization increased (decreased). This seems to suggest that the future prospects of a project (i.e., market capitalization) increase the project participation. It is speculated that an increase in the market capitalization leads to the acquisition of new contributors.
- On the contrary, no correlation was found between the past number of contributors and the future market capitalization (Table 2 case 2). It can be said that the factors that determine market capitalization are significantly influenced by popularity and public interest (such as in newspapers and social media). The increase in the number of contributors is seldom known to the general public; hence this seems reasonable.
- The results of the regression analysis are consistent with the result of the Granger causality test.

Our result does not prove the existence of a real causality between market capitalization and the number of contributors. A confounding factor, which influences both market capitalization and the number of contributors, may exist and be the real common cause. However, even if we assume the existence of such a confounding factor, we interpret such a factor as representing the "future prospects" of the cryptocurrency. For example, studies such as Refs. [24], [25] demonstrate the impact of social media on the market capitalization of the cryptocurrency. Such a factor may be a confounding factor. The important conclusion of this research, i.e., "the 'future prospects' of a project influence the participation of its contributor", does not change.

The framework used in this study is applicable to various analyses, and is structured as follows. 1) We extracted and analyzed mutually related projects of cryptocurrency, whereas previous research analyzed a group of unrelated projects. 2) A cryptocurrency has financial information, such as market price and volume. It is also possible to acquire social media information, search volume in search engines, transaction volume, event information covered by newspapers etc.

As for the participation of contributors, there were many unique studies. It is possible to apply these research methods to our framework. For example, we believe we can further strengthen the follow-up network analysis conducted by Yu et al. [26]. Yamashita et al. [27], [28] classified OSS projects by using metrics of magnet and sticky and identified what projects retain and attract contributors. By matching the information of our framework with these metrics, we may be able to analyze the behavior of contributors in more detail. Such analyses represent potential future endeavors.

References

[1] Fang, Y. and Neufeld, D.: Understanding sustained participation in open source software projects, *Journal of Management Information Systems*, Vol.25, No.4, pp.9–50 (online), DOI: 10.2753/MIS0742-1222250401 (2008).

[2] Grewal, R., Lilien, G.L. and Mallapragada, G.: Location, location, location: How network embeddedness affects project success in open source systems, *Management Science*, Vol.52, No.7, pp.1043–1056 (online), DOI: 10.1287/mnsc.1060.0550 (2006).

[3] GitHub: Celebrating nine years of GitHub with an anniversary sale, The GitHub blog (online), available from ⟨https://github.com/blog/2345-celebrating-nine-years-of-github-with-an-anniversary-sale⟩ (accessed 2018-02-12).

[4] Nakamoto, S.: Bitcoin: A Peer-to-Peer Electronic Cash System, *Www.Bitcoin.Org*, p.9 (online), DOI: 10.1007/s10838-008-9062-0 (2008).

[5] Malkiel, B.G. and Fama, E.F.: Efficient capital markets: A review of theory and empirical work, *The Journal of Finance*, Vol.25, No.2, pp.383–417 (1970).

[6] Zhang, W. and Skiena, S.: Trading strategies to exploit blog and news sentiment, *ICWSM 2010 - Proc. 4th International AAAI Conference on Weblogs and Social Media*, Vol.d, pp.375–378 (2010).

[7] Abdolmohammadi, M.J.: Intellectual capital disclosure and market capitalization, *Journal of Intellectual Capital*, Vol.6, No.3, pp.397–416 (2005).

[8] Granger, C.W.J.: Investigating Causal Relations by Econometric Models and Cross-spectral Methods, *Econometrica*, Vol.37, No.3, p.424 (online), DOI: 10.2307/1912791 (1969).

[9] Krogh, G.V., Haefliger, S., Spaeth, S. and Wallin, M.W.: Carrots and Rainbows: Motivation and Social Practice in Open Source Software Development, *MIS Quarterly*, Vol.36, No.2, pp.649–676 (2012).

[10] Roberts, J.A., Hann, I.-H. and Slaughter, S.A.: Understanding the Motivations, Participation, and Performance of Open Source Software Developers: A Longitudinal Study of the Apache Projects, *Management Science*, Vol.52, No.7, pp.984–999 (2006).

[11] Cerasoli, C.P., Nicklin, J.M. and Ford, M.T.: Intrinsic motivation and extrinsic incentives jointly predict performance: A 40-year meta-analysis, *Psychological Bulletin*, Vol.140, No.4, pp.980–1008 (online), DOI: 10.1037/a0035661 (2014).

[12] Alexy, O. and Leitner, M.: A fistful of dollars: Are financial rewards a suitable management practice for distributed models of innovation?, *European Management Review*, Vol.8, No.3, pp.165–185 (online), DOI: 10.1111/j.1740-4762.2011.01017.x (2011).

[13] Dabbish, L., Stuart, C., Tsay, J. and Herbsleb, J.: Social Coding in GitHub: Transparency and Collaboration in an Open Software Repository, *Proc. ACM 2012 Conference on Computer Supported Cooperative Work*, pp.1277–1286 (online), DOI: 10.1145/2145204.2145396 (2012).

[14] Shah, S.K.: Motivation, Governance, and the Viability of Hybrid Forms in Open Source Software Development, *Management Science*, Vol.52, No.7, pp.1000–1014 (online), DOI: 10.1287/mnsc.1060.0553 (2006).

[15] Goeminne, M. and Mens, T.: Evidence for the Pareto principle in open source software activity, *CEUR Workshop Proceedings*, Vol.708, pp.74–82 (2011).

[16] Stewart, K.J., Ammeter, A.P. and Maruping, L.M.: Impacts of license choice and organizational sponsorship on user interest and development activity in open source software projects, *Information Systems Research*, Vol.17, No.2, pp.126–144 (online), DOI: 10.1287/isre.1060.0082 (2006).

[17] Crowston, K., Wei, K., Howison, J. and Wiggins, A.: Free/Libre open-source software development, *ACM Computing Surveys*, Vol.44, No.2, pp.1–35 (online), DOI: 10.1145/2089125.2089127 (2012).

[18] Peterson, K.: The GitHub Open Source Development Process, pp.1–10 (2013).

[19] Gousios, G., Pinzger, M. and Deursen, A.V.: An exploratory study of the pull-based software development model, *Proc. International Conference on Software Engineering*, No.1, pp.345–355 (online), DOI: 10.1145/2568225.2568260 (2014).

[20] Fershtman, C. and Gandal, N.: Open source software: Motivation and restrictive licensing, *International Economics and Economic Policy*, Vol.4, No.2, pp.209–225 (2007).

[21] Pinto, G., Steinmacher, I. and Gerosa, M.A.: More Common Than You Think: An In-depth Study of Casual Contributors, *2016 IEEE 23rd International Conference on Software Analysis, Evolution, and Reengineering* (*SANER*), No.1, pp.112–123 (online), DOI: 10.1109/SANER.2016.68 (2016).

[22] Vasilescu, B., Posnett, D., Ray, B., van den Brand, M.G., Serebrenik, A., Devanbu, P. and Filkov, V.: Gender and Tenure Diversity in GitHub Teams, *Proc. 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, pp.3789–3798 (online), DOI: 10.1145/2702123.2702549 (2015).

[23] Hamilton, J.D.: *Time series analysis*, Vol.2, Princeton University Ppress Princeton, NJ (1994).

[24] Garcia, D. and Schweitzer, F.: Social signals and algorithmic trading of Bitcoin, *Royal Society Open Science*, Vol.2, No.9, p.150288 (2015).

[25] Phillips, R.C. and Gorse, D.: Predicting cryptocurrency price bubbles using social media data and epidemic modelling, *2017 IEEE Symposium Series on Computational Intelligence* (*SSCI*), pp.1–7 (online), DOI: 10.1109/SSCI.2017.8280809 (2017).

[26] Yu, Y., Yin, G., Wang, H. and Wang, T.: Exploring the Patterns of Social Behavior in GitHub, *Proc. 1st International Workshop on Crowd-based Software Development Methods and Technologies*, pp.31–36 (online), DOI: 10.1145/2666539.2666571 (2014).

[27] Yamashita, K., McIntosh, S., Kamei, Y. and Ubayashi, N.: Magnet or sticky? An OSS project-by-project typology, *Proc. 11th Working Conference on Mining Software Repositories - MSR 2014*, pp.344–347 (online), DOI: 10.1145/2597073.2597116 (2014).

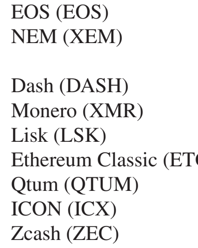
[28] Yamashita, K., Kamei, Y., McIntosh, S., Hassan, A.E. and Ubayashi, N.: Magnet or Sticky? Measuring Project Characteristics from the Perspective of Developer Attraction and Retention, *Journal of Information Processing*, Vol.24, No.2, pp.339–348 (online), DOI: 10.2197/ipsjjip.24.339 (2016).

Appendix

A.1 Major Cryptocurrency List

Table A.1 Cryptocurrencies with the top 30 market capitalization. (source: https://www.coingecko.com (accessed 2018-02-12))

name	URL
Bitcoin (BTC)	https://github.com/bitcoin/bitcoin
Ethereum (ETH)	https://github.com/ethereum/go-ethereum
Ripple (XRP)	https://github.com/ripple/rippled
Bitcoin Cash (BCH)	https://github.com/Bitcoin-ABC/bitcoin-abc
Cardano (ADA)	https://github.com/input-output-hk/cardano-sl
Litecoin (LTC)	https://github.com/litecoin-project/litecoin
Stellar Lumens (XLM)	https://github.com/stellar/stellard
NEO (NEO)	https://github.com/neo-project/neo
EOS (EOS)	https://github.com/EOSIO/eos
NEM (XEM)	https://github.com/NewEconomyMovement/NemCommunityClient
Dash (DASH)	https://github.com/dashpay/dash
Monero (XMR)	https://github.com/monero-project/monero
Lisk (LSK)	https://github.com/LiskHQ/lisk
Ethereum Classic (ETC)	https://github.com/ethereumproject/go-ethereum
Qtum (QTUM)	https://github.com/qtumproject/qtum
ICON (ICX)	https://github.com/theloopkr/loopchain
Zcash (ZEC)	https://github.com/zcash/zcash
Steem (STEEM)	https://github.com/steemit/steem
Bytecoin (BCN)	https://github.com/amjuarez/bytecoin
Verge (XVG)	https://github.com/vergecurrency/verge
Status (SNT)	https://github.com/status-im/status-react
Siacoin (SC)	https://github.com/NebulousLabs/Sia
Stratis (STRAT)	https://github.com/stratisproject/Breeze
BitShares (BTS)	https://github.com/BitShares/bitshares-2
Aeternity (AE)	https://github.com/aeternity/epoch
Dogecoin (DOGE)	https://github.com/dogecoin/dogecoin
Veritaseum (VERI)	https://github.com/veritaseum/Veritaseum
Waves (WAVES)	https://github.com/wavesplatform/Waves
Augur (REP)	https://github.com/AugurProject/augur-core
0x (ZRX)	https://github.com/0xProject/contracts



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