BLOCKCHAIN AS A GENERAL-PURPOSE TECHNOLOGY: PATENTOMETRIC EVIDENCE OF SCIENCE, TECHNOLOGIES AND ACTORS

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ABSTRACT

Blockchain is considered to be a General-Purpose Technology (GPT) by many scholars. However, previous studies offer no proof that Blockchain is a GPT. Thus, approximately 2500 Blockchain-related patent data are investigated by deploying the mixed-method approach, using patentometrics with the support of semi-structured interviews conducted with Blockchain experts. This study investigates six main GPT indicators: pervasiveness, improvement, spawning, prevalence, reallocation of resources and inclusive democratisation. Overall, the results demonstrate that Blockchain has not yet become a GPT, though it already shows some GPT characteristics. There are six specific findings: (1) Blockchain shows pervasive characteristics; (2) Blockchain is capable of further improvement; (3) Blockchain facilitates and encourages the creation of innovations; (4) several countries with strong R&D capabilities, particularly China and the United States (US), are showing the prevalence of Blockchain technology; (5) the Blockchain landscape is witnessing greater participation of "younger" companies; and (6) Blockchain is strongly related to the Information and Communication Technology domain with the potential of inclusivity and democratisation. China and the US have the potential to influence the future development of Blockchain technology. This study is assumed to be of great interest to a broad spectrum of stakeholders, such as scholars and policymakers.

Keywords: Blockchain, Distributed Ledger Technologies, General-Purpose Technology, Patentometrics, Technology Analysis

MANAGERIAL RELEVANCE STATEMENT

Technological innovations, such as Blockchain, which are counted as disruptive institutional technology, lead to institutional change as well as economic development and improve the accumulation of social capital, which ultimately enables inclusive democratisation. However, traditional institutions equipped with outdated bureaucratic tools are ill-positioned to understand the potential and risks associated with new-generation GPTs for our society. From this point of view, this study addresses this critical need, which is assumed to be of great interest to a broad spectrum of stakeholders, such as scholars and policymakers. The main implication of this study is that China and the US have the potential to influence the future development of Blockchain technology. Thus, the competition in the Blockchain field between China and the USA will define whether and to what extent Blockchain may become a GPT in the future.

1. INTRODUCTION

Blockchain is a particular type of Distributed Ledger Technology (DLT), that is, a decentralised database with no central trusted party maintaining and storing it [1]. DLTs are expected to have a structural impact on the whole of society and the economy due to their pervasive use in various sectors [1]. The DLT (or Blockchain) is considered to be a General-Purpose Technology (GPT) by many scholars, such as [1], [2] and [3]. GPTs, such as the steam engine and the semiconductor, play the role of "enabling technologies" in multiple sectors of the economy, undergoing continual technological improvements and spurring complementary investment by the adopting sectors [4], [5], [6]. A body of literature, including [4], [7], [8], [9], [10] and [11], investigates the GPT characteristics of various technologies.

There are currently a limited number of Blockchain-related studies published in Business and Management related domains, and very few studies can be found in Innovation [12], [13]. In the literature, such as [3], [14], [15] and [16], many authors refer to Blockchain either as a GPT or as a Key Enabling Technology (KET). Thus, in line with the literature, it is necessary to investigate whether and to what extent Blockchain will be the source of the next GPT. Currently, [1], [2], [3] and [14] are the only studies to investigate Blockchain from a GPT perspective. The findings of [1] show that Blockchain displays the main characteristics of GPT based on a qualitative assessment methodology by investigating Blockchain oriented applications from a GPT perspective. The findings of this study are helpful but limited due to the amount of data, the generalisability of the approach and the focus area, in which the majority of the applications are being developed by small groups of entrepreneurs and individuals.

Following an investigation of GPT characteristics, consisting of pervasiveness, technological spawning and technological improvement, [3] asserts that Blockchain represents an emerging GPT; meanwhile, [2] claims that Blockchain deserves attention as an emerging GPT as it already possesses scope for improvement in important GPT characteristics. However, this study claims that Blockchain has not yet become a GPT, although it already shows some GPT characteristics. Moreover, this study has a wider scope, encompassing six GPT characteristics, while [2] and [3] are based on a smaller number of GPT characteristics. For instance, prevalence is not considered in [2] and [3], although a number of scholars, such as [7], [9] and [17], already point to prevalence as a GPT characteristic. A methodological comparison between [2], [3] and this study shows that [2] and [3] are based solely on quantitative data, whereas this study improves the reliability and validity of the results due to the use of a mixed-method approach consisting of quantitative analysis enhanced with expert opinion.

Thus, an investigation of Blockchain with regard to its potential for GPT requires the most comprehensive approach possible, which is provided in this study, while covering different approaches from the conceptual and methodological perspectives. Moreover, this approach is particularly important as Blockchain is counted by some studies, such as [14], as a disruptive institutional technology, which refers to two Blockchain platforms, namely (1) Backfeed and (2) Steem; however, this is not based on an empirical investigation.

Quantitative and advanced approaches, such as scientometrics (a research method for examining scientific publications) or patentometrics (a research method for examining patent documents), could be better options to establish whether the progress of Blockchain shows it to be a GPT or whether it can become a GPT. These approaches are the most widely accepted ones in the literature in terms of the technological and scientific analyses necessary to deal with a volume of data of which the purpose is to show technological diffusion, progress and change. These quantitative approaches may have weaknesses, such as limitations to the in-depth analysis. However, these weaknesses can be reduced through qualitative approaches, such as interview analysis using expert opinion.

This study aims to understand the extent to which Blockchain technology may be considered as a GPT based on patentometrics analysis validated with five semi-structured expert interviews, but it does not claim that Blockchain may be considered as a GPT. Moreover, it emphasises Blockchain's role in financial and social inclusion, especially important for improved social capital and Bottom of Pyramid BoP [18], which enable inclusive democratisation. The Blockchain-related literature fails to use patent data with extensive analysis. This study adopted patentometrics to examine the degree of Blockchain's GPT characteristics and to validate further and deepen the patentometric results, five semi-structured interviews with Blockchain experts were conducted.

This research offers three distinct contributions: 1) it provides practical findings regarding Blockchain from the GPT perspective; 2) it extracts a comprehensive list of the GPT parameters based on an in-depth literature review of corresponding scholars, and 3) it offers a methodological contribution by assessing Blockchain-specific patent data. The findings of this study should be of great interest to decision-makers in the public and private sector who must decide how to deal with the associated benefits provided as well as the potential challenges posed by the appearance of Blockchain.

The study is structured as follows: Section 2 investigates the existing GPT and Blockchain literature and highlights the key findings; Section 3 introduces the mixed-method approach; Section 4 presents the results and discussion; and, finally, Section 5 concludes.

2. General-Purpose Technologies

Our civilisation is influenced periodically by particular technological innovations, that is, GPTs, which have a hugely disruptive impact on our civilisation.

GPTs follow their technical trajectory with incremental improvements, ultimately producing newer GPTs, to find their dominant design [19], [20]. For instance, electromotive engines, based on electricity (a GPT), were technically improved over time and spawned other application areas, such as electric trams or electric locomotives, based on electric power (a GPT), as well as electric lamps, based on electric light (a GPT). These developments ultimately led to the communication revolution, that is, ICT (a GPT).

It is important to underline that GPTs do not immediately lead to improved economic productivity and growth. As pointed out by [9], [11] and [21], the emergence of a new GPT may cause a slowdown or even result in negative economic activity. The emergence of a new GPT triggers a new economic cycle, as this is not used immediately in the most productive manner possible [6]. Moreover, it usually takes years for a GPT to have a significant impact on the economy [22], [23]. A technology that shows GPT characteristics sometimes may not turn out to be a GPT due to many factors, which proves the difficulty in predicting important technologies and therefore the underinvestment in them [4].

This study is based on an extensive literature review to identify GPT-relevant parameters, while some of which can be assessed directly through quantitative measures, that is, GPT characteristic parameters, such as technology spawning, while some other GPT parameters are particularly subject to interpretation, that is, GPT-enabling parameters, such as the effect of religion or culture on Blockchain. In this context, GPT-enabling parameters were excluded, as this study investigated GPT characteristic parameters caused by Blockchain, which is measured quantitively.

The characteristic parameters of GPT, for example, pervasiveness, technological improvement capabilities and technological spawning capabilities have been widely referenced in GPT-related studies. On the other hand, some further GPT parameters, namely prevalence, reallocation of resources and inclusive democratisation, have been referenced less often and were included in this study to achieve the most comprehensive coverage. In this regard, Table 1 provides a list of GPT characteristic parameters, which were selected from highly cited GPT-related studies, such as [4], [7], [8], [9], [11], [17], [24], [25], [26], [27] and [28], to achieve an unique academic contribution based on extensive coverage all the GPT-relevant parameters.

ID	Parameters	Literature	Description
1	Pervasiveness	[4], [7], [8], [11], [9]	GPTs should spread to most sectors. They should have an impact on technical change and productivity growth across a large number of industries.
2	Technological Improvement Capabilities	[4], [7], [8], [11], [9]	GPTs should improve over time and hence should keep lowering the costs of their users. They should lead to sustained productivity growth and cost reductions in several industries.
3	Technological Spawning Capabilities	[4], [7], [8], [11], [9]	GPTs should make it easier to invent and produce new products and processes.
4	Prevalence	[7], [9], [17]	The prevalence of technology is given by its persistency over time. In other words, such a technology is unlikely to be challenged by new alternative technologies – it seems to be incontestable, at least for some time.
5	Reallocation of Resources	[9], [11], [27]	The available resources are reallocated, dedicated partly to the development of the skills necessary for the use of the new technology and partly to the replacement of the old capital goods with new assets that allow the exploitation of all the potentialities expressed by the GPT.
6	Inclusive Democratisation	[11], [24], [28]	Progress in democracy and innovation foster growth by improving the accumulation of social capital and by lowering income inequality. This is exemplified by several GPTs, such as steam engines or electricity, which particularly emerged during industrial revolutions in democratic European and North American countries. For instance, the diffusion of electrically powered household appliances helped to increase female labour force participation by freeing up women's time from housework.

Table 1: GPT Parameters

2.1 GPT Characteristic Parameters

GPTs are usually characterised by (1) pervasiveness, (2) a series of significant changes to the economic and social systems, (3) many incremental innovations and (4) a wide range of applications in a large number of sectors, making prior products obsolete and giving rise to increasing returns to scale, that is, creative destruction [4], [10], [11], [17], [27]. Furthermore, significant incentives are required to persuade entrepreneurs to attempt to make technological advances in highly uncertain environments, so a GPT is also defined by (5) its prevalence, being present in the system for a long period and being accepted on a large scale so that the specific allocation of resources by stakeholders is stable over time. GPTs lead to institutional change as well as economic development and improve the accumulation of social capital, which ultimately enables (6) inclusive democratisation.

2.1.1 Pervasiveness

Pervasive technology is adopted by many market segments which reflects performance of its certain function that is vital to the functioning of a large segment of existing or potential products and production systems [4], [9]. However, for the pervasive deployment of technology, its adoption must be convenient, particularly from a cost perspective, with a potential to reach a certain level of efficiency so that it can be claimed to show technological improvement capabilities, and it must lead to the development of new so-called "secondary" or "complementary" technologies, thus demonstrating technological spawning capabilities [9]. ICT is a good example of pervasiveness, which is strongly related to network externality. An increasing number of users enabled higher profits, which were triggered by a particularly comprehensive system based on cable connections to a neighbourhood [11].

2.1.2 Technological Improvement Capabilities

GPTs must undergo continual technological improvements over time; hence, their adoption must be convenient from a cost consideration perspective by reaching a certain level of efficiency, facilitating the creation of new organisations, processes or technologies. Furthermore, GPTs should enable permanent technological development at every stage of the value chain [9], [29]. For instance, the scope for improvement of nanotechnology is related to reductions in size, lower costs and greater complexity [29], so it may lead to sustained productivity growth and cost reductions in several industries.

2.1.3 Technological Spawning Capabilities

The technological spawning capabilities of a GPT show the extent to which it may make it easier to invent and produce new products and processes. A GPT triggers the development of "secondary" or "complementary" technologies, that is, technological spawning capabilities [9], so that GPTs lead to product and process innovation with a broad range of uses/application sectors [17]. It is important to underline that complementary technologies are developed as long as the various actors involved share the belief that the GPT is spawning innovations in multiple technological areas [9]. Hybrid corn is counted as an invention of a method of breeding superior corn for specific localities rather than an invention that is immediately adaptable everywhere [11].

2.1.4 Prevalence

A GPT is also defined by its persistency [7], [9], which is based on three conditions: (1) the technical interrelatedness of the system components; (2) the costs of adopting the new technology; and (3) the positive network effects [17].

The coordination of actors' choices of a specific technology is particularly determined by the way how they understand and communicate the benefits received from the adoption of new technology, i.e. GPT [24]. The degree of diffused information points to the role of information and uncertainty in adoption, as it tackles potential coordination failures between innovation actors. Concerning coordination, large actors, such as large firms, public procurement organisations or large public utilities, may play a leading role not only in the design and development of GPTs but also in the encouragement of complementary innovations by users in specific directions [24]. For instance, the procurement policy of the United States (US) Department of Defence and NASA during the 1950s and 1960s enabled the microelectronics technology to play a significant role in the electronics industry, while they also shouldered much of the risk through procurement assurances.

2.1.5 Reallocation of Resources

GPTs lead to “destructive creation”, as resources are reallocated to develop the competencies necessary for the use of the new technology and to replace the old capital goods with new assets that enable the exploitation of all the potentialities expressed by the GPT [11] [30].

Just after the emergence of a new GPT, a phase of experimentation is witnessed in which companies explore different methods to exploit these opportunities, facing strong uncertainties and the skills required to succeed on the market. This leads to a reduction in entry barriers. At the end of this process, a dominant standard is established and the industry can develop, while economies of scale are the main target, leading to industrial and geographical consolidation [21]. An example of this is the arrival of microelectronics and the Internet, which shifted economic power from the east coast of the US to Silicon Valley.

Several potential symptoms are caused by the reallocation of resources during the emergence of a GPT [17], such as (1) a slowdown in productivity, due to learning effects and the allocation of productive resources to the development of the new compatible and complementary capital required to use the GPT; (2) an increase in the demand for skilled and qualified labour; (3) a rise in entries, exits and mergers; (4) an initial decline in stock prices due to the acceleration of the rate of obsolescence of old capital vintages caused by the adoption of the new GPT; (5) a change in the relative market shares of “young” companies; (6) a rise in the interest rate and a worsening of the trade balance due to asset reallocation and a reduction in output, pushing demand and consumption to search for foreign markets; and (7) the transformation of the industrial geography.

2.1.6 Inclusive Democratisation

Various studies, such as [28], [31] and [32], claim that technological progress, institutional change and economic development paths are interwoven. Progress in democracy and innovation foster growth by improving the accumulation of social capital and by lowering income inequality, facilitating inclusivity, which emphasises the role of institutions.

[31] and [32] describe institutional change as a path-dependent process in which institutions are a function of technological developments and previous institutions. For instance, the first and second industrial revolutions were triggered by several GPTs, such as steam engine or electricity, which supported the development of social capital in European and North American countries and caused the emergence of further GPTs. Similarly, [28] claims that recent democratisation developments between the 1980s and the 1990s fostered a new techno-economic paradigm based on converging technologies, such as ICT.

It appears to be the case that the development of social capital, such as BoP, is also influenced by the emergence of new GPTs. In this context, scholars such as [8], [11], [25] and [28] point out the revolutionary role of GPTs as new forms or sources of energy (e.g., steam, electricity and engines), new forms of transportation (e.g., ships and railroads) or a combination of these (e.g., steam-powered rail engines) as well as ICT.

ICT, as inclusive innovation [33], could leverage BoP to improve living conditions by enabling (1) the access of BoP buyers to goods and services, (2) the access of BoP producers to buyers of goods and services, (3) the demand for and creation of relevant goods and services for BoP consumers, (4) the generation of entrepreneurial opportunity and (5) an increase in overall skills, knowledge and confidence. In the same manner, Blockchain is referred to as a new-generation ICT that enables financial and social inclusion, which is especially necessary for improved social capital and BoP [18].

2.2 BLOCKCHAIN-SPECIFIC GPT AND PATENTOMETRIC STUDIES

In a variety of studies in the literature, such as [3], [14], [15] and [16], Blockchain is referred to either as a GPT or as an emerging multidisciplinary KET. Various GPTs are studied to understand their impact on civilisation. Similarly, there is a critical need in the academic world to understand whether and to what extent Blockchain may become a new GPT [1].

Scholars such as [1] and [34] claim that Blockchain, which is a disruptive institutional innovation, may be considered as a GPT and not only as an ICT, as it is a technology that may create new forms of organisations. Blockchain may be viewed as an emerging GPT that shows a particular scope for improvement, which is a widely acknowledged characteristic of GPTs [2].

However, there is a lack of studies describing the features of a system that are required to label it as a DLT or Blockchain, so these terms are used interchangeably in the literature. Although the same approach was deployed in the scope of this study, particularly for simplicity reasons, it is also essential to clarify what is meant by Blockchain: Blockchain is DLT-based special software that has shifted from being seen simply as a digital currency software to being viewed as a disruptive institutional technology [1]. It consists of a consecutive time-stamped chain of blocks in a decentralised fashion created through consensus and cryptographic mechanisms, which are stored by the nodes, that is, small servers, distributed across a P2P network.

Blockchain may be grouped into three categories [35]: Blockchain 1.0 (“Internet of Money”), Blockchain 2.0 (“Internet of Contracts”) and Blockchain 3.0 (“Internet of

Governance”). Blockchain 1.0 refers to the currency applications of Blockchain, namely Bitcoin, and relies on a public ledger system for transactions that is considered to be explicitly Turing incomplete [1], [36], that is, a distributed database. Blockchain 2.0 refers to entire markets and economies by relying on executable codes and applications, such as Ethereum, not just transactions, and is considered to be Turing-complete, that is, distributed computing [1], [37]. Blockchain 3.0 involves complete diffusion and adoption throughout society, which would expectedly cover Turing-incomplete and Turing-complete structures.

[1] claims that Blockchain displays the main characteristics of a GPT, although some may argue that it should not be counted as a GPT, while most of the literature refers to computers or the Internet as a GPT rather than this type of computer software database. In this regard, it is important to highlight that many technologies, such as steam or electricity, which are considered to be GPTs or KETs, usually spawn newer GPTs, such as the railway or ICT [20]. In the same manner, the emergence of computers (GPT) or the Internet (GPT) triggered further innovations considered to be GPTs, such as the Internet of Things (IoT) [38], Artificial Intelligence (AI) [39], [40] or Blockchain, all of which are expected to converge with each other soon [41]. Thus, the IoT and AI are counted as GPTs even though they are based on other GPTs, such as electricity (GPT), computers (GPT) or the Internet (GPT), so the same may be expected of Blockchain.

Blockchain may be claimed to lower production costs in the neoclassical approach or lower transaction costs as institutional technology [1], [34]. Although [34] refers to Blockchain as disruptive institutional technology, becoming a new GPT, [53] not only refers to technological innovations but also includes marketing and institutional innovations, so GPTs can be classified not just as technological but also as process and institutional innovations [1], [42].

A GPT can only truly be identified historically, as the technology may differ from its first iteration, whereas patents offer information about the current state of a technology and more commonly about the past development of that technology [9], [19]. However, new technologies, such as Blockchain, are in the process of emerging, so the patent characteristics that have traditionally been collected are either not available or are rather small in number and thus prone to statistical error. Moreover, Blockchain was designed initially as an open-source technology [1], so few of the Blockchain innovations and improvements can be identified in patents. Despite these disadvantages, as there has been a strong increase in patent applications over recent years, blockchain's path from a business process perspective might be understood now by investigating patent data [43].

2.3 RESEARCH GAP, AIM AND OBJECTIVES

The potentially pervasive nature of Blockchain and its increasing recognition as a GPT have also resulted in a desire in the academic world to investigate whether and to what extent Blockchain might be the next GPT and/or to what extent Blockchain already possesses the characteristics of a GPT. The fact that there are few Blockchain-related studies – such as [1], [2], [3] and [34], which discuss Blockchain as a potential GPT, and [12], [13] and [43] in the innovation management domain, which investigate Blockchain from an emerging technology perspective based on bibliometrics or a text-mining approach but without a GPT focus – points definitively to a research gap in the evaluation of Blockchain's potential as a new-generation GPT. In fact, to the best of our knowledge, only [2], [3] and [14], besides [1], investigate Blockchain from the GPT perspective and only [2] and [3] rely on patent analysis. Therefore, many Blockchain-related studies, such as [1], [12], [13] and [44], fail to conduct a patent data-based investigation, omitting extensive analysis of the topic. For instance, [1] focuses on a survey of Blockchain applications based on information provided by the Internet to investigate Blockchain rather than using historical data, that is, patent data, as there is a lack of such historical data to analyse this new technology. However, the analysis in [1] might be misleading as the entire Blockchain ecosystem is exceptionally dynamic, with small groups of entrepreneurs and individuals who are motivated by the hype playing a significant role.

[3] asserts that Blockchain does represent an emerging GPT following an investigation of GPT characteristics, namely pervasiveness, innovation-spawning effects and scope for improvement, while [2] claims that Blockchain deserves attention as an emerging GPT as it already possesses scope for improvement, which is a widely acknowledged feature of a GPT. However, this study took a different approach to the topic, claiming that Blockchain has not yet become a GPT, though it already shows some GPT characteristics. Moreover, this study has a wider scope as it is based on six different GPT characteristics, while [3] and [2] have a smaller focus concerning the GPT characteristics. For instance, prevalence is not considered in either study, although many scholars, such as [7], [9], [17], already point to this characteristic. A methodological comparison between [2], [3] and this study shows that [2] and [3] are solely based on quantitative data, which may provide restrictive results, whereas this study aimed to increase the reliability and validity of the results derived from quantitative analysis with expert opinion.

Thus, the investigation of Blockchain concerning its potential as a GPT requires the most comprehensive approach possible, which was realised in the scope of this study, so it differs from other studies from the conceptual and methodological perspectives. This approach is becoming more important, as some studies, such as [14], claim Blockchain to be a disruptive institutional technology; however, this is not based on an empirical investigation.

At first glance, [3] and this study seem to follow similar approaches, although this study tackles some critical weaknesses of [3]. For instance, comparing Blockchain's generality index with ICT appears to be very vague, while patent data already show that Blockchain is strongly related to ICT. On the other hand, in the scope of Blockchain's technological improvement characteristics, [3] claims that the detailed investigation of patent contents is not covered, while this parameter is extensively investigated with heatmap analysis supported by expert opinion in this study. This approach certainly provides a deeper insight into Blockchain's GPT characteristics.

[14] claims that Blockchain may be also counted as an institutional technology, as it is more than just a new-generation GPT. However, GPTs can be classified not just as technological but also as process and institutional innovations [42], so this distinction might not necessarily be correct. Moreover, this study assumed Blockchain to be widely deployed in our society, which demanded an empirical investigation. In comparison with [14], this study relied on patent data supported by expert opinion to investigate these assumptions empirically. For instance, the involvement of experts in the analysis of the heatmap of Blockchain patent data enabled a deeper investigation of Blockchain's technological improvement capability.

[2] follows the quantitative approach based on data from patents and the media to investigate Blockchain's scope for improvement. However, the GPT analysis of any innovation cannot be restricted to only a single GPT parameter. Moreover, [2] claims that the evolution of the total number of Blockchain patents serves as an indicator of the scope for improvement of technology. However, it does not provide any information on how particular fields of Blockchain technology are being addressed by innovation actors. For instance, [2] is missing any insights into how Blockchain patents that address the R&D aspect are categorised, which was addressed by this study.

Studies such as [12], [13] and [44] investigate Blockchain-related academic studies using a bibliometric method but at a higher level, which are difficult to align with Blockchain's

GPT characteristics. For instance, it is not possible to investigate whether Blockchain displays spawning characteristics as it is unclear whether the current research efforts aim to improve the technology or to work in related fields.

This study addressed this gap by deploying a mixed-method approach, consisting of patentometrics and semi-structured interviews, to examine Blockchain as a potential GPT. While investigating the GPT characteristics holistically, all the identified GPT characteristics were covered, without excluding any country- or sector-specific focus. Moreover, this study is the first academic work to study the Blockchain domain from a GPT perspective based on patentometric analysis, while contributing to the academic world by reviewing all the GPT parameters of relevant scholars.

Investigating Blockchain from a GPT perspective could challenge the existing organisational theories fundamentally [45], including organisational ecology, institutional theory, transaction cost economics, resource dependence and network theory.

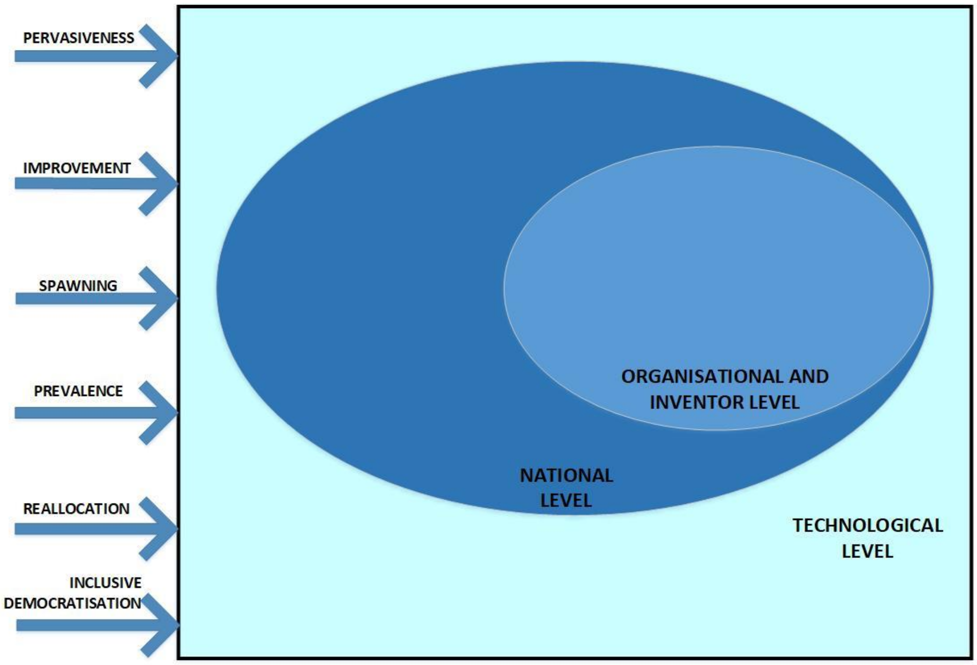

Figure 1: Research Framework

As mentioned earlier, Blockchain studies lack a data-based investigation of Blockchain's GPT characteristics, so that this study comprehensively investigates the topic with a patentometrics based extensive patent analysis. Based on the literature reviews in the GPT- and Blockchain-related domains (see Section 2 and Figure 1), this study aimed to answer the following research questions:

RO1: Does Blockchain display pervasiveness characteristics and, if so, to what extent?

RO2: Does Blockchain display technological improvement capability characteristics and, if so, to what extent?

RO3: Does Blockchain display technological spawning capability characteristics and, if so, to what extent?

RO4: Does Blockchain display prevalence characteristics and, if so, to what extent?

RO5: Does Blockchain display reallocation of resources characteristics and, if so, to what extent?

RO6: Does Blockchain display inclusivity and democratisation characteristics and, if so, to what extent?

3. Research Design

This study used a mixed-method approach to offer a deep and broad understanding of the subject by considering all the relevant GPT characteristics without reducing the focus to a single country or sector. The mixed-method approach is also suitable for this study as it increases the reliability and validity of the results. The patent data provided quantitative and comprehensive results, and the semi-structured interviews with experts deepened the interpretation of and validated the findings [46]. This sequential mixed-method approach [47], [48] began with patentometrics, followed by the interview method, which perfectly complemented the results retrieved from the patentometrics (see Figure 2).

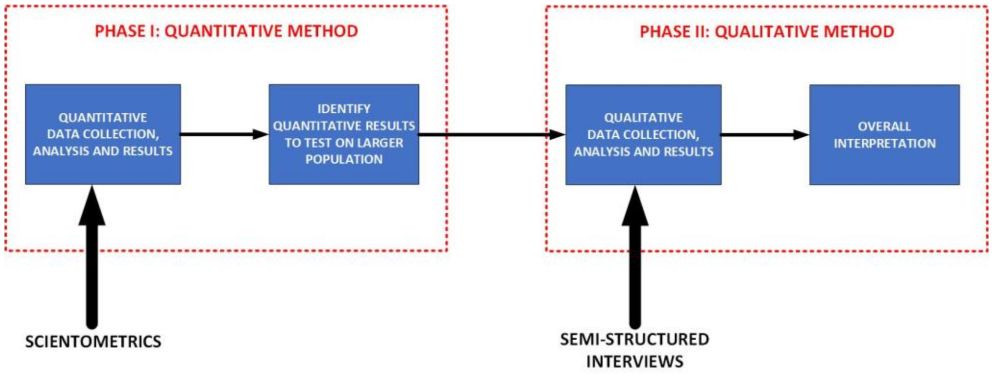

Figure 2: Sequential Exploratory Design

3.1 Quantitative Method: Patentometrics

Patentometrics is composed of five stages – (1) database selection, (2) data search, (3) data optimisation, (4) data analysis and (5) visualisation – followed by the interpretation of results for the patent data set [49]. To access the right set of patent codes and lexical search terms, the research and innovation areas in the Blockchain domain were grouped based on the literature and the qualitative examination of the sample patent data.

During the data collection process, 249 Blockchain-relevant terms were used; the following list of keywords shows some of the ones used to collect and create the data set: Blockchain OR Bitcoin OR Cryptocurrency OR "Distributed Ledger" OR "Smart Contract" OR "Zero-Knowledge Proof" OR Ethereum OR Hyperledger.

As a result, nearly 2500 Blockchain-related patents were examined. The total number of patenting organisations in relation to the number of organisations patenting for the first time in the Blockchain domain and the number of forward citations based on the number of distinct technological classes (IPCs) were investigated. Furthermore, Blockchain's proximity to other groups of GPTs and its impact on the innovation and management landscape were investigated.

3.2 *QUALITATIVE METHOD: SEMI-STRUCTURED INTERVIEWS*

In the qualitative stage of this research, semi-structured interviews were implemented to increase the reliability and validity of the results. Hence, information from the interviewees was used to support the analysis performed in the quantitative stage and to increase the depth of the study. Accordingly, the sample selection was designed to gather a variety of types of information from the relevant experts.

The interviewees were recruited from industry and academia based on the criterion that they were actively engaged individuals with at least one year of experience in Blockchain field. The experts are currently either working in a leading strategic position in their organisation or working on an ICT-related function that gives them information and knowledge on Blockchain technology [21]. In such a way, it was possible to generate comprehensive knowledge and critical insights from various organisations. On average, the interviews took between 45 and 60 minutes and contained open-ended questions about GPT-related parameters of Blockchain. The experts participated in the semi-structured interviews in two ways: either (1) they were shown the results of the quantitative analysis and asked for their confirmation and further comments; or (2) they were asked open-ended questions to extend and illustrate cases, such as “Can you provide use case(s) of Blockchain in which you might consider Blockchain as a GPT?” or “Do you observe or expect a paradigm shift in the economy triggered by Blockchain technology?” As shown in Table 2 below, five experts, consisting of one Blockchain developer, two independent Blockchain consultants, the CEO of a Blockchain company and one academic, the author of several studies, were included in the study.

Interviewee	Age	Highest Level of Education	Position in Organisation	Experience
X1	55	BSc	Blockchain consultant	3
X2	45	MSc	CEO of a Blockchain-related company	4
X3	35	PhD	Academic undertaking Blockchain research	3
X4	39	MSc	Blockchain developer	4
X5	38	MSc	Blockchain consultant	4

Table 2: List of Interviewees

During the study, it was possible to determine that the experts provided consistent information and that, in the last interview, a saturation point was reached, so the information provided was similar and repetitive. Thus, as the qualitative method was a supportive step in this study, our results were finalised based on these five experts' opinions. Considering the reliability of the results, all the experts confirmed the accuracy of the quantitative results regarding the validity of information gathered in the scope of GPTs and Blockchain, enabling the results of the quantitative investigation to become more related and deeper.

The semi-structured interviews were interpreted with the NVivo® qualitative data analysis software in five steps: (1) organisation of the data; (2) disassembling the data into groups; (3) reassembling the data by regrouping them according to GPT characteristics; (4) induction of meaning from the reorganised data; (5) deriving of conclusions from the data with a special focus on Blockchain.

4. RESULTS AND DISCUSSION

This section consists of the illustrative outputs retrieved from the mixed-method analysis to investigate the extent to which Blockchain shows GPT characteristics. The discussion section is divided into six sub-sections in line with the GPT characteristic parameters shown in Table 1. The investigation of Blockchain from a GPT perspective requires a holistic approach to the research objective so that all the identified GPT characteristics are covered without excluding a country- or sector-specific focus.

4.1 PERVASIVENESS

GPTs, such as Blockchain, disrupt different segments across the entire economy, particularly the ones that are based on database [1]. Although [1] claims that Blockchain applications are concentrated on Blockchain 2.0, that is, the “Internet of Contracts”, many interviewees claimed that Blockchain as the “Internet of Money” has a higher probability of transforming itself into a GPT, as they observed that many Blockchain developers are concentrating on corresponding topics. It is also important to note that [1] does not introduce a clear definition of Blockchain categories, so there is an arbitrary approach concerning the allocation of Blockchain applications to these categories. Furthermore, the interviewees pointed to the most significant application fields of the “Internet of Money”, namely (1) identity solutions; (2) logistics; (3) energy; (4) mobility; and (5) healthcare.

Interviewee X2 further claimed that the digital revolution, particularly fuelled by social media platforms, is expected to disrupt the existing traditional institutions. For instance, Facebook already connects 2.4 billion users worldwide, so it may easily transform itself into the “Internet of Money” platform as it is currently experimenting with Libra. Furthermore, another pervasive social media platform, WhatsApp, with 1.5 billion users, could be converted into the “Internet of Money” platform supported by Blockchain features.

X2 also emphasised the role and impact of policymakers as they can recognise an element existing in the online world, for example, electronic signatures, as if it exists in the physical world by law. For instance, two unique “Internet of Money” concepts, namely Initial Coin Offerings (ICOs) and Security Token Offerings (STOs), also depend on corresponding policies, as recent US regulations have proven. Initially, cryptocurrencies such as Ethereum or Bitcoin received considerable attention from US investors, which was unfortunately negatively affected by the recent decision of the Internal Revenue Service concerning the taxation of cryptocurrencies. Furthermore, the US Government prohibits Blockchain-related institutions located in other countries from selling securities, including ICO or STO tokens, to US citizens.

In the scope of the “Internet of Money”, digital identity solutions are also expected to benefit strongly from Blockchain. Considering Blockchain’s unique security features, it could provide the best storage medium for such highly sensitive data. For instance, the biometric data of BoP citizens could be stored securely on Blockchain, so BoP can be included in the civilised world. Thus, the unbanked people of BoP are currently highly emphasised by the Blockchain community.

However, interviewee X1 pointed out two main reasons for the slow diffusion of Blockchain technology: (1) Blockchain does not enable the realisation of a product as it needs to be integrated with other products or solutions; and (2) Blockchain alone is not at Technology Readiness Level (TRL) 9, the TRL indicating the maturity level of technology.

Year	Number of Terms (New)	Number of Terms (Existing)	Number of Terms (Total)
2014	0	0	0
2015	18	0	18
2016	32	6	38
2017	124	28	152
2018	298	120	418
2019	96	170	266

Table 3: Number of Technology Terms by Year

Table 3 indicates that the number of Blockchain terms increased dramatically, from almost 0 in 2014 to 418 in 2018, as newer technology terms have been increasingly introduced. [13] also confirms the publication and citation trends of Blockchain papers, stating that the number of Blockchain articles has been growing dramatically since 2013. Blockchain technology is obviously spreading to other technology fields.

Figure 3 shows the patents scores for each patent classification. In 2015, there were no patent applications, particularly because Blockchain was a very new technology; in 2018, Blockchain patents had already achieved a level of approximately 1400 in 10 different categories. This is also confirmed by the citation trends of Blockchain papers, which have been increasing since their initial publication in 2014 [13].

The patents shown in Table 3, Figure 3 and Table 4 point to three main patent categories: (1) G06Q; (2) G06F; and (3) H04L. G06Q deals with payment mechanisms, whereas G06F and H04L address security concerns for data transmission and storage. It seems that the Blockchain community is currently concentrating on the development of topics related to the "Internet of Money". Interestingly, G06Q patents also cover payment mechanisms, which enable the involvement of intermediaries, such as notaries, trusted third parties, stocks and commodities. This development confirms the statements of interviewees that highlighted the changing business models of various traditional institutions in society.

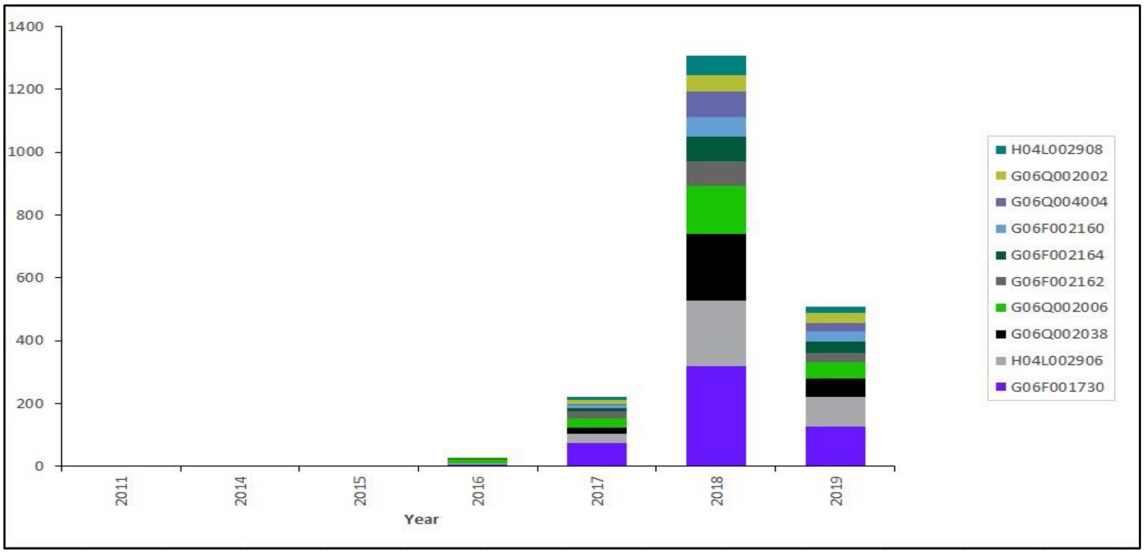

Figure 3: Technology Terms vs Year

Patent Class	Number of Records
G06F001730	524
H04L002906	333
G06Q002038	292
G06Q002006	248
G06F002162	132
G06F002164	125
G06F002160	110
G06Q004004	110
G06Q002002	98
H04L002908	92
G06F002110	79
G06Q001006	62
G06F002131	52
G06Q001008	52
G06Q002010	50
Other	2385

Table 4: Patents vs Technology Terms

Figure 4 shows the direction of 10 major countries in Blockchain landscape concerning their R&D efforts. None of the actors exhibits similar orientations in terms of R&D activities, demonstrating Blockchain's pervasive characteristics. It appears that the US actors are more focused on data processing, specially adapted for specific functions, such as information retrieval, database structures or file system structures, while China is engaged in communication control and protocol. Moreover, South Korea is strongly concentrated on payment protocols, that is, the "Internet of Money".

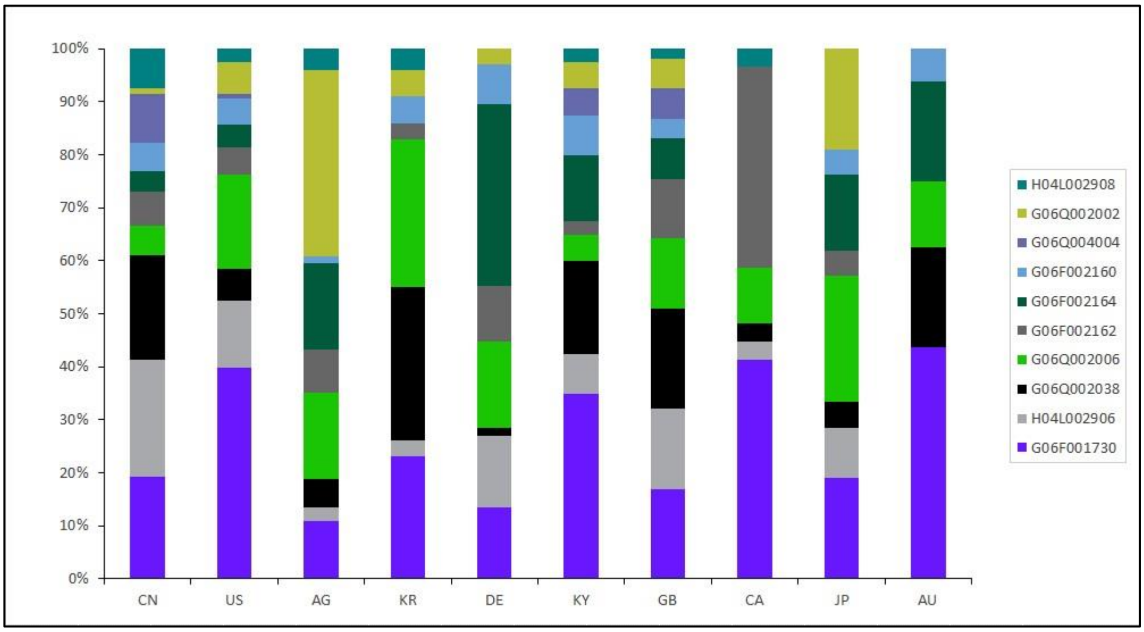

Figure 4: Technology Terms vs Location

In conclusion, it is clear that Blockchain already possesses pervasive characteristics as it is applied to a range of sectors, a fact that is also underlined by Vitalik Buterin, the founder of the Ethereum platform [1].

4.2 *Technological Improvement Capabilities*

In line with [1] and [2], most of the interviewees claimed that Blockchain code is available to the public as open-source software, so anyone may access the original Blockchain code and create applications, which points to Blockchain's technological improvement characteristics [1]. This also applies to soft and hard forks. Hard or soft forks occur when Blockchain's existing code is changed and the older version, Bitcoin, remains on the network, while the new version, Bitcoin Cash or Bitcoin Gold, is created to eliminate the existing malfunctions of the system. Blockchain's adoption is convenient from a cost consideration perspective [9], only if it shows continuous technological advancement, particularly in security, scalability and usability [50].

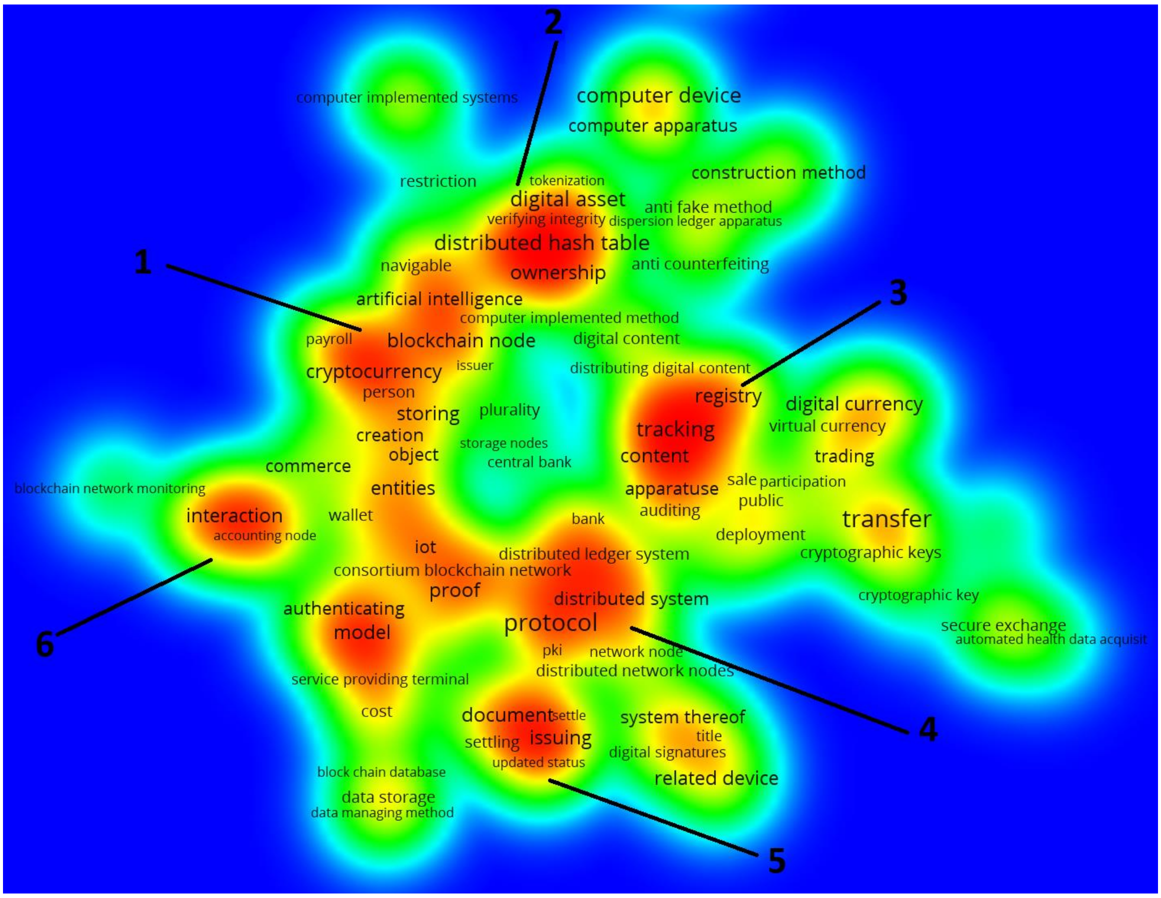

Figure 5: Heatmap Based on Blockchain Patents

In this regard, Blockchain's technological improvement characteristics may be investigated in Figure 5, which depicts a heatmap based on the analysis of Blockchain patents. The analysis shown in Figure 5 has been realised with VOSviewer, which generates maps using VOS mapping, while the distance between items depends on their similarity or relatedness. Thus, if the distance between the two terms is smaller, it implies greater relatedness between them. Furthermore, the font size of terms is dependent on their frequency of occurrence in patents.

The majority of academic work is dedicated to computer science, engineering and telecommunications domains [12], [13]. This is confirmed in Figure 7, which was investigated with the support of Blockchain experts to create Table 5. Table 5 consists of six clusters, namely (1) value management, (2) asset management, (3) tracking, (4) technology, (5) documentation and certification and (6) governance and interaction. Cluster 1 deals with value management, including value storage, value security, value transmission and value processing. Various use cases are patented in this cluster, such as the IoT, aviation, sustainability, 3D applications and energy, making it one of the most fundamental blocks. Cluster 2 covers asset management, including topics such as the verification of digital asset ownership, its exchange based on tokens and the secure, efficient transfer of entities. However, it seems that Blockchain actors concentrate less on Cluster 2. Cluster 3 is focused on the tracking of values besides storage and exchange as well as on micro-transactions. Interviewee X2 claimed that Blockchain needs to be improved in the context of micro-transactions. Cluster 3 also covers topics related to the enhancement of the Blockchain platform to store and exchange transaction data in a distributed computing network. Cluster 4 is particularly related to improving Blockchain technology, such as new types of Blockchain consensus methods and new types of Blockchain approaches. Cluster 5 deals with Blockchain-based document management, whereas Cluster 6 covers governance and interaction on the Blockchain platform and is particularly related to the enhancements required for Blockchain.

ID	Cluster Name	Key Words Identified	Interpretation
1	Value Management	Artificial Intelligence, Blockchain Node, Cryptocurrency, Storage	• The following fields are expected to be influenced by Blockchain technology: (1) genetics; (2) e-commerce; (3) gambling; (4) aviation; (5) sustainability; (6) creativity; (7) security; (8) energy; (9) finance management; (10) asset management; (11) 3D applications; (12) social media; (13) sports management; (14) gaming; (15) business operations, including accounting, HR, marketing and knowledge management; (16)

ID	Cluster Name	Key Words Identified	Interpretation
			healthcare; and (17) smart cities, including autonomous objects and the IoT. • The fields mentioned may be grouped into two categories, namely near-term and far-term use case categories. • To provide an example of a near-term use case scenario, a Blockchain-based payment system in aircraft (Patent Code US20180293555A1) may be counted as an interesting deployment of Blockchain technology. It appears that Blockchain will spread to such fields as well. • Another interesting near-term category is creativity, which deals with various topics, such as the monetising of intellectual property (Patent Code US20190130507A1), rewarding mechanisms concerning story creation (Patent Code KR20190113075A). • When it comes to the far-term use case category, the convergence of Blockchain and AI seems to be very promising, so categories such as (1) smart cities, including autonomous objects and the IoT, (2) healthcare or (3) energy management are expected to emerge. Thus, Blockchain enables distributed computing. • For instance, in the case of autonomous objects, Blockchain and AI are expected to be deployed to manage moveable autonomous devices (Patent Code CA2961357A1).
2	Asset Management	Digital Assets, Distributed Hash Table, Ownership	• Cluster 2 is focused more on topics related to the verification of digital asset ownership, exchange based on tokens and secure, efficient transfer of entities. These topics deal with the improvement of Blockchain technology.
3	Tracking	Registry, Tracking, Content	• There are various areas in which Blockchain technology may be deployed to trace value. This includes areas such as (1) finance; (2) virtual reality; (3) asset management; (4) various business functions, including document management and manufacturing; (5) tracing IoT data; (6) e-commerce; (7) security; and (8) healthcare. • One of the best examples of Blockchain's deployment is the track-driver-behaviour-to-prevent-drowsy-driving prevention method (Patent Code KR20190128479A). • Another example is the Blockchain-based tracing of energy consumption, water consumption, water quality, greenhouse gas emissions and air emissions (Patent Code US20190311443). • It appears that Blockchain's deployment will also occur in the digital world, as demonstrated by virtual reality (Patent Code KR102044008B1), which enables identity authentication and management.
4	Technology	Protocol, Distributed System, Network Node, Proof	• Cluster 4 deals with managing transactions of value data through Blockchain while covering topics including (1) secure data transactions (2) using infrastructure technologies, such as wireless telecommunication systems (Patent Code US20180048738A1). It also deals with updating the Blockchain network protocol. • Furthermore, it covers topics related to data storage in the distributed computing environment, that is, cloud computing (Patent Code WO2019152750A1), including various consensus mechanisms for Distributed Ledger Technologies. • Moreover, in the case of the IoT, a Blockchain-based sustainability protocol for IoT Sensors (Patent Code US20190122086A1) is described.
5	Documentation and Certification	Document, Issuing, Settling	• While some patents describe how to certify an electronic document, others deal with Blockchain-based signatures, such as signing PDF-based documents or due diligence in mortgage documents. • There are some specific use cases besides generic document management cases. For instance, in the case of identity management, Blockchain-based digital identity management and permission control mechanisms are described. • When it comes to certification-related patents, a mechanism is an interesting case as it describes how to manage lifelong learner events via Blockchain.
6	Governance and Interaction	Interaction, Accounting Node	• This cluster is focused on securing value using Blockchain, covering topics such as securing and disseminating time-sensitive information

ID	Cluster Name	Key Words Identified	Interpretation
			(Patent Code AU2017212801B2) or managing Blockchain access to user profile information (Patent Code US10129269B1). • Regarding the transmission of Blockchain data, it deals with how to reduce Blockchain transaction delays (Patent Code US20190114626A1) or cross-chain interactions in Blockchain systems (Patent Code US20190253263A1). • Concerning processing value data, several concepts are proposed, such as distributed reputational databases (Patent Code US20190052722A1) or new methods for Blockchain management (Patent Code US20180308072A1). • There are various fields in which Blockchain-based governance and interactions may play a role. • For instance, in the case of the IoT, they are patents that describe how object reconciliation for interaction in a Blockchain environment (Patent Code US10192073B2) may be realised. • Another Blockchain-based patent describes a gaming platform system for the interactive participation of players with a Bitcoin-based award mechanism (Patent Code WO2015117029A1).

Table 5: Interpretation of the Heatmap

In conclusion, Blockchain actors are either working on the improvement of weaknesses in the Blockchain technology, in line with [50], or trying to position themselves as competitively as possible to benefit from the Blockchain hype.

4.3 Technological Spawning Capabilities

As mentioned earlier in Section 2.2, Blockchain is also referred to as a KET [15] and [16] pointing to Blockchain's spawning capabilities. To exemplify this, interviewee X1 claimed that database technology might be considered to be a GPT as well, as it is responsible for 80–90% of ICT deployments, including Internet (GPT) or Global System for Mobile Communications (GSM) networks (GPT), with critical consequences for our civilisation. For instance, the Internet was enabled by the Domain Name System (DNS), which is a database-related technology. The transformation of Arpanet to the Internet was only possible through the spawning of database technology to the Internet, that is, the DNS. Thus, X1 strongly associated this concept with Blockchain and database technologies, whereby Blockchain is expected to be integrated into the Internet by solving its shortcomings and thus spawn through further pervasion in our society.

However, in line with several other scholars, including [51] and [52], interviewee X2 claimed that Blockchain can be used as an integral part of the IoT, as it lacks micro-payment mechanisms, which are one of the main problems of the IoT. However, the inefficient Blockchain architecture restricts money transactions on Blockchain which hinders the realisation of micro-payments. IOTA's Tangle, that is, "Blockchain without Blocks and the Chain", tackles this inefficiency, introduces a new way of reaching consensus and has the potential to enable the integration of IoT and Blockchain. Tangle is expected to enable faster payment mechanisms solely dedicated to IoT applications. Conditional on the current problems of Blockchain technology being solved successfully, it could spread successfully to other sectors, particularly in parallel with the diffusion of IoT technology. Furthermore, Blockchain could play a significant role in the IoT context concerning (1) Blockchains and smart contracts for the IoT and (2) IoT security, in which decentralisation, peer-to-peer realisations, keeping a log of sequential transactions and traceability are important factors to be considered [44].

The analysis of Blockchain-related patents may provide valuable insights into the innovation-spawning effects of Blockchain, although Blockchain is still in its premature stage.

Year	New People	Existing People
2014	0	0
2015	17	0
2016	50	0
2017	332	0
2018	1609	134
2019	648	198

Table 6: Investors' Trend

Table 6 indicates that the number of R&D personnel increased from almost 0 in 2014 to approximately 1800 in 2018, as there is increasingly a shift of human resources to Blockchain-related R&D.

Table 7 outlines 10 major actors with patent scores ranging between 50 and 250, whereas the "Other" bar consists of around 3800 patents. This confirms the widely distributed

Blockchain-related R&D landscape, as there is certainly a high number of actors with a low number of patent scores.

Organisation	Number of Records
NChain	270
IBM	154
Alibaba	150
Mastercard	138
Coinplug	70
Huawei	62
Walmart	58
Pingan	51
Intel	49
China Unicom	48
Other	3909

Table 7: Patents vs Organisations

Furthermore, Table 8 outlines that the major Blockchain actors are highly concentrated on "Internet of Money"-related topics, particularly payment mechanisms, data storage and data transmission, and they are either shifting their existing R&D capacity or increasing their R&D capacity by hiring new inventors. For instance, NChain is fairly focused on payment mechanisms (115 patents), whereas IBM is dealing with data storage (92 patents). Furthermore, it appears that IBM is working on some niche topics, including healthcare and traffic, that is, future promising IoT use cases, pointing to Blockchain's technology-spawning characteristics.

Ranking	Organisation	Patent Class	Patent Score (per Patent Class)	Description
1	**NChain**	G06Q	115	Payment Mechanisms
		H04L	107	Data Storage
		G06F	54	Data Transmission
		H04W	8	Wireless Communication Networks
2	**IBM**	H04L	92	Data Storage
		G06Q	66	Payment Mechanisms
		G06F	73	Data Transmission
		H04W	6	Wireless Communication Networks
		A63F	5	Games
		G16H	1	Healthcare Informatics
		G08G	1	Traffic Control
3	**Alibaba**	G06Q	39	Payment Mechanisms
		H04L	39	Data Storage
		G06F	28	Data Transmission
4	**Mastercard**	G06Q	39	Payment Mechanisms
		H04L	39	Data Storage
		G06F	28	Data Transmission
5	**Coinplug**	G06Q	39	Payment Mechanisms
		H04L	23	Data Storage
		G06F	16	Data Transmission
		H04W	3	Wireless Communication Networks

Table 8: Patents Classification vs Major Actors

In conclusion, there is obviously the reallocation of assets and entries of new actors, such as organisations or inventors, in the innovation process, which points to the arrival of a new GPT, that is, Blockchain.

4.4 Prevalence

The key point regarding prevalence is that different actors in the innovation landscape understand and communicate a set of beliefs concerning the wide applicability of the GPT [9]. Despite the widespread acceptance of Blockchain's potential, it is still seen by a majority of people as a niche technology, so few people utilise its services [1]. This requires strong coordination between a broad set of actors, particularly entrepreneurs, who need to be persuaded to attempt to make technological advances in a highly uncertain environment [7].

Interviewee X2 pointed to Facebook's Libra, which is in principle a stablecoin. Just after the introduction of Libra, the US Congress invited Zuckerberg to testify to his Libra project, while Germany and France declared Libra to be a national security risk. X2 claimed that US policymakers are extremely concerned about the risk that, following the introduction of Libra, the US would lose the ability to dominate the global economy economically. In return, China, which competes with the US, declared its support for Blockchain technology, banned any negative news related to Bitcoin and revealed plans to introduce a Chinese national cryptocurrency. Furthermore, members of the Chinese Communist Party are required to transfer and register all of their daily activities to Blockchain. Thus, as proven by various government-supported projects, the interviewees claimed that strong policies are essential to promote the implementation of Blockchain so that it may become a GPT. The role of policymakers is also described by [1], who claims that centralised traditional institutions in competition with Blockchain may stifle its development through regulations, which would certainly threaten the positive benefits that it offers to society and the economy.

The interviewees also confirmed the importance of the common perception of stakeholders in the Blockchain landscape, as Blockchain's wide deployment and recognition may be effectively hindered by a poor reputation among stakeholders. For instance, a dramatic depreciation of Bitcoin's value would cause investors to lose money, which in return would reduce their motivation for investing in Blockchain and related technologies. Another event with equally negative consequences would be either slandering or deterring actors from Blockchain, as has occurred in the US with new legislation regarding taxing cryptocurrencies.

Table 9 shows how each country is performing in the Blockchain landscape, including the most significant actors. Several countries have started to shift their R&D capacities to work on Blockchain technology, while private organisations, such as Huawei, IBM, Mastercard, Walmart, Samsung, Siemens, NEC, British Telecom and Alibaba, are also active in the Blockchain field.

China and the US are outcompeting other countries in terms of patent scores. X1 pointed to two main megatrends, namely the sharing economy and big data, and claimed that both countries are focusing on Blockchain as they are aware of the change in the global economy from traditional business models to a new type of business models, as proven by AirBnb, Uber and so on. Thus, they have started to prepare their economies for this paradigm shift to strengthen their position in the global economy.

The number of Blockchain-related patent scores in relation to the number of researchers is higher in the US (1350 patents) than in China (1880 patents). In other words, the intensity of Blockchain-related R&D efforts is greater in the US than in other countries, including China. Thus, one may conclude that the US is more focused on Blockchain than other countries.

On the other hand, the number of Blockchain-related organisations is much higher in China than in other countries, including the US. [13] provides an overview of the top funding agencies of Blockchain studies, and the majority of these institutions originate from China. Moreover, the majority of studies in the Blockchain field originate from China [12]. Thus, Blockchain-related R&D activities are more pervasive in China, whereas R&D activities are more concentrated in the US, led by large organisations such as IBM, Mastercard and Walmart, each from a different sector. However, interestingly, Switzerland plays a significant role in the Blockchain-related academic world, with its two leading journals, Sensors and Sustainability, but this is not reflected in Blockchain patents, as shown in Table 9. This occurrence confirms the open-source characteristics of Blockchain [12]. Furthermore, although Ireland is the country with the most citations per article in the field of Bitcoin, which functions as a proxy for the average scientific importance or quality of the academic work in the country, it is not identified in the list of countries with the most Blockchain patents [53].

Country	Number of Blockchain Patents (per Country)	Actors in the Particular Country	Number of Blockchain-Patents (per Organisation)
China	1880	Huawei Technologies Company Ltd.	59
		Pingan Sci & Technology Shenzhen Co Ltd	49
		China Unicom Group Co Ltd	47
US	1350	International Business Machines Corp	135
		Mastercard Inc	130
		Walmart Stores Inc	58
South Korea	199	Coinplug Inc	70
		Samsung Sds Co Ltd	17
		Samsung Electronics Co Ltd	11
Germany	162	Siemens Aktiengesellschaft	39
		Bundesdruckerei Gmbh	34
		NEC Corp	13
UK	105	British Telecommunications Plc	27
		R3 Ltd	7
		Alibaba Group Holding Ltd	6
		International Business Machines Corp	6
		Technicolor Sa	5
		Alcatel-Lucent	3
		Gemalto	3
		Ingenico Group Sa	3
		Maim E	3

Table 9: List of Countries and Selected Organisations

Interviewee X2 also pointed to the so-called hash power concerning the competition between China and the US. Currently, Chinese mining pools control more than 70% of the Bitcoin network’s collective hash power and therefore have an immense influence on the Blockchain landscape. Hash power is highly related to the Proof-of-Work (PoW) consensus mechanism, which is the fundament of Blockchain, including Bitcoin. Moreover, it is important to mention that 50% of cryptocurrency projects and the majority of miners are based in China, whereas 90% of Blockchain calculations are simply concentrated in the nine groups of Chinese organisations.

Table 5 also shows that South Korea (199 patents) is following the US and China, particularly due to the R&D efforts of companies such as Samsung, which recently created a secure area for Blockchain applications on mobile phones. Germany, which occupies the fourth place with 162 patents, is largely led by companies located in Berlin. In the German ecosystem, Siemens (39 patents) is mainly concentrated on IoT applications, whereas Bundesdruckerei (34 patents) deals with personalisation solutions, such as IDs or passports. As mentioned earlier, it is more secure to keep personalised information on Blockchain instead of one centralised server. Germany is followed by the UK with 105 patents, while, interestingly, the Chinese Alibaba (6 patents) also has some patent applications in the UK. Furthermore, R3 Ltd is located in the UK; this is a consortium consisting of various actors from the financial sector. They aim to develop a Blockchain platform, namely the Corda Platform, which may be compared to IBM’s Hyperledger.

In conclusion, it can be argued that prevalence can already be observed in the Blockchain landscape, particularly in China and the US. This situation is also reflected in academic studies, in which the US and China are recognised as the two leading countries with the most publications in the Blockchain field [12].

4.5 *REALLOCATION OF RESOURCES*

The introduction of GPTs usually follows an S-shaped diffusion pattern while resources are reallocated, causing an economic slowdown. Innovation actors are initially unable to exploit the potential of a GPT and require some time to adjust before they can start to benefit from it [1]. In that context, [11] claims that the introduction of new technologies to the market is usually accompanied by the emergence of new actors, who are ready to take more risks than other existing actors. Thus, during the GPT adoption, “younger” actors, who have been established for less than 25 years, are expected to perform better than “older” actors. In this scope, interviewee X3 pointed to the dominance of “younger” actors based on the validation in Crunchbase, which is a database consisting of information on public and private companies on a global scale. Only 20 out of 5261 organisations were established before 1995.

Table 10 depicts the companies with the highest Blockchain patent scores. IBM is the only company that has been in existence for more than 100 years; the majority of companies were established within a 25-year time frame, that is, “younger” companies (e.g. Mastercard in 2006, Alibaba in 1999 and CoinPlug in 2013). Thus, the larger portion of “younger” companies indicates that the “reallocation of resources” characteristic is already observable in the Blockchain landscape. However, it needs to be emphasised that large companies aiming to keep their monopoly on Blockchain might underinvest in R&D and therefore threaten younger companies [1], necessitating strong Blockchain-related policies.

Company Name	Patent Score
NChain Holdings	270
IBM	154
Alibaba	150
Mastercard	138
Coinplug	70

Table 10: Companies with the Most Blockchain Patents

4.6 *INCLUSIVE DEMOCRATISATION*

[54] briefly claims that technological development influences the institutional structure by changing the material setting in which it operates. In this scope, Blockchain as the "Internet of Governance" could enable democratic institutions and countries to coordinate their economic and scientific subsystems efficiently to increase their future technological and social progress. This would also extend from the sphere of politics to that of society, in which every citizen is expected to participate, enabling a condition of political and economic stability.

[28] claims that many democracies need to consider how to bring out the value of people and to increase the education of human capital, that is, the intangible capital accumulation, which would also exert a positive impact on technology production and the competitive advantage of countries. In this scope, X3 claimed that Blockchain could tackle the distribution of disaggregated power, currently controlled by the so-called "power elites" associated with many democracies, which is also capable of marshalling forces against innovation. Thus, Blockchain offers a new method of institutional coordination for a new type of collaborative network, which is more distributed, participatory, citizen-centric and inclusive [55].

As mentioned earlier in Section 2.1.6, inclusivity is highly related to BoP, which has the poorest population of the world and suffers from scarcity resulting from barriers to the flow of goods, information and money. [56] claims that Blockchain could allow BoP to improve living conditions by enabling financial inclusion. In this context, [57] outlines that BoP has been using basic mobile phones to benefit from this new paradigm shift, enabled by ICT particularly, and exemplifies this with M-PESA, which is a mobile money service offered by Safaricom with approximately 14 million subscribers in Kenya. Conversely, some interviewees, such as X1, doubted whether Blockchain may be deployed pervasively in BoP countries so that it may act similarly to electricity (GPT), which has been playing an inclusive role in developing countries. Moreover, interviewee X1 asserted that our civilisation's dependency on electricity is much greater than that on Blockchain, particularly considering BoP.

Figure 6 presents an overview of Blockchain patents in mind map format. The fonts of the patent classes are in proportion to the patent scores. Moreover, Figure 6 shows that actors are currently concentrating on G06 and H04, while G06 is related to computer technology and communication technologies. In other words, Blockchain seems to be highly related to the ICT domain, which is in line with scholars such as [12], [13], [44], who show that the majority of academic work is dedicated to the ICT domain, whereas other authors refer to Blockchain not just as an ICT innovation but also as an inclusive institutional technology [1].

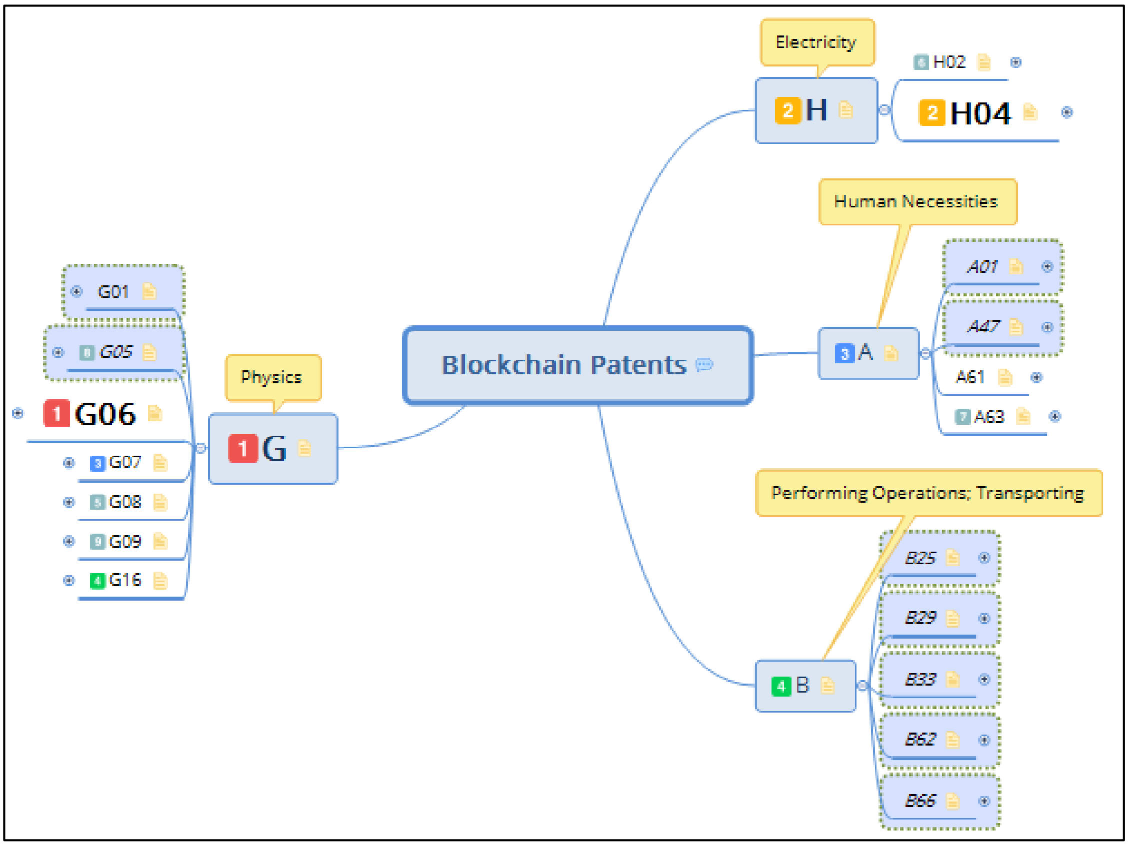

Figure 6: Overview of Blockchain Patents

4.7 Discussion And Implications

The findings of this study point to the critical need that Blockchain can only become a GPT if efficient policies are introduced that enable an effective innovation landscape and smooth coordination among Blockchain actors and tackle information asymmetry, along with strong leadership.

Although Blockchain shows some GPT characteristics, it should be highlighted that there are currently certain factors influencing Blockchain's progress towards becoming a GPT: (1) With cryptocurrencies, such as Bitcoin, Blockchain has proven to be pervasive [1]. This is also expected to happen with other features of Blockchain, such as smart contracts or Decentralized Autonomous Organisation (DAO) as well, which calls for Blockchain specific policies. (2) Patent data shows that Blockchain actors have already started to address several technological shortcomings of Blockchain [50], such as the speed of transactions or the rise in energy consumption. However, the existing Blockchain-specific information asymmetry needs to be addressed by policymakers to strengthen the competence of actors in the Blockchain field so that Blockchain's adoption may be accelerated. (3) Countries such as China and the US seem to be highly focused on Blockchain, which are already dominating the world in many perspectives. On the other hand, patent data also points to inefficient innovation landscape in many countries which calls for strong Blockchain specific policies aligned with national strategies. (5) Currently, there is a market shift in favour of "younger" companies, such as Mastercard or Alibaba, which were established in the last twenty-five years period. We might expect to witness another Blockchain-enabled "Google" or "Facebook" in the near future, which has either just established or is not existing in the market yet. However, large companies aiming to keep their dominance in the market might change the current trend of Blockchain and therefore threaten younger companies. (6) As a disruptive institutional technology, Blockchain is expected to enable inclusive democratisation, which will lead to disintermediation, decentralisation and disruption of existing policy frameworks. This requires Blockchain-specific policies which aim to enable appropriate leadership to utilise Blockchain for good purposes.

In this scope, the following table outlines the critical implications derived from this study which is particularly important for leaders from “Industry”, “State” and “Academia”.

Industry	1. Industrial actors are highly concentrated on the development of “Internet of Money”-related topics, particularly the various payment mechanisms and security concerns related to data transmission and storage. This points to the changing business models of various traditional institutions. 2. Industrial actors should concentrate on the most significant application fields of "Internet of Money": (1) Identity Solutions, (2) Logistics, (3) Energy, (4) Mobility and (5) Healthcare. 3. The software industry should prioritise Blockchain-based social media payment solutions in their strategy. This is as Blockchain is expected to play a critical role in this context as part of the “Internet of Money.” 4. Industrial actors should work on micro-payment mechanisms while Blockchain can be used as an integral part of IoT. This is one of the main problems of IoT. 5. The industrial actors can provide solutions for the unbanked people of BoP, as Blockchain can securely store the biometric data. 6. Industrial actors can focus on following fields as given by patent data, particularly from value management perspective: (1) genetics; (2) e-commerce; (3) gambling; (4) aviation; (5) sustainability; (6) creativity; (7) security; (8) energy; (9) finance management; (10) asset management; (11) 3D applications; (12) social media; (13) sports management; (14) gaming; (15) business operations, including accounting, HR, marketing and knowledge management; (16) healthcare; and (17) smart cities. Particularly the convergence of Blockchain and AI seems to be very promising, e.g. management of moveable autonomous devices. 7. From value tracing perspective, fields such as (1) finance; (2) virtual reality; (3) asset management; (4) various business functions, including document management and manufacturing; (5) tracing IoT data; (6) e-commerce; (7) security; and (8) healthcare, could be interesting fields for industrial actors.
State	1. From "Internet of Money" perspective, the integration between the digital world and the physical world should be enabled by law, e.g. Initial Coin Offering (ICO) and Security Token Offering (STO), where Blockchain is expected to become critical technology. 2. Blockchain’s pervasion in our society is highly impacted by the fiscal policies which require special attention. 3. To tackle missing collaborations between industry, academia and the state, Blockchain specific innovation policies should be introduced. 4. Governments should promote the implementation of Blockchain as centralised traditional institutions in competition with Blockchain may stifle its development. This would certainly threaten the positive benefits that it offers society and the economy. 5. To enable distributed hash power in the global Blockchain field, international cooperation should be enabled so than the global hash power doesn’t depend on a single country such as China. 6. Blockchain is expected to cause disintermediation, decentralisation and disruption of existing societal structures. This calls for Blockchain specific policies with the main focus on Blockchain as “Internet of Governance”.
Academia	1. Academia should clearly define Blockchain and its categories as there is currently a rather arbitrary approach in this context. 2. Considering Blockchain as a potential GPT and given its open-source characteristics, academic institutions should support the education of citizens in the Blockchain context. This is as anyone can access the original Blockchain code and create their applications. 3. Academic institutions need to investigate the collaborative innovation processes and activities based on smart contracts and DAOs. This is so then the proper policies may be introduced to enable collaborative innovation. 4. Policymakers should introduce policies to leverage BoP to a higher level to contribute to the achievement of SDGs. 5. Blockchain patents are currently concentrated on (1) Value Management, (2) Asset Management, (3) Tracking, (4) Technology, (5) Documentation and Certification and (6) Governance and Interaction, which asks for particular attention by the academic actors.

Table 11: Critical Implications

5. CONCLUSIONS

The pervasive nature of Blockchain, in addition to its potential for changing production processes and creating new technologies, has raised the question of whether Blockchain will be the next GPT. In this regard, this study aimed to understand the extent to which Blockchain may be considered as a GPT. This research differs from previous studies as it investigates approximately 2500 Blockchain-related patents according to six GPT characteristics, specifically pervasiveness, improvement capabilities, spawning capabilities, prevalence, reallocation of resources and inclusive democratisation, as identified during the literature review (Section 2.1). In this context, a mixed method, consisting of patentometrics and semi-structured interviews, was deployed to establish whether Blockchain may be considered to be a next-generation GPT.

By systematically examining the Blockchain-related patent data with a mixed method approach, this study has found preliminary evidence that Blockchain is a GPT, although the evidence is limited in terms of scope, coverage and timing.

The contributions of this study are threefold: (1) a comprehensive list of GPT relevant parameters based on the work of GPT-related scholars; (2) a methodological examination of Blockchain, that is, a mixed-method approach investigating Blockchain from a GPT perspective based on Blockchain-related patents with Blockchain-related word thresholds; and (3) practical contributions to the Blockchain field made by outlining Blockchain from the perspective of GPT-relevant parameters.

The important findings of this study are as follows: (1) Blockchain shows pervasive characteristics and is spread over various industrial fields; (2) Blockchain is capable of further improvement, while actors in Blockchain landscape are tackling the problems of Blockchain technology that are hindering its rapid adoption; (3) Blockchain facilitates and encourages the creation of new innovations, showing technological spawning capabilities; (4) several countries with strong R&D capability, particularly China and the US, are showing the prevalence of Blockchain technology; (5) the Blockchain landscape demonstrates reallocation of resources characteristics, while disrupted market conditions enable the emergence of new actors with distributed innovation network characteristics; and (6) as disruptive institutional technology, Blockchain has the potential to enable inclusive democratisation, thanks to its financial and social inclusion characteristics.

This study is likely to be of great interest to a broad spectrum of stakeholders, such as scholars and policymakers, who will be confronted with the associated benefits as well as the potential challenges raised by the appearance of Blockchain. The main implication of this study is that China and the US have the potential to influence the future development of Blockchain technology, while their competition is directly influenced by their so-called hash power. Chinese mining pools already control more than 70% of the Bitcoin network's collective hash power. Thus, China already has a significant influence on Blockchain, particularly in security-related topics. In conclusion, the competition between China and the US in the Blockchain field will define whether and to what extent Blockchain may become a GPT in the future.

Moreover, there are critical implications from a policy makers' perspective: (1) industrial actors should concentrate on the most significant application fields of the "Internet of Money": (a) identity solutions; (b) logistics; (c) energy; (d) mobility; and (e) healthcare; (2) the biometric data of BoP citizens may be securely stored on Blockchain, so BoP might be included in the civilised world and, in this context, industrial actors could provide solutions for the unbanked people of BoP; (3) integration between the digital world and the physical world should be enabled by law, for example Initial Coin Offerings (ICOs) and Security Token Offerings (STOs), in which Blockchain is expected to become critical technology; (4) governments should promote the implementation of Blockchain, as centralised traditional institutions in competition with Blockchain may stifle its development, which would certainly threaten the positive benefits that it offers to society and the economy; and (5) considering Blockchain as a potential GPT with open-source characteristics, academic institutions should support the education of citizens in the Blockchain context, as anyone may access the original Blockchain code and create applications.

This study is subject to the usual limitations of studies attempting to investigate the characteristics of emerging technologies based on patents: (1) despite many advantages, patent data have several limitations, as not all innovative activity is reflected in the patent system; and (2) a given patent class, which is assigned by patent examiners, does not correspond to a technological field. Thus, future studies aiming to investigate the GPT characteristics of Blockchain technology should consider additional data sources, such as academic journals.

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