Empirical Evidence and Economic Implications of Blockchain as a General Purpose Technology

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***Abstract*— Leading experts from academic, industrial and policy-making circles describe Blockchain as a disruptive and game changing technology across various sectors. However, the question, whether Blockchain does already have the properties of a General Purpose Technology (GPT) and, as such, will determine macroeconomic dynamics in the next decades, has been disregarded in the academic literature. This paper covers the research gap by systematically revealing the acknowledged features of a GPT – pervasiveness, innovation spawning effects and scope for improvement – in the newest available Blockchain-related patent data from PATSTAT. To gain insights about pervasiveness, (1) a generality index of Blockchain is compared to respective values of co-existing technologies usually considered (information and communication technology) and not considered (pharmaceutical technology) GPTs. The second feature, innovation spawning is dissected (2) analyzing variety of innovators patenting in Blockchain domain and (3) looking at firms' behavior in terms of entry and exit in line with industrial dynamics. (4) Investigation of evolution patterns of Blockchain patents provides insights about its scope for improvement. The empirical analysis advances the claim that Blockchain does already represent a GPT in the making and, therefore, has a potential to shape a technological era and cause substantial changes in the economic, social and institutional structures.**

Keywords—Blockchain, GPT, patents, technology trend, diffusion, pervasiveness

I. INTRODUCTION

Over the course of the history, several key technologies, such as electricity, steam engine, information and communication technology, nanotechnology to name the few, had a significant impact on the economy and led to substantial changes in institutional structures, industrial dynamics, allocation of resources, and skill requirements [15]. In economic literature, these technologies are defined as general-purpose technologies, or GPTs [1]. Despite the large amount of conceptual literature focusing on disruptive potential of Blockchain across various industries [18], there is still a lack of empirical evidence, whether this technology does indeed have a GPT nature [37].

However, a systematic identification of a GPT nature of an emerging technology represents an important task that builds the basis for further scientific discourse and is of high relevance for industrial and policy making circles because of several reasons [32], [36]. First, it assists policy makers in effective design of technology enhancement policies and supports practitioners in deciding allocation of resources between existing technologies and a new GPT [36]. Second, GPTs have a long-lasting effect on macroeconomic indicators, such as productivity, skill premium, and industrial dynamics in terms of entry and exit [13]. Therefore, early identification of a GPT in the making provides insights into economic changes in the subsequent years [36] and allows to prepare for major changes in the economic, political and societal structures caused by this GPT [15].

The paper at hand provides, to the best of the author's knowledge, the first complete quantitative assessment of the GPT nature of Blockchain in line with the GPT, industrial dynamics and technology management literature. The rest of the paper is structured as following. A presentation of the relevant literature on GPTs and Blockchain in the next section is followed by explanation of data source and employed methodology. The empirical evidence for all the three acknowledged features of a GPT – pervasiveness, innovation spawning effects and scope for improvement [1] – in Blockchain-related patent data is provided in the results section. Discussion of the economic implications of the study and possible directions for the further research conclude.

II. RELEVANT LITERATURE

A. General-Purpose Technologies

The term 'General Purpose Technologies', or GPTs, was introduced in the economic literature by Bresnahan and Trajtenberg [1] to define key technologies that benefit a wide range of industries, initiate innovations in other fields, and shape the macroeconomic dynamics in a long term. The basic idea behind the GPT concept that "major technological changes are the main determinants of cyclical and non-linear patterns in the evolution of the economy" [2] appeared long before the term GPT has been coined. For example, [27] noticed that drastic innovations can lead to a long wave of economic development, and [17] referred to 'macro inventions' that cause long-run economic growth.

There are three widely acknowledged necessary features for a technology to be regarded a GPT: pervasiveness, innovation

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spawning effects, and scope for improvement [1], [13], [32], [36]. Pervasiveness means applicability of a GPT across numerous industries [15]. Innovation spawning effects refer to its ability to give rise to complementary innovations in the downstream application sectors. Advancements in the fields of application also trigger further development of a GPT itself – this two-sided relation is known as a 'dual inducement mechanism' [1] or a 'GPT reciprocal causality model' [28]. Since GPTs do not offer final solutions but rather act as 'enabling mechanisms' for innovations in the downstream application areas [1], their implementation in the application fields and development of complementary technologies play a crucial role in the GPT evolution. The third defining feature of a GPT - a scope for improvement – has a two-fold definition in the literature. Some scholars define scope for improvement as a permanent technological development at every stage of the value chain [32], whereas others mean by it benefits offered by a GPT [13], [28]. It is important to mention, that a GPT has all three of these features, since any technology might have at least one of the characteristics [36].

Numerous scholars dedicated their works to assessment of the GPT nature of certain technologies. [4], [10], and [13] consider information and communication Technology (ICT) as a classic example for a GPT that shaped the economy. Nanotechnology is addressed as an emerging GPT due to its pervasiveness and significant scope for improvement in the [9], [21], [28], [32], and [36]. [33] argues that Artificial Intelligence causes innovations in a wide range of applications sectors and, therefore, has a potential to become a new GPT in the near future. [15] provide a list of 24 transforming GPTs over the history, including printing, steam engine, electricity, railways, lean production, internet, and nanotechnology. Some of these GPTs were introduced exogenously to the economic system, the development of others was endogenous; some can be classified as process technologies, whereas others as product and organizational technologies. However, all of them share a high degree of pervasiveness, cause technological complementarities in downstream sectors, and have a scope for improvement [15].

There are also examples of some disruptive technologies in the literature that, however, do not fit into the definition of GPT due to the relatively low pervasiveness: gunpowder technology [15], combustion engine [32], and pharmaceutical technology [36] to name the few.

B. *Blockchain as a GPT*

Although Bitcoin White Paper first appeared in 2008 [19], its main technological pillars - public key cryptography, game theory and distributed computation – have been a subject of active scientific investigation over the past decades. The combination of these disciplines resulted in an innovative technology with a disruptive potential [25]. Blockchain has a number of functional features, such as decentralization, auditability and persistency, which make this technology potentially beneficial for a broad range of industrial fields [37]. Because of its possibility to ensure security of transactions between mistrusting actors without involvement of the trusted third party, scholars addressed potential of Blockchain to fundamentally change the intraorganizational business processes [16]. Many scholars acknowledge that with the introduction of smart contracts, the potential applications of Blockchain technology became infinite [25].

Proofs of concept for Blockchain use cases exist, among others, in supply chain tracking, governmental processes, financial transactions, construction project management, energy management and distribution, healthcare, identity management, tax collection, consumer electronic industry, insurance, and sustainability challenges [25]. [37] categorized potential Blockchain use cases into financial applications, Internet of Things, security, public service and reputation systems. [25] revised 460 commercially attractive applications for Blockchain and grouped them into 17 classes: cryptocurrencies account for 26,5% of total number of applications, financial transactions – for 21%, platform development – for almost 13%. Other Blockchain applications include energy distribution, digital identity, gaming, customer loyalty, and advanced tracking [25].

Blockchain is increasingly compared to an emerging GPT in the conceptual works of several authors. For example, [20] define Blockchain as a general-purpose technology to exchange information in distributed networks. [3] also compare Blockchain with an emerging GPT because it enables exchange of a wide range of data, such as contracts, financial assets, IP rights, university certificates, and others. [14] and [31] shortly mention that Blockchain might be a new emerging GPT, without providing systematic arguments in line with GPT literature supporting this statement.

Some scholars attribute selected GPT features to Blockchain. [12] stated that Blockchain can find applications in any industry where transactions take place. [6] describe Blockchain as all-pervasive technology and summarize its application fields. Several scholars also attribute innovation-spawning effects - a second necessary feature of a GPT - to Blockchain. [24] and [30] conclude that completely new business models will be spawned from Blockchain. [8] predicts the emergence of new organizational forms in a Blockchain-based economy. Several authors mention that Blockchain provides signigicant benefits: for example, it substantially reduces transaction costs [12], ensures transparency of data [23], and provides advanced security [18]. [37] also point out the continuous improvement of technology over the last years.

While many scholars acknowledge disruptive potential of Blockchain in the subsequent years, its current adoption rate within industrial sectors still remains low due to several technological imperfections, superiority of existing technologies, and absence of necessary complementarities [30], [37]. Moreover, Blockchain is supposed to be suitable for particular application scenarios, rather than an appropriate solution for all problems (see [34] for critical discussion). This view does not contradict the eventual GPT nature of Blockchain, as it might seem at first glance, but rather confirms that "transforming GPTs first appear in a crude embryonic state with only a few specific use cases" [15], and need a facilitating structure, complementary innovations [1], [2], and numerous incremental refinements [28] before they diffuse through the economy. The analysis of factors that influence diffusion patterns of Blockchain goes beyond the scope of the present paper, which primarily deals with the question, whether

Blockchain does represent a general-purpose technology in the making with respect to acknowledged GPT features.

III. Data

Consistent with the other empirical works on GPTs [4], [10], [32], [36], the main data for assessing the GPT nature of Blockchain are related patents. Despite some general shortcomings of patent datasets, such as different patterns of patenting activity within various industries, non-patentability of certain inventions [32], late appearance in the innovation cycle, and strong dependency on policy, they are widely used to capture technological development. Patents represent promising source for modelling emerging technologies in their early stages when market data is scarce [28] and for identification of potential GPTs [10]. Forward patent citations enable tracing the links between the present and the previous inventions and, therefore, are widely used in GPT literature to calculate the degree of pervasiveness and scope for improvement of a certain technology [10].

Despite the open-source nature of original Bitcoin code, Blockchain inventions are patent eligible, and the related patents mostly represent improvements over existing technology (alternative consensus mechanisms, scalability and security solutions, etc.) or refer to Blockchain usage within a specific domain. For this study, Blockchain-related patent data have been retrieved from PATSTAT Online database, Autumn 2018 Edition. The emerging nature of Blockchain and, therefore, absence of international patent classification (IPC) codes assigned to this technology, makes retrieval of Blockchain-related patents from PATSTAT not a trivial task. Taking in consideration general shortcomings of a keyword search [32] and other usages of the term 'block chain' in chemistry, software engineering and machinery, a search strategy for Blockchain patents based on both keyword combinations and IPC codes was developed and discussed with the EPO (European Patent Office) domain experts. This search strategy includes primary keywords, such as '*crypto(-/)currenc(y/ies)*', '*smart contract(s)*', '*bitcoin*', '*ethereum*', '*distributed ledger*', '*consensus mechanism/algorithm*', '*block(-/)chain*' (it is important to exclude keywords '*polymer*', '*polyol*' and '*block chaining*' as well as IPC class B from the search query). Secondary keywords, such as '*proof-of-work*', '*digital currenc(y/ies)*', '*hash tree*', '*merkle tree*', and '*counterparty*' are used in combination with IPC subclasses G06Q20/065, G06Q20/0655, G06Q20/0658, G06Q20/4016; H04L9/0643, H04L9/3236, H04L9/3239, H04L9/3242, H04L9/3247, H04L9/3252, H04L9/3257, H04L2209/30, H04L2209/38, and H04L2209/56.

After careful screening of titles and abstracts of retrieved patents, the total number of 2,081 distinct Blockchain-related patent families filed between 2008 and 2017 and translated into English have been taken for the further analysis.

IV. Methodology

A. Pervasiveness

The first feature of a GPT is pervasiveness, or the degree to which a technology is spread over various industrial fields [1], which is commonly measured by a generality index of the related patents [9], [10], [32], [36]. In essence, a generality index of a patent is based on forward citations and reflects the number of distinct technological classes (IPCs) the subsequent inventions based on a certain patent relate to. The index represents a modified Hirschman-Herfindahl index and is calculated as following:

$$G_i = 1 - \sum_j s_{ij}^2 \quad (1)$$

where s_{ij} is a share of citations received by patent i that belong to patent class j, out of n_i patent classes [10].

The value of a generality index can be between 0 and 1. The larger the number of technological classes the patents that cite the focal patent belong to, the closer to 1 a generality index is, the more pervasive is a technology [10]. Due to a highly skewed distribution of patent importance [32], the generality indexes are calculated for the top 10 cited Blockchain-related patent families.

The generality index is a relative value, therefore, informative only when compared to the analogous values of other technologies [9], [32], and [36]. Scholars increasingly compare Blockchain with information and communication technology (ICT) in its early years [11], [18]. While ICT is a widely recognized example of a GPT [4], [10], the pharmaceutical technology is an example of a non-GPT due to its low pervasiveness [36]. In such a way, comparison of generality indexes of these technologies may provide useful insights in the pervasiveness of Blockchain. To minimize the bias by comparing technologies at a different maturity level, the ICT and pharma patents filed between 1976 and 1980 are taken into consideration, and their forward citation time window is fixed at the level of Blockchain-related patents. These years were marked with the beginning of the ICT age and growing interest in the technology [22], which subsequently resulted in the relatively high generality scores [36].

B. Innovation spawning

Scholars used different approaches in measuring the second defining GPT feature – innovation spawning effects. Some economists calculated the length of the citation lags of related patents [10], [36]; others analyzed the share of technology-related inventions in the downstream application sectors [32]. Both of these approaches are inappropriate for Blockchain at current maturity level, since the technology is only in the beginning of its development curve [18]. Industrial dynamics literature provides useful insights about the measurement of innovation spawning of emerging technologies. In fact, the arrival of a new GPT is usually accompanied by a large variety of so-called "Schumpeterian" companies [5] that try to capture the value of the promising technology in its early phase [4], [13]. These companies, attracted by possibility to get high profits from exploiting new technology, constitute an integral part of economic "trail-and error procedures associated with the search for new technological paths" [5]. Taking in consideration these observations, analysis of, first, variety of innovators in the Blockchain domain, and, second, the degree of entry of new innovators provides useful insights about innovation spawning effects of Blockchain at its current technological maturity level. The degree of entry of new innovators is calculated as:

$$Entry_i = \frac{New\ Oi}{Oi} \quad (2)$$

where O_i is a total number of patenting organizations in the field, and *New* O_i is a number of organizations patenting for the first time [4]. Consistent with the related literature, the degree of entry of new innovators within the Blockchain domain is calculated based on the top 20 patent applicants in the field.

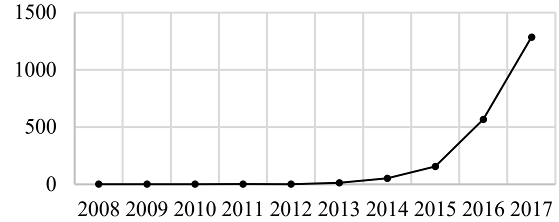
C. *Scope for improvement*

The differences in the definition of the third GPT feature – scope for improvement – result in various methodologies the scholars use for its measurement. Authors that conceptualize scope for improvement as the ability of a GPT to provide significant benefits to its users [13], [28] commonly analyse development of its application sectors. For example, [13] investigate decrease in equipment prices caused by electrification. Scholars that understand permanent technological development as indicator for scope for improvement especially of emerging GPTs [32] look at their patenting patterns. [21] and [32] simply investigate the growth rate of technology-related inventions, whereas [26] consider average number of forward citations per most cited patent applications. Due to the emerging nature of Blockchain and the importance of understanding the course of its technological development [37], the scope for improvement is measured by looking at evolution of the Blockchain-related patents. The first aspect of this technological evolution of Blockchain consists in efforts aimed at overcoming its R&D challenges, such as security, scalability, usability and wasted resources [35], whereas the second aspect – consistent with the evolutionary approach [2] – refers to adaptation of technology to various application domains. Such measurement of scope for improvement extends the GPT literature and can also be applied for investigation of technological evolution of other emerging technologies.

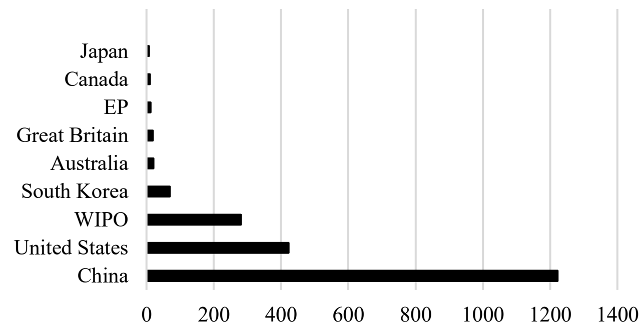
V. RESULTS

The amount of Blockchain-related patents remained negligible in the first four years after the publication of Bitcoin White Paper in 2008. In the subsequent years, 2013 onward, the number of inventions in Blockchain domain grew substantially from 14 patent families filed in 2013 to 1285 – in 2017. The filings from 2018 are not fully represented in the Autumn 2018 PATSTAT Edition, therefore, were dismissed from the present analysis. The negligible number of patents filed from 2008 to 2012 were also dismissed for the investigation of GPT features in order to avoid the small sample bias.

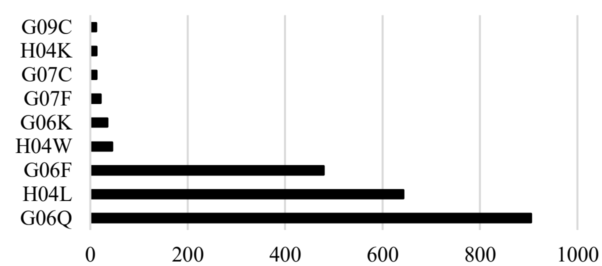
Fig. 1 presents the summary statistics of the Blockchain-related patent data. Panel a) shows, on the one side, the exponential growth of number of patent filings starting from 2013, and on the other side, empirically demonstrates the late appearance of patents in the innovation cycle. Panel b) maps top application authorities and, therefore, provides insights about geographical distribution of Blockchain patents. According to it, the most part of the patents have been filed in China (1,222 in total), followed by the United States (422 in total). Other countries actively involved in the patenting process are South Korea, Australia, Great Britain, Canada, and Japan. European countries (noted as 'EP' in the panel b) have not been among the top applicants of Blockchain patents so far. In addition to single countries, the substantial number of patents (281 in total and growing in the last few years) are so-called WO patents, which are granted by the World Intellectual Property Organization (WIPO). This is the evidence of the increasing number of Blockchain-related patent filings at the international phase and the growing importance of technology itself [29].



a) Number of Blockchain patents (2008-2017)



b) Geographic distribution of Blockchain patents (2008-2017)



c) IPC4 classes of Blockchain patents (2008-2017)

Fig. 1. Summary statistics of the Blockchain-related patents (2008-2017)

Each patent is assigned with one or more IPC classes, which indicate its technological areas. Panel c) shows top IPC 4-digit classes to which the Blockchain-related patents belong. The more IPC classes are associated with the certain technology, the more pervasive is its character [10]. As evident from the panel c), the most part of the Blockchain-related patents belong to classes G06Q ('data processing systems or methods'), H04L ('transmission of digital information'), and G06F ('electrical digital data processing'). The most part of the Blockchain-related patents classified as G06Q refer to commercial applications of the technology in a specific domain. Other common IPC 4-digit classes include H04K, H04W, G06K, G07C, and G09C. In such a way, Blockchain is established primarily within the areas of computing and electric communication techniques.

The next paragraphs are dedicated to detailed description of the GPT nature of Blockchain according to its three defining features – pervasiveness, innovation spawning effects, and scope for improvement.

A. *Pervasiveness*

Pervasive technologies benefit a large number of industrial sectors [15]. In patenting terms, it means that the related inventions belong to a variety of technological IPC classes and are subsequently cited by other patents from different IPCs [10]. While the panel c) of the Fig. 1 shows the distribution of IPC classes of Blockchain patents filed between 2008 and 2017, the Fig. 2 demonstrates the growing number of IPC 4-digit classes assigned to Blockchain (from only 5 in 2013 to 23 in 2017) and, thus, the increasing degree of pervasiveness of the technology.

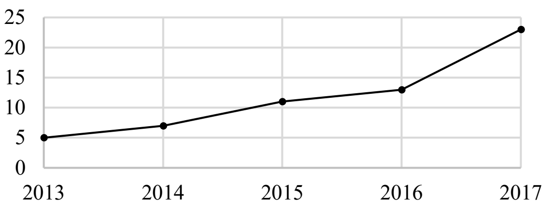


Fig. 2. Number of IPC4 classes assigned to Blockchain patents (2013-2017)

A generality index is an acknowledged measure for the pervasiveness degree of a certain technology [10].The values of the average generality indexes of the top ten cited Blockchain patent families, calculated in PATSTAT according to the formula (1) and graphically represented in the Fig. 3, reveal a clear pattern: the generality index values show constant growth from 0.562 in 2013 to 0.783 in 2017. As evident, the average generality index grew fast from 2013 to 2016 and remained almost constant from 2016 to 2017. This is explained by the fact that patents filed in 2017 still have short citation lags which is going to be changed in the subsequent years.

Such an upward trend in the generality index proves the growing pervasiveness of the Blockchain technology over the past years. In fact, the patents filed in 2013-2014 were mainly cited by IPC classes G06Q ('data processing systems or methods') and H04L ('transmission of digital information') whereas in 2016-2017 the variety of technological domains the citing inventions relate to increased substantially and included such distant classes as, for example, A45C ('diagnosis, surgery') or H03K ('pulse technique').

The comparison of the values of the generality indexes of Blockchain-related patents with analogous values for ICT (considered a GPT) and pharmaceutical technology (not considered a GPT) at the similar maturity levels provides additional insights about the GPT nature of Blockchain (see Fig. 4). Although the absolute number of ICT-related patents filed between 1976 and 1980 was substantially higher than Blockchain patentings between 2013 and 2017, the generality scores of both technologies are comparable and amount to, on average, 0.73 for ICT and 0.69 for Blockchain with a fast growing upward trend. Es evident from the Fig. 4, Blockchain generaliy scores were low in 2013 and 2014 (0.56 and 0.62 respectively), however then grew fast, reached the level and even exceeded the ICT generality in 1979 and 1980. A generaliy index of pharmaceutical technology remains more or less constant over the analysed period and is substantially lower than of the other two technologies (0.56 on average).

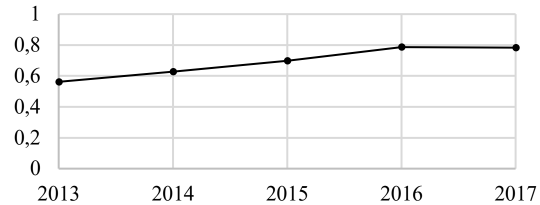


Fig. 3. Generality index of top 10 cited Blockchain patents (2013-2017)

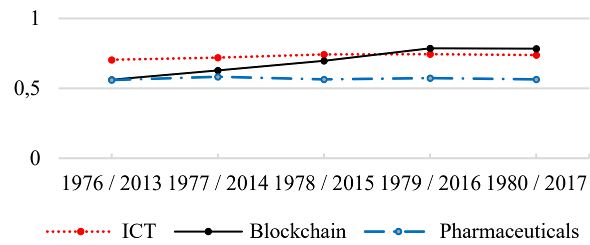


Fig. 4. Generality indexes of Blockchain (2013-2017), ICT and pharma technology (1976-1980)

To sum up, the analysis demonstrates comparability of a generality index of Blockchain technology with an acknowledged GPT (ICT) at the similar development stage with a potential to grow in the subsequent years. The comparison of the generality index of Blockchain with the analogous value of a non-GPT technology (pharmaceuticals) at a comparable maturity level shows that Blockchain is more pervasive. This result leads to a conclusion that Blockchain does already have a pervasive character with a potential to become even more pervasive in a subsequent years, eventually exceeding the level of ICT.

B. *Innovation spawning*

Definition of GPTs as 'enabling platforms' refers to innovation spawning effects, or ability of these technologies to initiate complementary innovations in their downstream application sectors [1]. As discussed in the methodological section of the paper, the variety of patenting organizations in the domain and a degree of entry of new innovators provide valuable insights about the innovation spawning effects of emerging technologies at their early development stages [4], [13].

Fig. 5 maps the landscape of the most active innovators in the Blockchain field between 2013 and 2017. There is an exponential growth of companies that file patents within the Blockchain domain 2013 onward, which reflects the overall upward trend in patenting activities in the field. A relatively large number of financial institutions in 2013 - 2015, such as, for example, Bank of America, Mastercard International, NASDAQ, Fidelity Investments, Toronto Dominion Bank, and Bank of China, is explained by the currently largest share of cryptocurrencies and financial transactions in industrial applications of Blockchain [25]. After 2015, the firms from other industries started entering in the Blockchain domain. In the last years, the most active applicants of Blockchain-related patents are specialized Blockchain R&D companies that focus mainly on overcoming current technical challenges of the technology. A substantial part of these R&D companies are located in Asia and were established between 2009 and 2014. Some examples include Coinplug from South Korea, Hangzhou Fuzamei Tech from China, and EITC Holding that was later renamed NChain Holding. Coinplug focuses on cryptocurrencies and Blockchain-based identity solutions, whereas EITC Holding is active in fundamental Blockchain research. Their recent patents include also applications of technologies within specific settings, for example, digital rights management on Blockchain.

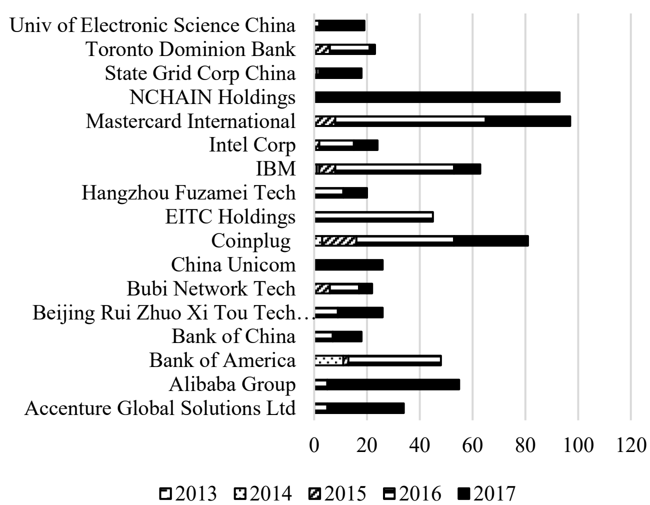


Fig. 5. Top applicants of Blockchain patents (2013-2017)

IBM and Intel Corporation are also active in patenting within the Blockchain domain – IBM filed one of the first Blockchain-related patents in 2013. Some smaller companies, such as Spondoolies, Cardstack, Monegraph, DAGlabs Ltd and others also appear among the active applicants of Blockchain-related inventions. In the last years, the universities also play a more important role in the field: for example, 17 patent filings came from the University of Electronic Science and Technology of China in 2017.

An arrival of a new GPT is often accompanied by a high degree of entry of new innovators because of reallocation of assets caused by the emerging technology [13]. In fact, calculation of the degree of entry of new innovators in the Blockchain space based on Top 20 applicants according to the formula (2) showed, that this value is very high (on average, 0.85) in the analysed period between 2013 and 2017 (see Fig. 6). This value is comparable to the early years of development of other GPTs over the history, such as nanotechnology [28], [36]; electricity [13]; and Internet [22]. The highest value of degree of entry can be observed in 2013 and 2014 (1.0 and 0.95 respectively) which reflects the early stage of technological development of Blockchain. From 2015 onwards, entry degrees remain high, however, lower than initially. In 2017 several important players entered the Blockchain market. For example, large communications corporations, such as China Unicom and Nippon Telegraph and Telephone in Japan started actively patenting Blockchain. State Grid Corporation of China, the largest utility company in the world, became also very active on the market with substantial number of Blockchain-related patent filings in 2017. Alibaba Group Holding filed almost ten times more patents in 2017 than a year before. Chinese university Jinan, with 10 Blockchain patent filings in 2017, is also a new innovator in the domain.

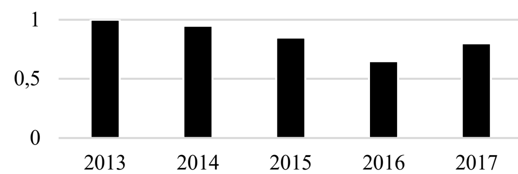


Fig. 6. Degree of entry of new innovators in Blockchain field (2013-2017)

To sum up, Blockchain domain is characterized by „economic trial-and-error" phase [5], with a high degree of entry and a growing variety of „Schumpeterian" companies. Such a dynamic is peculiar to GPTs in the making [15], and provides evidence for innovation spawning effects of Blockchain.

C. *Scope for improvement*

Scholars of technological change acknowledged, that "transforming GPTs never enter the world in a fully developed form" [15]. Therefore, a continuous technological advancement at the early stages constitutes an integral part of technological maturity and is commonly used as an indicator of scope for improvement of an emerging GPT [26], [32]. Blockchain, at its current maturity level, has several technological issues to overcome in order to realize its potential and be applied across various industrial sectors [35]. For the purposes of the present analysis, inventions that aim at overcoming the major technological challenges of Blockchain, such as security, usability, wasted resources, and others, are defined as patents covering R&D aspect. Inventions that refer to the usage of Blockchain within a specific application domain, such as financial transactions, energy management, supply chain, and others, are termed as patents covering application aspects. Though the detailed investigation of patent contents goes beyond the scope of the present paper and is covered in [7], the evolution trend of patents relating to R&D and application aspects of Blockchain is represented in the Fig. 7.

As evident from the Fig. 7, the period between 2013 and 2015 is characterized by more or less identical distribution of R&D and application patents. This can be explained by the prevalence of cryptocurrency-related filings in the early years of Blockchain patenting. From 2015 onwards, the number of inventions that improve the current technological problems of

Blockchain grows fast and outweighs the application-focused patents. Such a prevalence of R&D-oriented patents reflects the clear focus on overcoming basic shortcomings of the technology and serves as evidence to the claim, that Blockchain does indeed undergo a continual technological improvement and, therefore, shows a scope for improvement peculiar to the GPTs in the making [32].

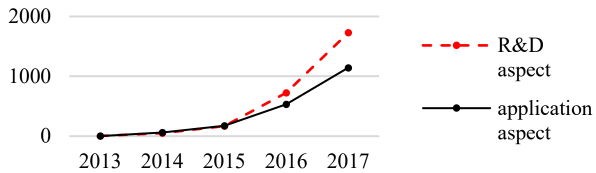


Fig. 7. Blockchain patents related to R&D and application aspects of technology (2013-2017)

The next section discusses the economic implications of the empirical results and briefly sketches possible directions for the further research.

VI. Discussion and Implications of Results

According to the analysis of Blockchain-related patent data conducted in line with the GPT and industrial dynamics literature, Blockchain – already at the relative early stage of its development - can be considered a general-purpose technology in the making. The pervasiveness of Blockchain grows over time, and its generality index is comparable to the analogous values of an acknowledged GPT (ICT) at the similar maturity level. The growing number of IPC classes to which the Blockchain patents relate is another indicator for its pervasiveness. It is still too early to observe the range of complementary innovations in the downstream application sectors of Blockchain in related patent data. However, the analysis of its innovation spawning effects, conducted in line with industrial dynamics literature, demonstrated the large variety of organizations that are actively involved in the innovation process. Large financial institutions, technological companies, but also a range of universities and applied research institutions, energy and e-commerce companies are present in the space. In addition to established organizations, Blockchain gave a rise to a range of newly created R&D companies, mainly located in China, South Korea and Japan, that are currently on the front of technological innovations in the field. The existence of these so-called "Schumpeterian" companies is essential for the phase of economic trial-and error, and massively contributes to GPT development and diffusion [5], [13]. Peculiar to emerging GPTs [13], several technological challenges of Blockchain currently hinder its wide adoption within various industries. The continuous efforts to overcome these challenges, observed in the patent data, provides evidence for scope for improvement of the technology.

To sum up, Blockchain does represent an emerging GPT. This empirically funded conclusion has a number of important implications for designing technology enhancement policies. First, policy makers should be aware of the interrelation of a GPT and facilitating structure in its application sectors. Due to this so-called 'dual inducement mechanism' [1], policies should be aimed not only at supporting technology itself, but at adjusting the facilitating structure through regulation, creation of new education programs necessary for building know-how required by the new GPT, and establishment of technology information networks [15]. Since high degree of uncertainty accompanies development of all GPTs [36], and Blockchain is no exception [12], enhancing policies should be designed in a flexible manner, avoiding concentration of support only within one area [15]. Furthermore, policies should support diffusion of GPTs, which is a slow, however, essential process in realization of their economic impact [1]. This can be achieved through dispersion of sunk costs associated with the new GPT and, as far as possible, by assisting in acquisition of necessary tacit knowledge [15].

The present study is, to the best of the author's knowledge, a first complete empirical investigation of the GPT nature of Blockchain that provides the basis for the further scientific discourse. The one group of questions arises from the interdependency between a GPT and its downstream application sectors [1], [28]. Not only Blockchain as a GPT does influence the application areas, but also the advancement in its downstream sectors will determine the velocity and evolution of the technology itself in the subsequent years. What complementary innovations are needed for successful implementation of Blockchain-based solutions? What are the interaction patterns of Blockchain with existing technologies? How should current business processes be redesigned in order to capture value from Blockchain innovation? What new infrastructure and managerial structures should be created? What are other factors that influence Blockchain materialization as a GPT? These and other questions should be tackled in order to understand the course of the further development of Blockchain.

The theoretical models predict various effects of GPTs on long-term macroeconomic dynamics (see [2] for overview), which opens up promising direction for the future economic research. What is the impact of Blockchain on various macroeconomic indicators, such as productivity, skill premium, and others? How does this technology influence the labour market? Do the existing GPT models explain the influence of Blockchain on economy? These questions are just few examples that the economists will face in the subsequent years.

VII. Conclusion and Limitations of the Study

The study has some limitations. Patent data, though being commonly used to detect technological trends and discover the key technologies, have some general limitations, such as non-patentability of certain inventions, strong dependency on policy, and others [36]. The scholars of the future studies dealing with the similar topic might take in considerations additional data sources, such as scientific papers, market data, data on ICOs, and others. The emerging nature of technology itself and late appearance of related patents in the innovation cycle allow only for a relative short period of tracking the Blockchain trend. Therefore, the observation of the GPT nature of Blockchain is relevant also in the subsequent years, allowing for a higher maturity level of the technology.

The contribution of the present study is twofold. First, to the best of the author's knowledge, it is the first one to systematically examine the defining features of a GPT – pervasiveness, innovation spawning effects, and scope for improvement – in the Blockchain-related patent data from PATSTAT. The analysis, conducted in line with GPT literature is complemented by methods taken from industrial dynamics literature – such an approach is appropriate for analyzing emerging technologies and can be used by scholars in the subsequent studies. Second, the fact that empirical analysis advances the claim that Blockchain is a GPT in the making opens up numerous research avenues and is of high relevance not only for scholars, but also for policy makers and practitioners.

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