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Review

A bibliometric analysis of bitcoin scientific production

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ABSTRACT

Blockchain technology, and more specifically bitcoin (one of its foremost applications), have been receiving increasing attention in the scientific community. The first publications with bitcoin as a topic, can be traced back to 2012. In spite of this short time span, the production magnitude (1162 papers) makes it necessary to make a bibliometric study in order to observe research clusters, emerging topics, and leading scholars. Our paper is aimed at studying the scientific production only around bitcoin, excluding other blockchain applications. Thus, we restricted our search to papers indexed in the Web of Science Core Collection, whose topic is "bitcoin". This database is suitable for such diverse disciplines such as economics, engineering, mathematics, and computer science. This bibliometric study draws the landscape of the current state and trends of bitcoin-related research in different scientific disciplines.

1. Introduction

Bibliometric studies has become an emergent and buoyant discipline, given the importance posed on the assessment of scientific production in recent times. Eugene Garfield, with the establishment of the Institute for Scientific Information (ISI) in the 1960s, initiated the metrification of papers, journals, researchers, and institutions. Scientific papers are now compiled and indexed in large databases, which allow to measure different aspects of such papers, such as number of authors, keywords, topic, citations, institutional collaboration, etc. The rationale for indexing articles is the following: authors cite other papers due to its connection with the core idea of his/her paper. Given that authors must select carefully which papers to cite, including only the most relevant and most closely related to his/her paper, most cited papers could reflect the importance of them within its discipline. Institutions can obtain valuable information about individual and aggregate impact. Therefore it could help in either faculty recruiting process or in defining the global research strategy of universities and research councils.

However, the importance of bibliometric studies goes beyond the institutional level. They could help new researchers of a discipline to understand the extent of a topic, emergent trends, and its evolution through time. In this sense it is different from a traditional literature survey.

This kind of analysis is possible due to the availability of big databases such as the Web of Science. This indexing service is an important input of the evaluation process in academia. The Web of Science is a citation indexing service, administered by Clarivate Analytics, and constitutes a selective list of journals and conference proceedings, with indexing coverage from 1898. It covers more than 59 million records. The firm produces several impact metrics included in the Journal Citation Report, e.g. Impact Factor, Eigenfactor, 5-year Impact Factor, among others. These metrics are available on a subscription basis. Further details can be consulted at its website [Clarivate Analytics \(2018b\)](#).

From a macroscopic level, we can obtain certain metrics that are common to many journals, and they are useful to different

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stakeholders. However, there are some features that change from discipline to discipline. There is an uneven number of researchers and journals per discipline. In recent years there has been an expansion in the number of journals and an increase in its periodicity, probably due to the expansion of the academic sector in the last decades in several countries. In addition, disciplines have different traditions regarding publication. Some disciplines, such as biomedicine, is prone to 'hyper-authorship' (Cronin, 2001), where a single paper includes massive collaboration, where some of them have minimal involvement in the production of the paper, and a subgroup of authors acts as reporters of the whole group. Therefore, it is important to study the intrinsic characteristics of homogeneous disciplines and/or topics, in order to provide for a meaningful classification.

Bitcoin research has soared in recent years. From a technological point of view, blockchain is a disrupting paradigm. It introduced the concept of distributed consensus-based validation, instead of centralized validation. Its first application, introduced by Nakamoto (2009), comprises the creation of a sort of means of payment, which runs parallel to the established financial system. Since its introduction, bitcoin has been increasingly become an important investment and speculative device. It got the attention of mass media, as more and more money was poured into the cryptocurrency market. At the beginning, most researchers were attracted trying to understand how blockchain worked (Zyskind et al., 2015; Zheng et al., 2018). Early research within economics was focused on the potential of bitcoin as a substitute of national currencies (Yermack, 2013; Böhme et al., 2015). Currently, most of the research from an economics and finance point of view is to analyze all its financial properties for several reasons. Firstly, because of its traded volume. Secondly, its distinct behavior *vis-à-vis* traditional assets such as stocks, bonds or fiat currencies. Thirdly, the fact that cryptocurrencies trade on a 24/7 basis, makes studies especially interesting for algorithmic trading, and poses new challenges on how to process efficiently a continuous flux of big data. More recently, a topic which is being studied is the possibility of bitcoin to become a safe-haven asset due to its low correlation with the traditional markets (Smales, 2018; Klein et al., 2018; Shahzad et al., 2019), or to use it for portfolio diversification (Liu, 2018; Platanakis and Urquhart, 2019).

The aim of this paper is to analyze metadata of all the papers indexed in the Web of Science Core Collection, whose topic is "bitcoin", excluding other blockchain applications. This study is targeted to a broad and diverse audience. Bitcoin stakeholders come from several fields: computer programmers, investors, libertarians thinkers, and financial economists. This paper provides useful information for them on the main journals interested in publishing papers on this topic, as well as on the evolution of topics addressed in those papers. Additionally, we discuss other aspects such as highly cited papers, top publication sources and keyword analysis.

Published research on bitcoin begun in 2012, and until January 2019 there are 1162 papers on this topic. This paper in some aspects, extends that by Holub and Johnson (2018), adding almost two year data. Unlike Holub and Johnson (2018), which uses multiple data sources, we restricted our search to Web of Science. The reason for such restriction is that Web of Science is the most important database of scientific papers, whose metrics are widely used in academic assessment in several countries. Additionally, it improves the analysis adding graphical representation of citation, journal and author's networks, using VOSviewer software.

This work conducts an analytic study of the papers included in the sample using "bibliometrix" R package (Cuccurullo et al., 2016; Aria and Cuccurullo, 2017). In addition, we add a graphical analysis of the bibliographic material using VOSviewer software (van Eck and Waltman, 2010). This software collects the data and generates maps based on bibliographic coupling, co-authorship, citation, co-citation and co-occurrence of keywords (Merigó et al., 2016).

The rest of the paper is structured as follows. Section 2 describes the literature on bibliometric studies on econometric journals. Section 3 details the data under analysis and comments the main findings of our study. Finally, Section 5 draws the main conclusions.

2. Related literature

Bibliometrics is a research field within library and information sciences that studies the bibliographic material by using quantitative methods (Pritchard, 1969; Broadus, 1987). Over the years, bibliometrics has become very popular for classifying bibliography and developing representative summaries of the leading results.

There are many bibliometric studies of a wide variety of issues. For example, Cobo et al. (2011) analyze the thematic evaluation of the Fuzzy Sets Theory. Bonilla et al. (2015) analyze the academic research developed in Latin America in economics between 1994 and 2013. Cancino et al. (2017) develop a bibliometric analysis of the publications of the Computers & Industrial Engineering between 1976 and 2015. Related to economics there are several examples. Andrikopoulos et al. (2016) performed a bibliometric analysis in the economics field by reviewing the first forty years of the Journal of Econometrics, focusing on collaboration patterns and the internationalization of research in econometrics. Another example of a bibliometric analysis of economic journals is done by Wei (2019). More specifically, Costa et al. (2019) conduct a bibliometric analysis of the scientific field of Behavioral Economics and Behavioral Finance, proving how they have turned into an important field of study. Furthermore, Claveau and Gingras (2016) introduce a combination of different bibliometric tools to the history of economics. So, combining bibliometrics with dynamic network analysis, they identified a changing specialty structure in economics from the late 1950s to 2014. In a different way, Korom (2019) explored the potential of interdisciplinary perspectives by investigating the thematic overlap between economic and socio-logical approaches to wealth inequality.

In 2009, an anonymous individual, under the pseudonym "Nakamoto", published a white paper setting the grounds for the creation of a decentralized, non-government controlled, currency. Those were the times of the global financial crisis, considered by many specialists to have been the most serious economic downturn since the Great Depression (Almunia et al., 2009). Many people stopped trusting banks. Nakamoto's idea was timely and rapidly adopted by the public. Bitcoin allows for peer-to-peer money transfer, avoiding the established financial system. In addition, transactions are encrypted. Although not anonymous, transactions are blind to national authorities. Bitcoin success has been so great, that it became tantamount to cryptocurrency. The success of bitcoin encouraged other crypto-entrepreneurs to develop their own currencies. As of February 2019, there are more than 2000

cryptocurrencies, with a total market capitalization of \$131.8 billions, and daily transactions exceeding \$24 billions (Coinmarket, 2019). Despite the large number of cryptocoins, bitcoin constitutes half of the market. According to Bariviera et al. (2018) most studies focus their attention on bitcoin, rather than on the other coins.

Unlike Miau and Yang (2018), and considering that blockchain is such a broad research area, we narrow our paper's scope only to bitcoin research. Consequently, this paper gathers all the literature produced so far regarding, exclusively, bitcoin.

There are few previous papers on this topic. The first paper in this strand is by Liu (2016), which collects 253 articles related to bitcoin from Scopus database. This author finds three groups of papers, related to the (a) technological, (b) economic and (c) legal aspects of bitcoin. Our paper differs from Liu (2016) in two aspects: (i) the origin of data and (ii) the methodology. Ours is from Web of Science, whereas Liu's is from Scopus. This is an important difference, because Scopus is a broader database, which includes other sources such as periodic magazines, which are not frequently cited in scientific journals. The second difference is regarding the treatment of data. Liu (2016) uses a supervised learning algorithm, whereas we prefer to use unsupervised learning, considering the quantity and diversity of papers. The second paper in this topic is Holub and Johnson (2018). They collect 4429 papers from several sources, including public working papers repositories such as ArXiv or SSRN. Their paper identify seven main categories of papers: (a) Technology, (b) Economics, (c) Finance, (d) Regulation, (e) Taxation, (f) Accounting, and (g) Critical Thought. The last category includes papers on political, philosophical and ethical aspects of bitcoin. Their methodology is substantially different from ours. Whereas they classify papers after reading a sample of abstracts and full articles, we use an advanced machine learning technique in order to classify papers. In addition we study in detail authors productivity, journal citation influence, and keywords. The third paper, Corbet et al. (2019), provides a systematic literature review on empirical economic aspects of cryptocurrencies. Their approach is based on a traditional literature review, whereas our approach is mainly a bibliometric approach. In addition, we consider a broader bibliographic *corpus*, in order to provide a broader view of the scientific production around bitcoin.

We also identified some papers dealing, tangentially, with our subject. Zeng et al. (2018) present a bibliographic analysis of the blockchain-related literature between January 2011 and September 2017, taking EI Compendex (EI) and China National Knowledge Infrastructure (CNKI) databases as the literature sources. Considering that EI is database centered in engineering literature, and CNKI provides mainly China knowledge resources, our scope and coverage is far broader. Chatterjee et al. (2018), despite not doing a bibliometric analysis, provide a state-of-the-art survey over bitcoin related technologies and making a summary of its evolution. Dabbagh et al. (2019) present a bibliometric analysis of 995 papers dealing with blockchain. Their analysis indicate that researchers have shifted their research interests from bitcoin to blockchain in the recent two years. Their study differs from ours in their broader search query, which included, in addition to 'bitcoin', the following words: 'Blockchain', 'cryptocurrency', 'ethereum', and 'smart contract'. As a consequence, papers in their sample are more technological-focused. Yli-Huumo et al. (2016) analyzed 41 papers, excluding explicitly papers dealing with economic, legal, business and regulation perspectives of blockchain. Their study is conducted using a systematic mapping process described by Petersen et al. (2008).

Consequently, our paper could be considered an expanded contribution to the literature, providing a full overview of the current trends on bitcoin research, and identifying top researchers, institutions, and journals in this field.

3. Data and results

This paper works with data from Web of Science Core Collection (WoS), Clarivate Analytics. We selected all indexed papers that contain 'bitcoin' as topic, which makes a total of 1162 documents, published in 703 sources (journals, books, etc.), during the period 2012–2019. These documents were (co-)authored by 2293 people. The vast majority of the documents are multi-authored, being only 322 documents single-authored. The average number of authors per document is 1.97.

Bitcoin as a research topic comprises several disciplines. It is a recent and emerging topic, considering that the first paper is found in 2012, omitting the seminal paper by Nakamoto (2009). Articles cover different aspects of this novel product: legal concerns, economic perspectives or computer peculiarities. However, they are concentrated around two main research areas: computer science and business economics. Web of Science assigns indexed papers to one or more research areas. The 1162 papers considered in our sample were assigned 1543 research areas. The top five research areas are displayed in Table 1.

The detail of yearly publications is displayed in Table 2. We can observe that in the first two years of the sample, the relative increase exceeds 400%. This is produced by the small initial figures. In more recent years the yearly increment is around 40%. The expected scientific production for year 2019¹ is 384, which gives a flat growth rate for the current year. The decreasing growth rate could signalize that research in this field is consolidating. In fact, cryptocurrencies emerged as an all-new area in science and technology almost ten years ago. During these years, the initial papers were devoted to the study of the underlying blockchain technology. Soon after it, economic and financial studies on bitcoin began.

3.1. Corresponding author's geographical distribution

Table 3 shows that the USA is the country whose authors have published both more documents and obtained more total citations, followed by the United Kingdom in both aspects. The ten first countries accumulate the 65% of the articles published related to bitcoin.

Table 4 displays the main countries, ordered by total citations. The average number of citations per article, which is 4.2. The USA

¹ The linear forecast for the expected number of papers is $32 \cdot 12 = 384$.

Table 1
Main research areas assigned to papers in the sample.

Research areas	Records	% of 1543
Computer Science	541	35%
Business Economics	279	18%
Engineering	196	13%
Telecommunications	106	7%
Science Technology Other Topics	79	5%
Total top 5 research areas	1201	78%

Table 2
Number of papers published by year, with ‘bitcoin’ as topic. *Source:* Web of Science Core Collection.

Year	# articles	Yearly growth rate
2012	3	–
2013	17	467%
2014	90	429%
2015	148	64%
2016	192	30%
2017	296	54%
2018	384	30%
2019	32 ^a	
Total	1162	124% ^b

^a The projected # of articles for 2019 is 384.

^b Average growth rate per year from 2012 to 2018.

Table 3
Top ten corresponding author's countries.

Country	Articles	Frequency	Single country publications	Multiple country publications	MCP_Ratio
USA	249	23%	214	35	14%
United Kingdom	100	9%	67	33	33%
China	99	9%	66	33	33%
Germany	57	5%	37	20	35%
Australia	41	4%	30	11	27%
Italy	40	4%	25	15	38%
India	31	3%	28	3	10%
Switzerland	31	3%	21	10	32%
France	30	3%	13	17	57%
Spain	26	2%	14	12	46%
Total 10 countries	704	65%	515	189	27%

Table 4
Top ten total citations per country.

Country	Total citations	Average article citations
USA	1353	5.4
United Kingdom	569	5.7
Australia	247	6.0
Germany	222	3.9
Ireland	187	15.6
China	180	1.8
Spain	170	6.5
Switzerland	150	4.8
Israel	146	13.3
Austria	138	11.5
Total (all countries)	5019	4.2

and the United Kingdom, the two countries with more articles published and total citation are above this figure, with 5.43 and 5.69 respectively. In spite of the fact that China is the third country in terms of published articles, it has the lowest average citations per article among the leading countries in total citations. It is also important to highlight that Ireland is the country with more citations per article, which can be used as a proxy for average scientific importance or quality of the articles.

Table 5

Top ten most relevant sources.

Sources	#Articles	Type
Economics Letters	29	Journal
Physica A: Statistical Mechanics and its Applications	19	Journal
IEEE Access	17	Journal
PLOS ONE	15	Journal
Finance Research Letters	14	Journal
Communications of the ACM	11	Journal
New Scientist	16	Magazine
The Digital Currency Challenge	17	Book
Financial Cryptography and Data Security FC2015 Workshop	13	Conference Proceedings
Financial Cryptography and Data Security FC2014 Workshop	12	Conference Proceedings

Furthermore, around 35% of the articles published are made by authors of multiple countries. The international collaboration in the USA and India are below the average, with a multiple country publications rate of 14% and 10%, respectively. The international collaboration reaches a maximum for Spain, where 46% of the papers are of this kind.

3.2. Top publication sources

Table 5 shows the ten main sources publishing articles related to bitcoin. Six of this sources are journals, and reflect the interdisciplinarity of this research field. *Economics Letters* and *Finance Research Letters* are two leading economics journals. *Economics Letters* is, undoubtedly, the main publishing device, with 29 published paper on this topic. *Physica A* is a physics journal, which is very friendly in publishing papers dealing with econophysics and statistical mechanics applications to economics. *IEEE Access* and *PLOS ONE* are two important multidisciplinary open access journals. Finally, *Communications of the ACM* is leading publication for the computing and information technology fields, which is very much recognized among industry. Another important source is *New Scientist*, which is a popular weekly science and technology magazine, founded in 1956. There is also one book title “The Digital Currency Challenge” and published by Palgrave Macmillan US. This book details legal issues and technological developments of digital currencies in the US. Finally, there are two conference proceedings, providing a significant number of papers. The diversity of the sources, in type and discipline, reflects the multidisciplinarity in this research topic.

3.3. Main keywords.

Table 6 shows the ten most used keyword in the bitcoin articles. Web of Science provides two types of keywords: (a) Author Keywords, which are those provided by the original authors, and (b) Keywords-Plus, which are those extracted from the titles of the cited references by Thomson Reuters (the company maintaining WoS). Keyword Plus are automatically generated by a computer algorithm. The two more frequent Author Keywords are ‘Bitcoin’ and ‘Blockchain’. It is remarkable that the word ‘Economics’ is the second most frequent Keyword-Plus, but it does not appear as an Author Keyword. It is clear that ‘Economics’ is too general to describe an article; authors do not use it as keyword, but the algorithm used to find Keyword-Plus does not discriminate such a useless keyword. On contrary, Keyword-Plus is precise at identifying keywords such as ‘Volatility’, ‘Inefficiency’, or ‘Returns’, as many economics papers are focused on these aspects of bitcoin. It is also relevant to notice that Blockchain is the second more used Authors Keywords as it is gaining a lot of attention among researchers but it is not in the ten more used Keywords-Plus.

3.4. Highly cited papers

Table 7 shows the list of the 17 articles categorized as a highly cited paper. According to [Clarivate Analytics \(2018a\)](#), “Highly

Table 6

Main keywords.

Author keywords (DE)	# articles	Keywords-plus (ID)	# articles
Bitcoin	501	Bitcoin	102
Blockchain	229	Economics	39
Cryptocurrency	126	Inefficiency	33
Cryptocurrencies	60	Volatility	30
Digital currency	41	Gold	21
Ethereum	32	Money	20
Virtual currency	31	Internet	18
Security	27	Market	17
Money	23	Prices	17
Anonymity	20	Returns	17

Table 7

Highly cited articles, descending order by number of citations.

Author (year)	Title	Source	# Citations
Böhme et al. (2015)	Bitcoin: Economics, Technology, and Governance	Journal of Economic Perspectives	107
Urquhart (2016)	The inefficiency of bitcoin	Economics Letters	68
Dyhrberg (2016a)	Bitcoin, gold and the dollar - A GARCH volatility analysis	Finance Research Letters	58
Ciaian et al. (2016)	The economics of BitCoin price formation	Applied Economics	54
Dyhrberg (2016b)	Hedging capabilities of bitcoin. Is it the virtual gold?	Finance Research Letters	45
Nadarajah and Chu (2017)	On the inefficiency of bitcoin	Economics Letters	41
Bouri et al. (2017)	On the hedge and safe haven properties of bitcoin: Is it really more than a diversifier?	Finance Research Letters	41
Katsiampa (2017)	Volatility estimation for bitcoin: a comparison of GARCH models	Economics Letters	38
Bariviera (2017)	The inefficiency of bitcoin revisited: a dynamic approach	Economics Letters	36
Balcilar et al. (2017)	Can volume predict bitcoin returns and volatility? A quantiles-based approach	Economic Modelling	34
Meng et al. (2018)	When Intrusion Detection Meets Blockchain Technology: a review	IEEE Access	29
Urquhart (2017)	Price clustering in bitcoin	Economics Letters	28
Khan and Salah (2018)	IoT security: Review, blockchain solutions, and open challenges	Future Generation Comp. Sys.	24
Kuo et al. (2017)	Blockchain distributed ledger technologies for biomedical and health care applications	J. of the A. Med. Informatics Assoc.	21
Zheng et al. (2018)	Blockchain challenges and opportunities: a survey	Int. J. of Web and Grid Services	16
Lahmiri and Bekiros (2018)	Chaos, randomness and multi-fractality in bitcoin market	Chaos Solitons & Fractals	13
Corbet et al. (2018)	Exploring the dynamic relationships between cryptocurrencies	Economics Letters	10

cited papers are the top one percent in each of the 22 ESI subject areas per year. They are based on the most recent 10 years of publications. Highly Cited Papers are considered to be indicators of scientific excellence and top performance and can be used to benchmark research performance against field baselines worldwide". This measure is useful in the sense that separates each article depending on its field and it is a known fact that depending on the field, the number of citations used per article is different. So, it is good way to highlight important articles from different fields. These papers signalize, in some way, research paths in the literature. [Ciaian et al. \(2016\)](#) study bitcoin price formation following the methodology by [Barro \(1979\)](#). They find that bitcoin price was mainly influenced by demand and supply (partly also by speculative investors), but that that macroeconomics has no significant effect. [Urquhart \(2016\)](#) develops a methodology to measure inefficiency in bitcoin using six tests. His methodology has been subsequently used in several articles. This paper concludes (and it was tested by other papers) that bitcoin was, initially, an inefficient market; but it could be in the process of moving towards a more efficient market. [Dyhrberg \(2016a,b\)](#) were among the first applying GARCH models to cryptocurrencies. Moreover, it was on the first articles to compare bitcoin with Gold in order to classify bitcoin as an asset due to its characteristics. Their papers concluded that bitcoin has a place on the financial markets and in portfolio management as it can be classified as something in between gold and the American dollar. [Nadarajah and Chu \(2017\)](#) followed the methodology by [Urquhart \(2016\)](#), and find that a power transformation of bitcoin returns could be weakly informationally efficient. [Katsiampa \(2017\)](#) focus her attention on time series volatility, and detects short and long-run components in bitcoin conditional variance. [Bariviera \(2017\)](#) also finds high persistence in daily variance, which makes GARCH models suitable for variance modelization. [Bouri et al. \(2017\)](#) use a dynamic conditional correlation model in order to study the potential use of bitcoin as a safe-haven asset. Their main findings are that bitcoin is acts as a poor hedge, but it is suitable for diversification purposes. [Balcilar et al. \(2017\)](#) perform a non-parametric quantile analysis in order to analyze causal relation between trading volume and bitcoin returns and volatility. Their study reveal that volume has some predictive power on returns, but not in volatility. [Lahmiri and Bekiros \(2018\)](#) also detect long-range correlations in returns, and a dynamical nonlinear behavior in the time series. In addition, prices and returns exhibits multifractality probably due to the fat-tailed distributions.

[Table 8](#) show the most productive authors of bitcoin related articles. The first one is P. Carl Mullan with 17 articles published followed by Elli Androulaki, Elie Bouri and David Roubaud, all of them with 10 articles published.

Table 8

Most productive authors.

Authors	Institution	# articles
Mullan PC	Private consultant	17
Androulaki E	IBM Research	10
Bouri E	Universit Saint-Esprit de Kaslik	10
Roubaud D	Montpellier Business School	10
Karame G	NEC Laboratories Europe	9
Kiayias A	University of Edinburgh	9
Dziembowski S	University of Warsaw	8
Eyal I	Technion	8
Gupta R	University of Pretoria	8
Liu Y	National University of Defense Technology	8

3.5. Degree of concentration of selected variables

In this subsection we analyze globally several bibliometric variables, in order to show the degree of concentration of them. One important characteristic in bibliometric studies is the evenness of the contribution of authors, countries, and journals to a research topic. Information theory provides alternative metrics to traditional statistical measures of concentration, such as standard deviation, skewness or kurtosis. In particular, [Shannon and Weaver \(1949\)](#) developed the celebrated Shannon entropy. Given a discrete distribution probability $P = \{p_j; j = 1, \dots, N\}$, with $\sum_{j=1}^N p_j = 1$, Shannon entropy is defined as:

$$S[P] = - \sum_{j=1}^N p_j \ln(p_j) \quad (1)$$

This formula could be interpreted from different points of view. Within the data communication realm, it can be seen as the average rate of information produced by a stochastic source, and it is frequently used in data compression ([Huffman, 1952](#)). From a statistical mechanics point of view, it represents the degree of order/disorder of a physical system ([Lamberti et al., 2004; Rosso et al., 2007](#)). It is used in economics in order to construct measures of business concentration ([Horowitz, 1970; Hart, 1971](#)). In biological sciences, it is used as a measure of the diversity at the species level ([Pielou, 1966; Fedor and Spellerberg, 2013](#)). Finally, it is used in bibliometric studies in order to study the evenness/concentration distribution of different important variables such as research topics or authors, among others ([Polyakov et al., 2017](#)).

In order to make interpretation easier, it is better to normalize Shannon entropy, dividing by its maximum value. Thus, the normalized entropic concentration index reads:

$$\mathcal{H}[P] = \frac{S[P]}{S_{\max}} = \frac{-\sum_{j=1}^N p_j \ln(p_j)}{\ln N} \quad (2)$$

Under this configuration $0 \leq \mathcal{H} \leq 1$, where 1 means that all categories are evenly represented. In other words, $\mathcal{H} = 1$ means an absence of concentration, and $\mathcal{H} = 0$ a concentrated distribution at one single point.

We calculate the normalized entropic concentration index for the distribution of authors, sources, countries, research areas and citations. The results are displayed in [Table 9](#). We observe that papers citations are very concentrated ($\mathcal{H} = 0.3042$). In fact, only 58 out of the 1162 papers in our sample account for 50% of all citations. Similarly, the research areas where bitcoin-related papers are published are concentrated in a few areas. In fact 70% of the papers corresponds to either computer science, business economics, engineering or telecommunications. We also detect that publications by countries is very concentrated. However, authors are rather evenly distributed. Taking together both results, it means that despite most production is concentrated in a few countries (see [Table 3](#)) authors are rather evenly distributed within those countries. [Table 10](#) shows that there are very few authors with 3 or more papers. Finally, we detect that there is a moderate concentration in publication sources. We identify some journals with a significant quantity and quality of publications (see [Tables 5 and 7](#)). In particular the journals *Economics Letters*, *Finance Research Letters* and *IEEE Access* not only are among the journals that have published many articles on bitcoin, but also have several highly cited papers.

An alternative measure of authorship concentration is Lotka's law. According to [Lotka \(1926\)](#) empirical finding, authors' productivity follows a form of Zipf's law. The original finding, based on a restricted database of physics and chemistry, can be summarized by the equation:

$$a_n = \frac{a_1}{n^c}, \quad n = 1, 2, \dots, N \quad (3)$$

where a_n is the number of authors publishing n papers, and a_1 is the number of authors publishing one paper. Power laws, as measures of concentration, are also used firms demography ([Zambrano et al., 2015](#)), population studies ([Hernando and Plastino, 2012](#)), and other social applications ([Hernando and Plastino, 2013](#)).

Considering that [Lotka \(1926\)](#) deduced his empirical law from a very specific sample, a natural generalization could be:

$$a_n = \frac{a_1}{n^c}, \quad n = 1, 2, \dots, N \quad (4)$$

where c is a parameter that should be estimated, so that it best fit data.

In our sample $c = 2.70$, with an $R^2 = 0.98$. [Table 10](#) summarizes the actual and fitted distribution of the number of authors publishing n papers. We observe that the actual number of authors publishing only 1 paper is greater of what predicted by Lotka's

Table 9
Entropic concentration index (\mathcal{H}) of selected variables.

Variable	\mathcal{H}
Authors	0.9432
Sources	0.8817
Countries	0.4595
Research areas	0.3195
Papers citations	0.3042

Table 10

Observed distribution of the number of authors who wrote a given number of papers, and Lotka's law fitted values.

# Articles	# Authors	Observed frequency	Fitted frequency
1	1885	0.8221	0.7081
2	262	0.1143	0.1087
3	67	0.0292	0.0363
4	26	0.0113	0.0167
5	20	0.0087	0.0091
6	12	0.0052	0.0056
7	9	0.0039	0.0037
8	6	0.0026	0.0026
9	2	0.0009	0.0019
10	3	0.0013	0.0014
17	1	0.0004	0.0003

law, which confirms that authorship is widely and more evenly distributed. Comparing our results to those by Chung and Cox (1990), we detect that author concentration in bitcoin is lower than in several top financial journals (for any topic).

3.6. Citation, sources and authors graphs

The following figures were generated using VOS viewer software, which allows to count the words which appear in the title, abstract and keywords to build all the relations which appear between different documents published in the Web of Science (van Eck and Waltman, 2010).

Fig. 1 represents the cloud map with relevant words of the article. This map shows how many times the words appear in the articles and how related are between them. The main finding is that the cloud could be divided into two parts. The right side is more related to economics and finance issues (blue and red) and the left side is more related to engineering and computer science (green and yellow). In the economics and finance part, we can distinguish between: (i) the blue part, more focused in the finance part of bitcoin; and (ii) the red area, more specific in topics related to monetary economics. The engineering and computer science side also offers two distinctive subareas. One is more related more specifically to blockchain technology and smart contracts. The other is more related to mining protocols, security and cyber attacks. It is also relevant to observe that the expressions ‘blockchain technology’, ‘money’, and ‘protocol’ act as a nexus among different clusters.

Fig. 2 represents something similar to Fig. 1, with the slight difference that it is binary counted. This means that when a word appears, it is only counted once independently from how many times it appears in the document. This can change the results in the sense that if a word is very repeated in a document, it does not overestimate the results. In this cloud map, we can see that with the binary counting, there are three main clusters. The two economics and finance clusters merged into one bigger cluster. This difference suggests that the difference which appeared in Fig. 1 could be because some specific words from economics or finance are enough

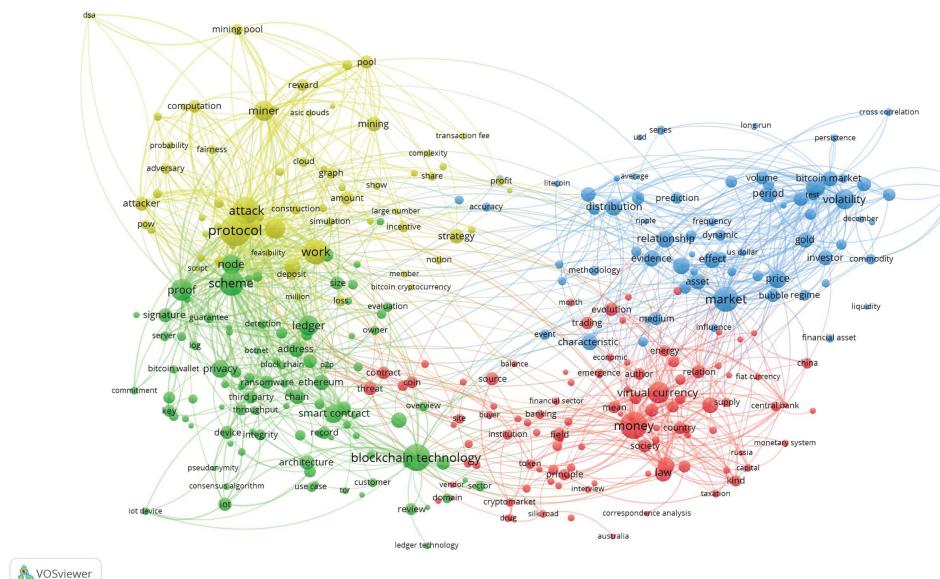


Fig. 1. Cloud map of words in titles and abstracts (full counting), generated with VOSviewer (<http://www.vosviewer.com/>). (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

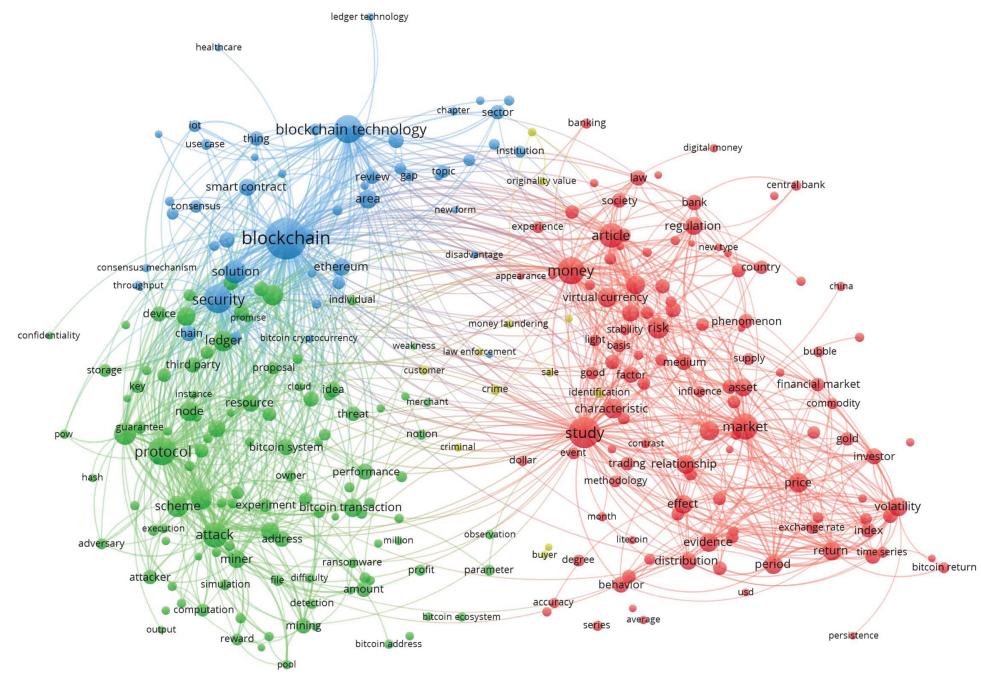


Fig. 2. Cloud map of words in titles and abstracts (binary counting), generated with VOSviewer (<http://www.vosviewer.com/>). (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

repeated in the same article to create this difference. The main keywords used are: blockchain and blockchain technology (blue), protocol (green), study and money (red).

In terms of the source of the articles, we observe in Fig. 3 again two well differentiated journals types: economics journals, and computer science and engineering journals. This result is consistent with those from Figs. 1 and 2, in the sense that bitcoin is a multidisciplinary field, where economists and computer scientists are the most interested in it. In agreement with Table 5, we detect several journals that are highly connected among them. In addition, *PLOS ONE* occupies a position in the middle of the graph, which is expected as it is a multidisciplinary journal. We should also highlight that *Physica A* is located in the economics area. In spite of the fact that it is a statistical physics journal, it publishes many papers on quantitative finance and is a highly respected journal within the econophysics community.

Fig. 4 show all the articles and the size of the node depends on the number of citations. In this figure, we can observe that the most cited article from 2012 is the one written by Zyskind et al. (2015), published in *IEEE Security and Privacy Workshops (SPW)*, and dealing with the technological part of bitcoin. The second one, which is the one written by Böhme et al. (2015) and published in the *Journal of Economic Perspectives*, is more related to economics studies. There is a group on the right of the map which are closely related papers, mostly published in *Economics Letters* and *Finance Research Letters*, such as Urquhart (2016), Cheah and Fry (2015), Dyrberg (2016a) and Bariviera (2017).

There are some other outstanding articles in terms of number of citations such as the one by Van Hout and Bingham (2014) published in the *International Journal of Drug Policy* or the one written by Miers et al. (2013) and published in the *2013 IEEE Symposium On Security and Privacy (SP)*.

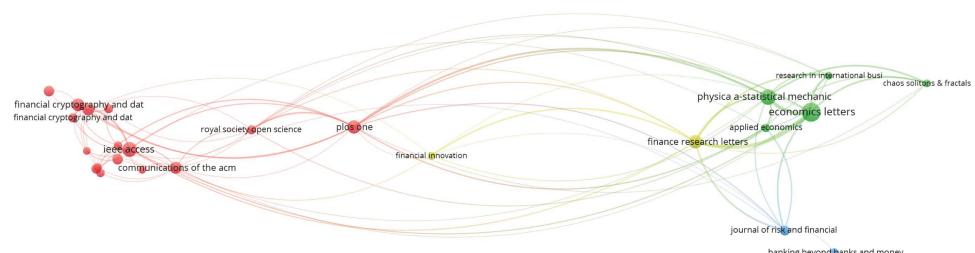


Fig. 3. Cloud map of journals where papers on bitcoin were published, generated with VOSviewer (<http://www.vosviewer.com/>).

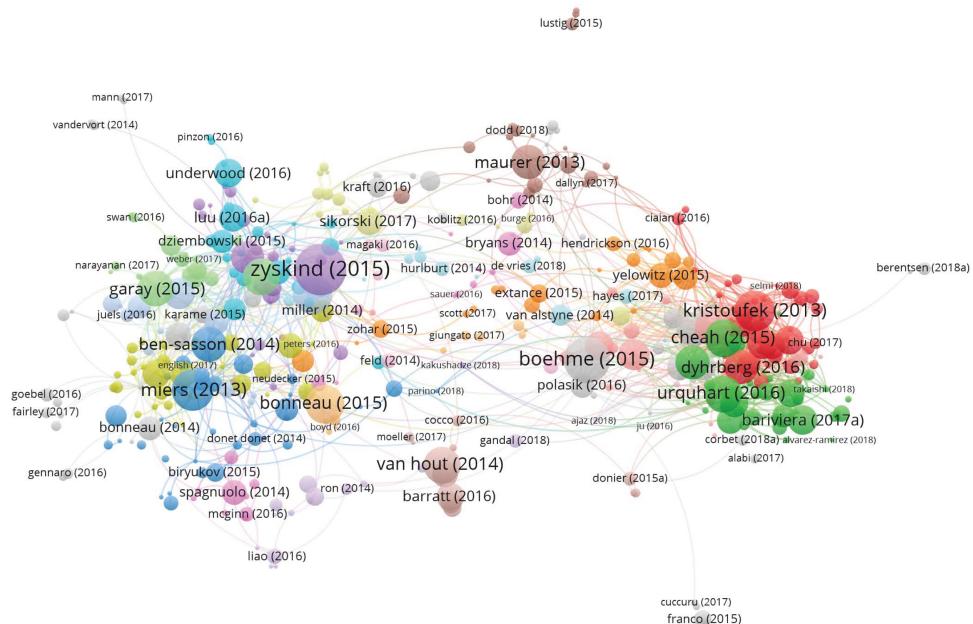


Fig. 4. Cloud map of journals of authors with papers on bitcoin were published, generated with VOSviewer (<http://www.vosviewer.com/>).

4. Potential research lines

Fig. 2 signalizes a clear separation between technology-oriented and economic-oriented papers. Considering the intrinsic technological component of bitcoin and its strong economic impact, we detect a lack of interdisciplinary works. For example, despite the correlation found among cryptocurrencies (Zhang et al., 2018; Katsiampa, 2019; Klein et al., 2018; McMillan, 2019), economic literature seems to overlook the impact of the technological setting (i.e. the different cryptocurrencies protocols) in the cross-behavior of cryptocurrencies. An exception is Aslanidis et al. (2019), who speculate on the distinct Monero validation algorithm to justify its singular behavior. However, their explanation is provisional. Consequently, joint works by economists and computer scientists could add significant value to future research.

There are several papers that find inefficiencies in bitcoin market. However, the reasons for such inefficiencies are unknown. Compared to traditional markets (bonds, stocks, etc.), where efficiency analysis has been tested against the behavior of institutional agents, levels or liquidity, macroeconomic shocks, among others, we detect a lack of such type of studies in the bitcoin market.

One of our findings is that legal studies of bitcoin are within the economic aspects. In this line, there is a lack of studies linking the economic impact of changes in legal regulations in bitcoin.

Finally, research on behavioral aspects of bitcoin are needed, in order to understand a market, where there are heterogeneous individuals, interacting in real time. Related to this aspect, there are almost no paper regarding societal impact of bitcoin.

5. Conclusions

This study shows that cryptocurrencies' literature comprises mainly combination computer science and economics. Even though it is originally a technologically product, the foremost blockchain applications are the cryptocurrencies. Among them, bitcoin is the dominant actor, both in the market and in the literature interest. The number of documents published on this topic has been increasing at a yearly rate of 124%, albeit diminishing over the years. This paper constitutes the first comprehensive bibliometric study of bitcoin literature, comprising all the papers indexed in the Web of Science since 2012. The large amount of data (1162 papers) allows to find significant results regarding top scholars, main journals and keywords of this multidisciplinary research field. We detected a high concentration in publishing countries. However, authors are diverse, and less concentrated than in leading finance journals. Additionally, citations are concentrated among a few papers. In future works we would like to study the temporal evolution of keywords. Additionally, we would like to test if the quick growth and the subsequent fall in bitcoin price in 2017 have affected the bitcoin related research. Finally, related words such as "cryptocurrencies", "fintech", and "peer-to-peer lending" will be addressed in further research.

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