RAND EUROPE

Understanding the landscape of Distributed Ledger Technologies/Blockchain

Challenges, opportunities, and the prospects for standards

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Preface

RAND Europe was commissioned by the British Standards Institution (BSI) in January 2017 to carry out a rapid scoping study to examine the potential role of standards in supporting Distributed Ledger Technologies (DLT)/Blockchain. This report documents the results of the study, which was conducted over a six-week period.[1] DLT/Blockchain refers to a type of database which is spread over multiple locations (i.e. a distributed database) and which can be used like a digital ledger to record and manage transactions. Although the technology is at a relatively early stage of adoption and significant challenges remain, it is becoming apparent that DLT/Blockchain holds the potential for major opportunities across several sectors. Furthermore, standardisation efforts related to DLT/Blockchain have recently gathered momentum with the setting up of the International Organization for Standardization (shortened to ISO) technical committee on Blockchain and electronic distributed ledger technologies.

In this report, we present an overview of the current landscape of DLT/Blockchain developments and closely examine the issues that are central to the development of DLT/Blockchain. We articulate a set of areas for further consideration by DLT/Blockchain stakeholders regarding the potential role of standardisation. Rather than providing a definitive list of topics, the aim of the study is to provoke further discussion across DLT/Blockchain stakeholders about the potential role of standards in supporting the development and adoption of the technology. We carried out the research using a mixed methods approach involving a focused review of the literature, in-depth interviews with stakeholders from public and private organisations, and an internal workshop. Although the study is primarily intended to inform the BSI's approach towards developing a standards strategy in relation to DLT/Blockchain, it is also likely to be of relevance to DLT/Blockchain stakeholders, including policymakers, industry, other standards organisations (national and international), and academia.

RAND Europe is a not-for-profit policy research organisation that helps to improve policy and decision making in the public interest, through research and analysis.[2] RAND Europe's clients include European governments, institutions, NGOs and firms with a need for rigorous, independent, multidisciplinary analysis.

1 A summary version of this report can be found here: https://www.rand.org/pubs/external_publications/EP67133.html

2 For more information on RAND Europe, please see http://www.randeurope.org (as of 13 March 2017). For more information on BSI, please see http://www.bsigroup.com.

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Table of contents

List of figures

List of tables

List of abbreviations and acronyms

AML	anti–money laundering
API	application programming interface
B2C	business-to-consumer
BSI	British Standards Institution
DAO	decentralised autonomous organisation
DLT	distributed ledger technology
EBAWGEAP	Euro Banking Association Working Group on Electronic Alternative Payments
ESMA	European Securities and Markets Authority
FCA	Financial Conduct Authority
FINRA	Financial Industry Regulatory Authority
IoT	Internet of things
IP	intellectual property
ISO	International Organization for Standardization
IT	information technology
ITU	International Telecommunication Union
KYC	know-your-customer
M2M	machine-to-machine
MDL	Mutual Distributed Ledgers
P2P	peer-to-peer
STP	Straight-Through Processing
SWIFT	Society for Worldwide Interbank Financial Telecommunications

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Executive summary

Background and context

Distributed Ledger Technologies (DLT) have received growing attention in recent years as an innovative method of storing and updating data within and between organisations. The key features of DLT/Blockchain, as distinct from other databases, are associated with its distributed nature. Multiple copies of the ledger are held by different parties, with data added by consensus and without the need for a third party. This means that DLT/Blockchain is able to offer:

- An *immutable record*: Data added to the ledger is in theory unchangeable, secure and preserved for the life of the ledger, with the agreement of all participants as to the contents.
- *Disintermediation*: Nodes are able to interact directly, without the need for an intermediary. This includes the ability to initiate direct transactions of data or digitised assets (which may be a dedicated cryptocurrency, such as Bitcoin, or a digital representation of real-world assets, such as land titles or fiat currency).
- A *lack of central control by one party*. Additions to the ledger or changes to the governing structure are decided on a consensus basis by multiple participants.
- *New opportunities for management and sharing of data*. These opportunities are achieved by facilitating the storage and access of various forms of data for participants.

Together, these systems provide a transparent and verifiable record of transactions. As a result, DLT/Blockchain can provide gains in efficiency, trust and data reconciliation among ledger participants. While the financial sector has shown widespread early interest in DLT/Blockchain, its use has also been explored in education, the creative industries, and the agriculture and food industries (to name a few).

Research objectives

Standardisation efforts related to DLT/Blockchain have recently gathered momentum with the setting up of the ISO technical committee on Blockchain and electronic distributed ledger technologies (ISO, 2017a). Against the backdrop of this changing landscape, the BSI commissioned RAND Europe to carry out a rapid scoping study to understand some of the areas related to DLT/Blockchain that would potentially require standardisation based on stakeholder needs in the UK. The study is intended to inform the BSI's approach towards developing a standards strategy in relation to DLT/Blockchain. In addition, the research will

be used by the BSI as input to hold discussions in the context of the ISO technical committee on DLT/Blockchain. More specifically, the purpose of this study is threefold:

- to explore the potential role of standards in supporting DLT/Blockchain based on the needs of stakeholders;
- to identify what sectors could benefit most from the advent of DLT/Blockchain standards to accelerate implementation of the technology; and
- to identify key stakeholders that would need to work together on developing standards related to DLT/Blockchain.

Methodology

To achieve these objectives, RAND Europe: (a) conducted an accelerated literature review to explore the challenges and opportunities associated with DLT/Blockchain; (b) consulted a range of stakeholder types to validate the observations from the evidence review and to better understand the implications of potential standards development within the UK context; and (c) synthesised the evidence to articulate a set of areas for further consideration by the DLT/Blockchain community on the potential role of standardisation. Rather than providing a definitive list of topics, the aim of the study is to provoke further discussion across the DLT/Blockchain community about the potential role of standards in supporting the development and adoption of the technology.

Key findings from the analyses

Our approach was to determine the main challenges and opportunities related to DLT/Blockchain and, from these, to extrapolate a set of priority issues for stakeholders which could potentially be addressed through the development of standards.

Assessing the challenges and opportunities in relation to DLT/Blockchain

In order to understand the broader landscape of DLT/Blockchain technologies and the role that standards could play in its development and adoption, it is essential to understand the challenges faced by DLT/Blockchain in relation to development and adoption of the technology by markets and end-users, and in relation to governance and implementation; as well as the opportunities that the technology offers, including improvements to business practices, such as cost reduction at the operational level and increased resilience in transactional systems, and particular applications, such as digital identity management and smart contracts.

Table 1 summarises the key observations with regard to these challenges and opportunities from the interviews and accelerated evidence assessment.

The prospective role of standards to support DLT/Blockchain

We have identified areas where standards could – to varying degrees – potentially overcome the challenges and could support innovation, growth and competitiveness in the DLT/Blockchain ecosystem:

- Standards could play an important role in ensuring interoperability between multiple DLT/Blockchain implementations and, in doing so, could help reduce the risk of a fragmented ecosystem;
- Using standards to establish a stronger consensus on consistent terminology and vocabulary could improve understanding of the technology and help progress the market;
- Establishing standards to address the security and resilience of, and the privacy and data governance concerns related to

Table 1: Key challenges and opportunities in relation to DLT/Blockchain

Challenges	Insufficient clarity regarding and inconsistent understanding of the terminology, combined with the perception that DLT/Blockchain is an immature technology, poses challenges to wider adoption of DLT/Blockchain. The potential high costs of initial implementation, perceived risks associated with early adoption of DLT/Blockchain, and possibility of disrupting existing practices may pose significant challenges to businesses. The lack of clarity about the improvements the technology offers over existing solutions may delay its adoption by businesses. In the absence of widespread DLT/Blockchain adoption, the broader economic impact of the technology in the medium and long term is difficult to determine. Because of the nascent nature of the technology, there is a lack of clarity with regard to the governance of DLT/Blockchain systems. There is uncertainty related to the way current regulatory frameworks would apply to DLT/Blockchain and the changes that might be needed in the event of wider DLT/Blockchain adoption across sectors. The emergence of multiple non-interoperable DLT/Blockchain implementations could lead to a fragmented ecosystem and limit widespread adoption. Potential security vulnerabilities and concerns about data privacy are seen to be significant challenges, particularly if users are entrusting DLT/Blockchain solutions with personal data. Safeguarding data integrity and ensuring strong encryption mechanisms are perceived as key challenges to the wider adoption of DLT/Blockchain. The distributed nature of DLT/Blockchain systems and the need for increased computing power could potentially result in high energy consumption and associated costs. Key obstacles remain with respect to the legal enforceability of smart contracts, primarily related to the lack of clarity regarding the definition of smart contracts and how to implement them through DLT/Blockchain.
Opportunities	By automating processes and reducing the need for third-party intermediaries, DLT/Blockchain solutions have the potential to provide significant efficiency gains and cost savings for businesses and end-users. The adoption of DLT/Blockchain technologies could potentially enable new revenue sources for businesses. The growth of the DLT/Blockchain ecosystem could result in the creation of novel business and economic models, such as new forms of business collaboration and cryptocurrencies. The decentralised nature of DLT/Blockchain and the lack of a central point of failure could facilitate transactional systems to become more resilient and secure. DLT/Blockchain has the capability to empower users by putting them in control of their own information, and it has the potential to improve users' trust in carrying out transactions. The immutability of DLT/Blockchain transactions offers a number of benefits, including providing a clear audit trail and reducing the propensity for fraud. Depending on the use case, DLT/Blockchain could enable efficient and cost-effective management of digital identity through the use of public key cryptography. DLT/Blockchain technology could be used to implement the underlying mechanism for smart contracts and enable the use of smart auditing capabilities across different sectors.

DLT/Blockchain could help create trust in the technology;

- Standards could play a role in digital identity management and foster end-user trust in the technology;
- There are potential opportunities for standards to play a role in sectors where provenance tracking is important;
- It may be too early to think about standards related to the technical aspects of DLT/Blockchain.

The list of topics we have highlighted is not definitive, and our intention is not to be prescriptive; rather, the list is a spectrum of wide-ranging topics that would benefit from further exploration and consideration by the DLT/Blockchain community. The evidence from the literature review and interviews on the role for standards suggests the need for a measured approach to developing standards in the near and medium terms. It may be too early to think about standards related to the technical aspects of DLT/Blockchain. Although a majority of interviewees agreed that standards have a role to play in shaping the development and adoption of DLT/Blockchain in the long term, most of them were also of the opinion that additional time may be needed to enable a more informed approach to deciding which aspects and uses of the technology should be prioritised.

In Figure 1, we illustrate the priority areas and provide an approximate indication of the relative timelines for potentially developing standards in relation to these areas.[3] To reiterate, our analysis suggests that, despite the consensus on the overall importance of standards to support the growth of DLT/Blockchain, views differ with regard to the areas for potential standardisation and the timelines for developing and implementing the standards.

In Figure 2, we show an all-encompassing visualisation that depicts: (a) the areas we have identified where standards could play a role in supporting DLT/Blockchain, (b) the potential sectors which could benefit from the advent of DLT/Blockchain standards, and (c) the overarching challenges and opportunities identified in relation to DLT/Blockchain.

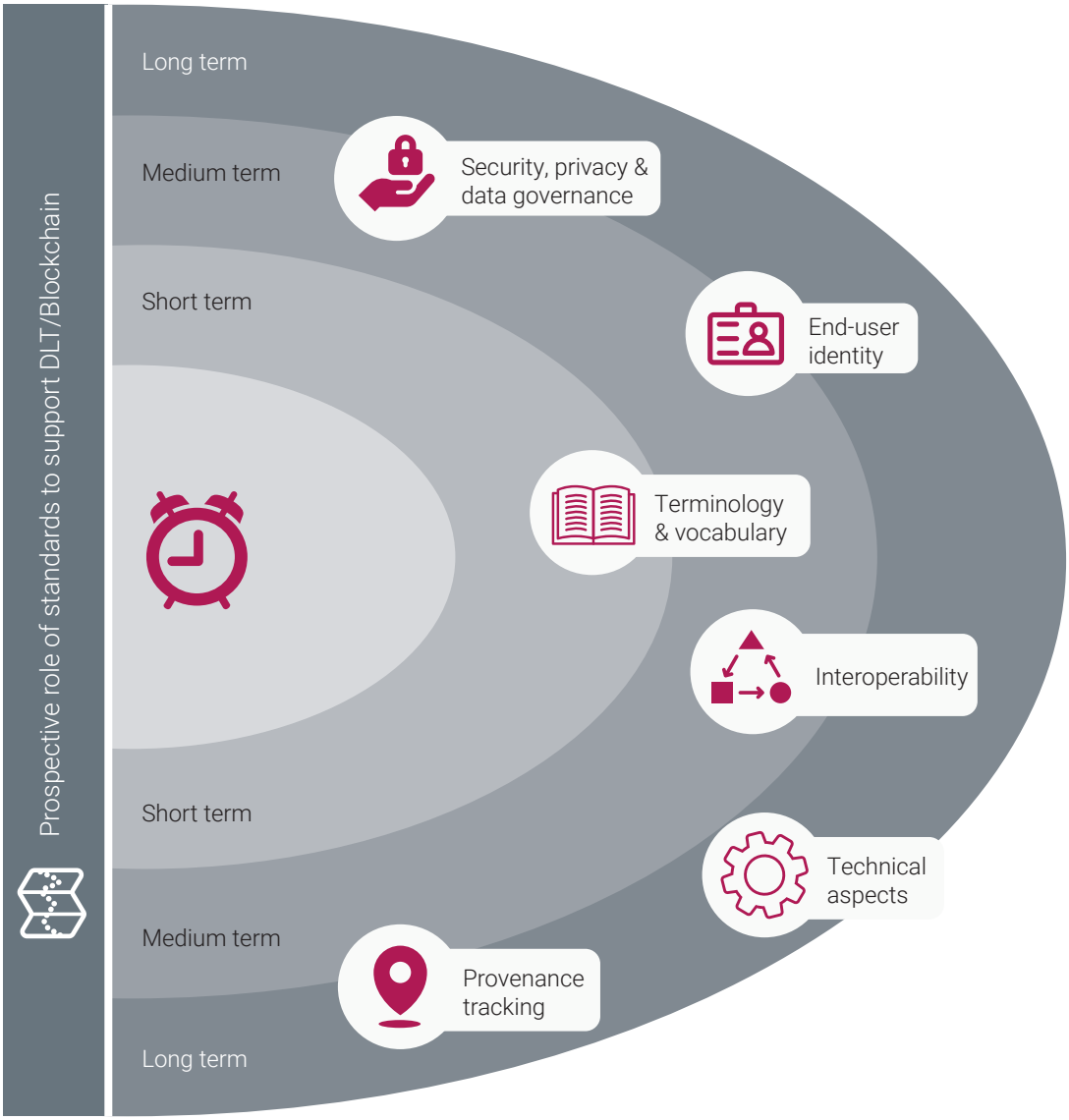
Concluding remarks

Our analysis suggests that the opportunities arising from DLT/Blockchain are vast; however, there are also many challenges to contend with. In this regard, we note that there is scope for standards to play a role in supporting the technology, for example, to act as an enabler to create the necessary space for the development and adoption of Blockchain/DLT and its market.

However, as is generally the case with emerging technologies, the timing for developing and introducing standards (which may build on existing standards) is critical. An intervention that occurs too early could run the risk of locking in stakeholders to solutions that, in the long run, might not be the most effective and, in the process, potentially stifle innovation. A standards strategy that occurs too late with regard to a technology potentially risks missing opportunities to maximise the benefits the technology could deliver. Although it is a field characterised by rapid change and uncertainties, steps can be taken to better understand the current realities, drivers of change and impacted sectors.

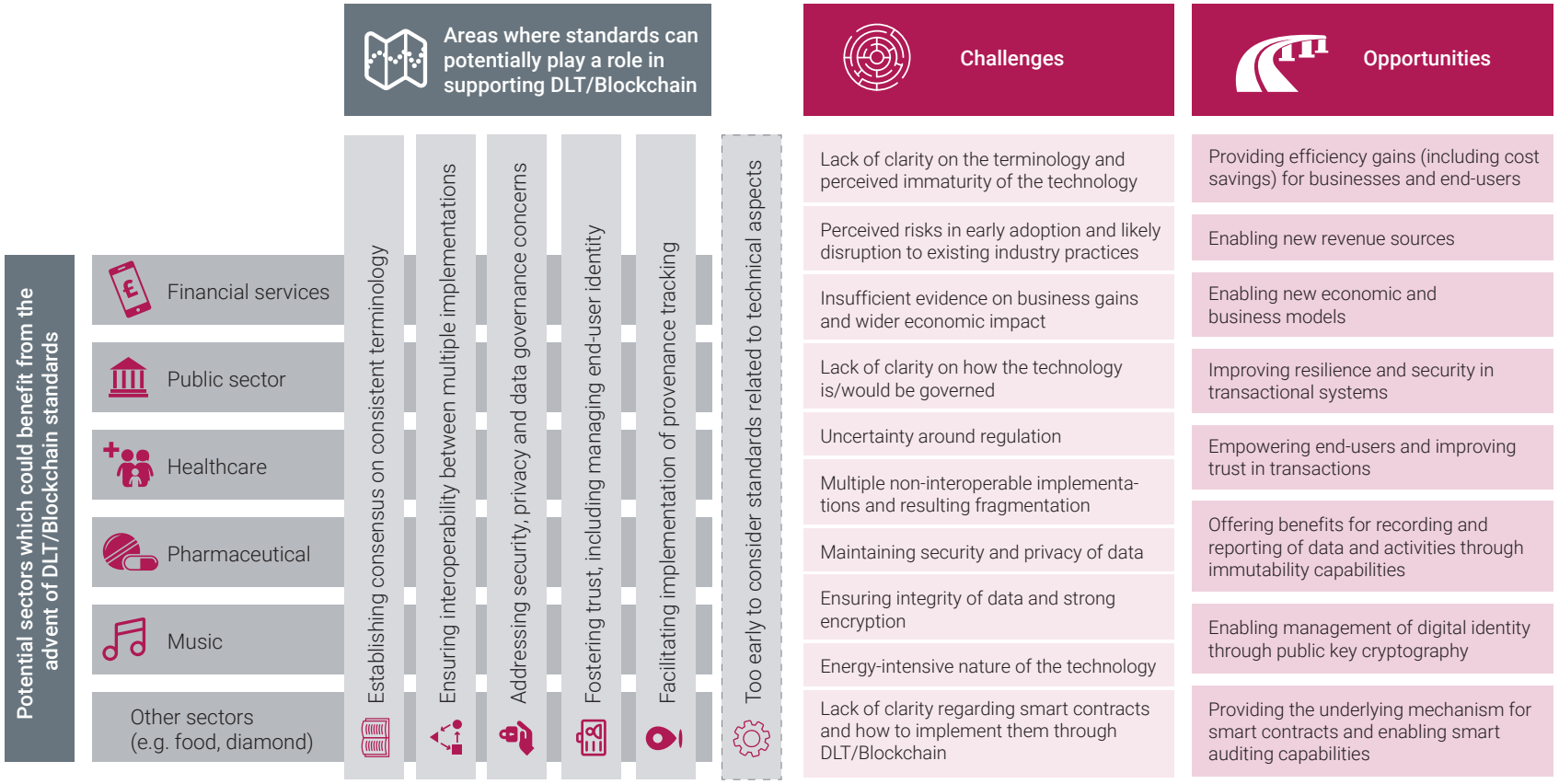
3 The timelines shown in Figure 1 are merely indicative at this stage and are based on our examination of the DLT/Blockchain ecosystem established through the rapid scoping study we have undertaken. Further research and continued engagement with the stakeholder communities that would input to them is needed to establish a better understanding of the timelines for developing standards.

Figure 1: Areas where standards could potentially play a role in supporting DLT/Blockchain and an indication of the prospective timelines



Source: RAND Europe

Figure 2: Visualisation depicting (a) the areas where standards could play a role in supporting DLT/Blockchain, (b) the potential sectors that could benefit from the advent of DLT/Blockchain standards, and (c) the challenges and opportunities identified in relation to DLT/Blockchain[4]



Source: RAND Europe

4 Note: This visualisation provides a very high-level 'summary' of the analyses presented in the report. The DLT/Blockchain landscape is complex and varied; therefore, not all the areas for standards and not all the challenges and opportunities identified in our study will be applicable to all DLT/Blockchain designs and sectors.

1 Introduction and overview

1.1. Background and context

Distributed Ledger Technologies (DLT) have received growing attention in recent years as an innovative method of storing and updating data within and between organisations. A distributed ledger is a digital ledger[5] that is different from centralised networks and ledger systems in two ways. First, information is stored on a network of machines, with changes to the ledger reflected simultaneously for all holders of the ledger. Second, the information is authenticated by a cryptographic signature. Together, these systems provide a transparent and verifiable record of transactions. Blockchain technology is one of the most well-known uses of DLT, in which the ledger comprises 'blocks' of transactions, and it is the technology that underlies the cryptocurrency Bitcoin. However, the possible uses of DLT go well beyond the financial sector; its use has also been explored in education, the creative industries, and the agriculture and food industries (to name a few).

The key features of DLT/Blockchain, as distinct from other databases, are associated with its distributed nature. In DLT/Blockchain, multiple copies of the ledger are held by different parties, with data added by consensus and without the need for a third party (known as intermediaries in industry parlance). As a result,

A note on the terminology used in the literature and this report in relation to Distributed Ledger Technologies and Blockchain

Because the technology is under active development, the terminology is evolving and formal definitions have not been fully established. Indeed, as discussed later, one of the challenges encountered in the Distributed Ledger Technologies/Blockchain community is insufficient clarity about and inconsistent understanding of the terminology being used by stakeholders. Recognising that the terms DLT and Blockchain are often used interchangeably in the literature, from this point forward, unless specified, we use the more all-encompassing term 'DLT/Blockchain' throughout this report.

5 As used in this document, the term digital ledger refers to a computer file used for recording and tracking transactions. These transactions need not be monetary in nature and may refer to interchange, addition, and modification of data in the computer file.

DLT/Blockchain can provide gains in efficiency, trust and data reconciliation among ledger participants. This means that DLT/Blockchain is able to offer:

- An *immutable record*: Data added to the ledger is in theory unchangeable, secure and preserved for the life of the ledger, with the agreement of all participants as to the contents.
- *Disintermediation*: Nodes are able to interact directly, without the need for an intermediary. This includes the ability to initiate direct transactions of data or digitised assets (which may be a dedicated cryptocurrency, such as Bitcoin,[6] or a digital representation of real-world assets, such as land titles or fiat currency[7]).
- A *lack of central control by one party*. Additions to the ledger or changes to the governing structure are decided on a consensus basis by multiple participants.
- *New opportunities for management and sharing of data*. These opportunities are achieved by facilitating the storage and access of various forms of data for participants.

The potential applications of DLT/Blockchain are wide-ranging, and the potential benefits to the UK are considerable (Government Office for Science, 2016). A prominent recent report by the UK Government Office for Science noted three main opportunities presented by the particular functionalities of DLT/Blockchain: enabling cryptocurrency[8] exchange, managing contracts and creating new forms of contracts (e.g. smart contracts[9]), and prompting new applications by third parties to create new efficiencies (Government Office for Science, 2016). The distributed nature of the ledger, in which historical transactions can be independently verified and protected from tampering, has potential utility for a broad range of transactional and verification services, such as financial transactions, smart contracts, identity management, and the verification of records.[10] While the financial sector has shown widespread early interest in DLT/Blockchain, other public and private organisations that rely on recordkeeping and management of secure transactions may also benefit – for example, agencies involved in collecting taxes, issuing passports, conducting asset transfers, and recording asset claims, such as land registries.

6 Bitcoin is an open source, decentralised, peer-to-peer payment network maintained by users, with no central authority. Bitcoin provides completely digital money for transactions on the Internet/web (i.e. it has no offline equivalent). For more details, see Bitcoin (2017) and Glance (2015).

7 The term 'fiat currency' refers to 'currency that a government has declared to be legal tender but it is not backed by a physical commodity.... Most modern paper currencies are fiat currencies; they have no intrinsic value and are used solely as a means of payment' (Investopedia, 2017).

8 Cryptocurrency refers to a digital or virtual currency which uses cryptographic measures for security purposes. See http://www.investopedia.com/terms/c/cryptocurrency.asp (as of 13 March 2017).

9 A smart contract is 'a set of promises, specified in digital form, including protocols within which the parties perform on these promises' Szabo (1996), as quoted in Murphy & Cooper (2016).

10 See, for example, the Blockcerts project, which encourages the recording of academic certificates on a Blockchain for efficient verification by employers (Blockcerts, 2017).

Permissioned and permissionless ledgers

Permissionless, or public, ledgers are seen by some as the 'purest' form of Blockchains (Brennan & Lunn, 2016). A typical example of a permissionless, or public, Blockchain is the one that underlies the Bitcoin network. In this type of configuration, the participation is 'permissionless' and anyone can take part in the ledger and validate transactions, with fully devolved authority (Bogart & Rice, 2016). Participants are identified through pseudonyms or are kept anonymous, and transactions are validated by 'miners' through an incentivisation system (Biondi et al., 2016). This form of distributed ledger enables high security but also incurs high transaction costs due to the resource-intensive consensus mechanism[11] (Brennan & Lunn, 2016).

Permissioned, or private, ledgers have attracted attention from businesses (Bogart & Rice, 2016). This type of ledger restricts transparency by disclosing the identity of participants in the network; access is restricted to a certain number of participants, which are known to each other, and is subjected to approval from other members of the network.[12] No 'proof-of-work' is needed to validate transactions, unlike in the case of permissionless ledger, and therefore there is no incentivisation system (Biondi et al., 2016). Permissioned ledgers can be distributed for closed communities that share similar but competing interests, or they can be private for one or more organisations that share common interests (Biondi et al., 2016).[13]

As the opportunities for the use of DLT/Blockchain in the market grow, issues related to the governance of the market, interoperability of these emerging platforms and an understanding of 'good practice' in the development and use of DLT/Blockchain will become more pressing. As discussed later, many challenges to the full adoption and use of DLT/Blockchain remain. DLT/Blockchain itself, once adopted, may present new concerns regarding topical issues such as data protection, legal status of contracts and individual privacy. However, identifying appropriate policy responses to address these concerns while avoiding derailing a nascent technology will be a critical step in the development of DLT/Blockchain. Success will depend on the outcome that is intended to be achieved, the differences in the regulatory environment for each market in which DLT is applied, and the variations in the responses from different industries. For questions bound up with existing regulatory frameworks, such as those relating to consumer protection, competition and the enforceability of contracts, this may involve regulation or legislation at a national or European level. At the other end of the spectrum, addressing some issues may instead involve voluntary codes within or between businesses. Similarly, standards are likely to play a role, whether at International Organization for Standardization (shortened to ISO) or national level.

11 Consensus mechanism is a method of authenticating and validating a value or transaction on DLT/Blockchain without the need to trust a central authority. See Seibold and Samman (2016).

12 The transaction validation process is also restricted and relies on whitelists to permit participants and some elements of distributed consensus.

13 Permissioned ledgers are currently being looked at, especially in the financial services, because they introduce trust in the ledger system. This is in contrast to permissionless ledgers, which rely on 'trustless' transactions; they can also be cheaper due to their simplified consensus mechanism, but they may increase risks for the ledger integrity (Brennan & Lunn, 2016).

Standards

'A standard is an agreed way of doing something. It could be about making a product, managing a process, delivering a service or supplying materials – standards can cover a huge range of activities undertaken by organizations and used by their customers.... Standards are the distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent – people such as manufacturers, sellers, buyers, customers, trade associations, users or regulators.... Standards cover a wide range of subjects from construction to nanotechnology, from energy management to health and safety, from cricket balls to goalposts. They can be very specific, such as to a particular type of product, or general such as management practices.'

Source: BSI, 2017

1.1.1. Current standardisation-related and industry initiatives associated with DLT/Blockchain

A range of standardisation-related and industry initiatives have commenced across the globe examining different aspects of DLT/Blockchain. Various activities, including exploratory workshops[14] and cross-industry collaboration initiatives, such as the Hyperledger project (Hyperledger, 2017) have served as forums for discussion of potential technical challenges around the widespread adoption of DLT. Such initiatives as Interledger (Interledger, 2017), the Chain Protocol (Chain Protocol, 2017), and Blockcerts (Blockcerts, 2017) have sought to advance open standards and protocols in different areas of use. In addition, an ISO technical committee[15] was set up in 2016 to develop standards on DLT/Blockchain based on the market need (ISO, 2017a). The aim of the committee is to 'support interoperability and data interchange among users, applications and systems (ISO 2017a).' The committee is being led by Standards Australia and includes, at the time of writing, 20 participating countries (including the UK, represented by the BSI) and 15 observing countries (ISO, 2017b).[16] We summarise examples of these initiatives in Table 2.

1.2. Research objectives

Understanding the current landscape of the DLT/Blockchain market and the priority areas for the UK regarding the development of standards will be an important step in developing a strategy to maximise the benefits of this technology for UK and global stakeholders. Even though the technology is at a relatively early stage of adoption, it is becoming apparent that DLT/Blockchain present major opportunities for several sectors. Furthermore, as noted above, standardisation efforts related to DLT/Blockchain have recently gathered momentum with the setting up of the ISO technical committee on Blockchain and electronic distributed ledger technologies (ISO, 2017a).[17] Against

14 See, for example, a workshop held by W3C in June 2016 (W3C, 2016).

15 The ISO technical committee is called ISO/TC 307 Blockchain and electronic distributed ledger technologies (ISO, 2017a).

16 The first international meeting of ISO/TC 307 took place in Sydney, Australia, in April 2017.

17 As a constituent member of the ISO, the BSI will be a key voice in the international discussion regarding the development of the DLT/Blockchain market and utilisation of DLT/Blockchain by public and private bodies.

Table 2: Examples of existing standards-related and industry initiatives

Initiative	Stakeholders	Summary
ISO/TC 307	DLT/Blockchain developers and users in all sectors	An ISO Technical Committee (ISO/TC 307) established to explore potential ISO standards for DLT/Blockchain (ISO, 2017a)
Chain Open Standard	Organisations involved in digitised asset transfers	Open-source protocol for ledger design for the financial services sector (Chain Protocol, 2017)
R3CEV	Financial services	Initiative by a consortium of banks to collaborate on DLT development for financial services, including industry standards (R3CEV, 2017)
Hyperledger	DLT/Blockchain developers and users in all sectors	Open source collaborative effort hosted by Linux Foundation to advance cross-industry blockchain technologies through shared technical frameworks and infrastructure (Hyperledger, 2017)
Interledger Protocol	Organisations involved in ledger-based payments	Open-source protocol for sending and receiving money between ledgers (Interledger, 2017)
Blockcerts	Education and skills providers, employers	Open standard for the creation of ledger-based certificates (Blockcerts, 2017)
International Telecommunication Union-led	ICT and communications sector and associated organisations, policymakers	Workshop scheduled by International Telecommunication Union (ITU) for March 2017 to explore security aspects of DLT/Blockchain, for potential consideration in future security standards (ITU, 2017)

the backdrop of this changing landscape, the BSI commissioned RAND Europe to carry out a rapid scoping study to understand some of the areas related to DLT/Blockchain that would potentially require standardisation based on stakeholder needs in the UK. The study is intended to inform the BSI's approach towards developing a standards strategy in relation to DLT/Blockchain. In addition, the research will be used by the BSI as input to hold discussions in the context of the ISO technical committee on DLT/Blockchain. More specifically, the purpose of this study is threefold:

1. To explore the potential role of standards in supporting DLT/Blockchain based on the needs of stakeholders;
2. To identify what sectors could benefit most from the advent of DLT/Blockchain standards to accelerate implementation of the technology; and
3. To identify key stakeholders that would need to work together on developing standards related to DLT/Blockchain.

To achieve these objectives, we: (a) conducted an accelerated literature review to explore the challenges and opportunities associated with DLT/Blockchain; (b) consulted experts across a range of stakeholder types to validate the observations from the document review and to better understand the implications of potential standards development within the UK context;

and (c) synthesised the evidence to articulate a set of areas for further consideration by the DLT/Blockchain community on the potential role of standardisation. Rather than providing a definitive list of topics, the aim of the study is to provoke further discussion across the DLT/Blockchain community about the potential role of standards in supporting the development and adoption of the technology. A full description of the methodology is provided in Chapter 2.

1.3. Outline of the report

This report is structured as follows: The methodology used in the research is presented in Chapter 2, along with the main caveats of the analysis. In Chapter 3, we present a detailed assessment of the challenges and opportunities facing DLT/Blockchain on the basis of evidence collected through a literature review and a series of stakeholder interviews. In Chapter 4, we synthesise the key issues, challenges and opportunities identified and examine our observations in the context of the potential role of standards in supporting DLT/Blockchain. Specifically, we reflect on the evidence gathered through the literature and expert interviews to identify areas that potentially require standardisation and further examination by stakeholders within the DLT/Blockchain community. Some concluding remarks are presented in Chapter 5, in which we also highlight topics for future consideration that the findings raise. Finally, the appendices in this report present supplementary information, namely, an overview of definitions of DLT/Blockchain (Appendix A), the list of search terms used in the targeted literature review (Appendix B), and the interview protocol (Appendix C).

2 Study design and methods

2.1. Study design and scope

The objectives of this study, conducted over a six-week period, were addressed through four primary tasks, as illustrated in Figure 3. Given the cross-sectoral implications of DLT/Blockchain, we adopted a broad, sector-neutral approach to understanding the needs of stakeholders. Our approach combined research methods to leverage, synthesise and develop existing knowledge and understanding on the current landscape, key areas and sectors, and stakeholders for DLT/Blockchain. We assembled a senior advisory group for the study to provide additional knowledge and insight directly relevant to the UK DLT/Blockchain sector. We consulted members of the senior advisory group at various points in the study to obtain their feedback. The overall aim of our approach was to determine the main challenges and opportunities related to DLT/Blockchain and, from these, to extrapolate a set of priority issues for stakeholders which could potentially be addressed through the development of standards. The main components of the work were:

- An accelerated evidence assessment of existing literature on DLT/Blockchain tailored to the requirements of the study (Task 1);
- A series of interviews with DLT/Blockchain stakeholders in the UK (Task 2);
- An internal workshop to identify the prospects for using standards based on the evidence collated in Tasks 1 and 2 (Task 3); and
- A synthesis of the evidence from the different sources to produce the final report (Task 4).

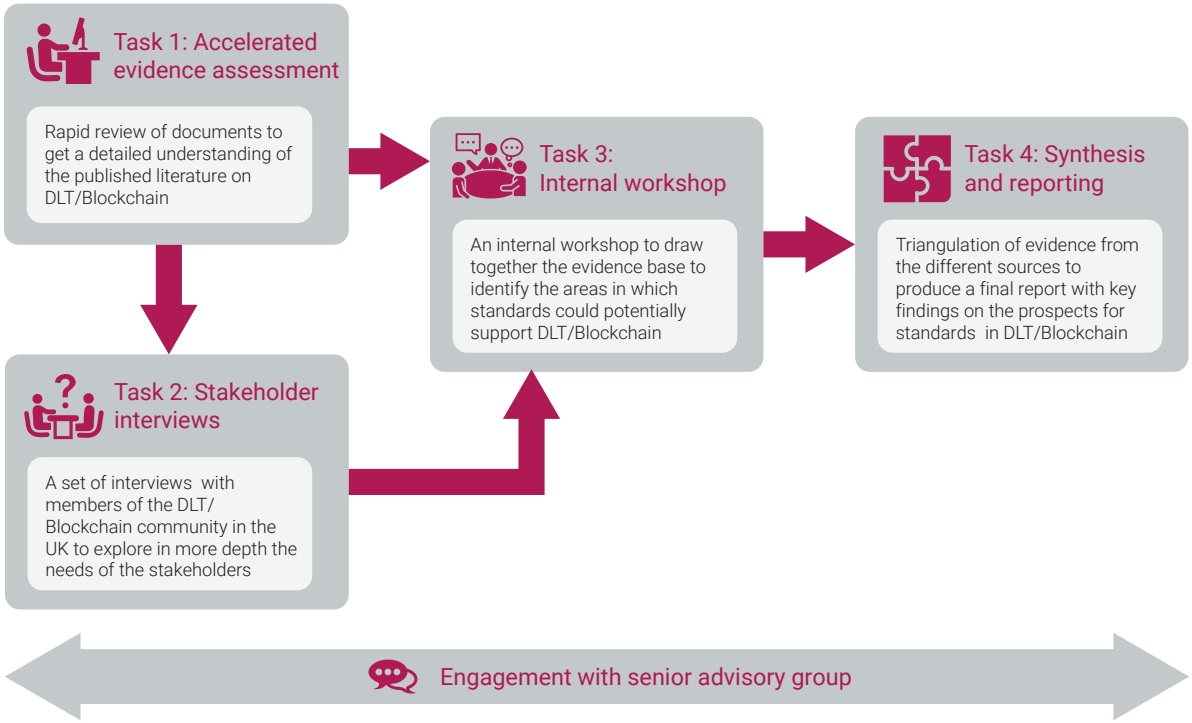
In the following section, we describe each of these components in more detail. The caveats and limitations of the analysis are discussed in the final section of this chapter.

2.2. Description of methods

2.2.1. Accelerated evidence assessment (Task 1)

To build a rounded picture of the current state of play with regard to DLT/Blockchain within the study timelines, we conducted a rapid review of the academic and grey literature available online. One of the primary aims of this task was to establish a deeper understanding of the challenges and opportunities that are central to the development of DLT/Blockchain and of their implications for the potential development of standards within the area. To align with the overall objective of the study, the emphasis of the task was on the market issues related to DLT/Blockchain rather than the technical or implementation-specific aspects. We also used this task to identify (a) key sectors

Figure 3: Methodological schema of our research approach



Source: RAND Europe

that could potentially benefit from the emergence of DLT/Blockchain standards and (b) the main stakeholders whose prospective inclusion in the standardisation of DLT/Blockchain would be relevant and important to advance the area.

The search was conducted using Google Scholar and Google searches to ensure a sufficiently broad coverage of the academic, policy and consultancy literature. We also searched a limited number of technology blogs and news sites. A number of search strings were developed to retrieve the articles (the complete list of search terms is included in Appendix B). An initial long list of articles was generated; these were then screened for relevance on the basis of their title and abstracts. To ensure that we obtained as much relevant evidence as possible, we also used a 'snowballing' approach to identify additional articles from the bibliographies of selected articles. For pragmatic reasons, the search was limited to articles from 2006 onwards. Our searches revealed that the majority of relevant literature was published in the past seven years. Finally, before we started to conduct our searches, we consulted our senior advisory group to identify existing literature sources and to validate the search terms used in the analysis.

2.2.2. Stakeholder interviews (Task 2)

As mentioned previously, the overarching objective of the research was to understand, on the basis of the needs of the stakeholders in the UK DLT/Blockchain community, some of the important areas related to DLT/Blockchain that potentially require standardisation. To

allow us to explore this in more depth as well as to validate and enrich the findings from the accelerated evidence assessment, we conducted a series of interviews with a selection of stakeholders from the UK DLT/Blockchain community. We were particularly interested in (a) examining each of our experts' general understanding of DLT/Blockchain and the evolving landscape within the UK and internationally (where appropriate); (b) their perceptions and awareness of the notable challenges and opportunities; (c) their insights into the key areas where standards could potentially support DLT/Blockchain; and (d) any sector- or topic-specific observations they had with respect to the development and adoption of DLT/Blockchain.

In total, we conducted 14 interviews (15 interviewees) in February and March 2017 across a range of stakeholder groups in the UK – including different industry sectors, academia, government, and the third sector (e.g. industry trade organisations, industry-led consortia). The interviews were semi-structured and lasted between 45 minutes and 1 hour. 13 of these interviews were conducted by telephone. One interviewee responded to our questions via email. The semi-structured format ensured that a similar set of questions was asked of all interviewees, but it also allowed for emergent issues to be explored. All interviewees were sent an interview information sheet and topic guide a few days in advance. This included information about the aims of the project, the purpose of the interview, a note on confidentiality, and a list indicating the topics to be covered during the interview. To safeguard the anonymity of the experts we interviewed, the analysis presented in the report does not make any specific references to either individuals or stakeholder groups (we use the identifiers INT01, INT02, etc. to make reference to insights from the interviewees). The semi-structured interview protocol is provided in Appendix C.

2.2.3. Internal workshop (Task 3)

After collecting and analysing the data in Tasks 1 and 2, we organised an internal workshop to draw together the evidence base, with the aim of: (a) undertaking a thematic examination to corroborate the primary challenges and opportunities identified from the literature and interviews in relation to DLT/Blockchain; (b) validating the different sectors and stakeholders which could be impacted; and (c) identifying the main areas and topics in which standards – either national or international – could potentially support DLT/Blockchain.

2.2.4. Synthesis and reporting (Task 4)

In the final phase of the project, we triangulated the evidence from the different sources to produce a final report with observations and key findings that addressed the core objectives of the study. This included: (a) demonstrating the prospects for developing standards in relation to DLT/Blockchain, with a focus on the UK perspective; (b) identifying sectors that might benefit from the advent of DLT/Blockchain standards; and (c) identifying stakeholders that would need to work together on developing standards related to DLT/Blockchain. The analysis identifies a series of areas or topics for further consideration related to the potential role of standards to support the growth of the DLT/Blockchain ecosystem in the UK.

2.3. Limitations of the analysis

There are some caveats to consider for those interpreting the analyses presented in this report. First, because of the tight timelines within which the research had to be completed (six weeks), we undertook an accelerated assessment of the evidence. Nevertheless, we ensured that the analysis was

as comprehensive as possible.[18] We reviewed a diverse range of academic and grey literature to obtain a rounded picture of the current state of play as regards DLT/Blockchain.

There is an increasing body of information on DLT/Blockchain available in the public domain and the literature frequently tends to discuss future or potential opportunities and challenges rather than focussing on real examples of implementation. We believe that this is an inherent characteristic of the topic, which is in a nascent stage of development and has recently been receiving a growing amount of attention in the media.

Additionally, the study was not intended to cover detailed issues related to the technical and implementation aspects of DLT/Blockchain. The analysis therefore does not discuss these points in detail but, rather, focuses on the market issues related to DLT/Blockchain.

We conducted a series of in-depth interviews to validate the findings from and complement the accelerated evidence assessment. As the analysis was based on a small sample of stakeholder interviews, the findings from this component of the study should be treated with some caution and should be considered to be more along the lines of a perceptions audit. Furthermore, it was beyond the scope of this study to independently verify all the information that was provided during the interviews. Within this small sample, we attempted to seek expert opinions and views on DLT/Blockchain and the potential role of standards across a range of stakeholders in the UK covering experts from industry, academia, government, and the third sector (e.g. industry trade organisations, industry-led consortia). The discussions in this report present the majority opinions conveyed across the sample of interviewees. Where appropriate, we have also attempted to articulate a divergence of views.

Finally, the set of priority areas for potential standardisation that we identified is neither an exhaustive nor a definitive list; rather, it is intended to serve as a set of topics for further examination and debate by the BSI and by the DLT/Blockchain community more generally.

Notwithstanding the caveats discussed above, we hope that the analyses presented in this report will be useful to inform future thinking related to the role that standards could play in supporting the growth of DLT/Blockchain.

18 For example, in relation to keywords used in the search strategy; furthermore, as noted previously, we adopted a 'snowballing' approach to identify additional articles from the bibliographies of selected articles.

3 Assessing the challenges and opportunities in relation to DLT/Blockchain

Summary box: Challenges and opportunities related to DLT/Blockchain

What are the challenges facing DLT/Blockchain?

- Lack of clarity on the terminology and perceived immaturity of the technology
- Perceived risks in early adoption and likely disruption to existing industry practices
- Insufficient evidence on business gains and wider economic impact
- Lack of clarity on how the technology is/would be governed
- Uncertainty around regulation
- Multiple non-interoperable implementations and resulting fragmentation
- Maintaining security and privacy of data
- Ensuring integrity of data and strong encryption
- Energy-intensive nature of the technology
- Lack of clarity regarding smart contracts and how to implement them through DLT/Blockchain

What are the opportunities for DLT/Blockchain?

- Providing efficiency gains (including cost savings) for businesses and end-users
- Enabling new revenue sources
- Enabling new economic and business models
- Improving resilience and security in transactional systems
- Empowering end-users and improving trust in transactions
- Offering benefits for recording and reporting of data and activities through immutability capabilities
- Enabling management of digital identity through public key cryptography
- Providing the underlying mechanism for smart contracts and enabling smart auditing capabilities

3.1. Introduction

Despite the potential of DLT/Blockchain technology and its perceived capability to transform existing systems, processes and businesses, challenges remain for the realisation of

benefits to the prospective sectors and use cases[19] identified by stakeholders. In order to understand the broader landscape of DLT/Blockchain technologies and the role that standards could play in its development and adoption, it is essential to understand the challenges faced by DLT/Blockchain as well as the opportunities that the technology offers.

> *"There is a lot of interest [in the technology] … and there are organisations that are already putting the 'thermometer in the water', but it does seem to be very much that. They are just going and having a look at a particular small area and doing piloting. It does seem to be something that industries have been chasing since the technology became better known, so I think the [business] need is there but maybe there is a degree of scepticism [as well] of whether it would really work at scale and 'at what point do I see significant benefits?'* [INT07]

This chapter begins by discussing some of the important challenges to the wider development and implementation of DLT/Blockchain. This is followed by analysis of the opportunities presented by DLT/Blockchain. The narrative synthesis of challenges and opportunities presented in this chapter is informed by the literature surveyed as part of the accelerated evidence assessment and the insights provided by the interviewees. As noted previously, the evidence from the interviews has been made anonymous throughout the text in this report by using identifiers (INT01, INT02, etc.). We conclude by summarising the discussion as a precursor to the following chapter which examines the prospects for standards in relation to supporting DLT/Blockchain.

3.2. Challenges faced by DLT/Blockchain

In this section we cover the challenges faced by DLT/Blockchain in relation to development and adoption of the technology by markets and end-users, and in relation to governance, implementation, and challenges around specific aspects, such as smart contracts and identity management.

Smart contracts

Smart contracts are a form of automated digital contract in which the terms of the transaction are embedded in computer code, to be automatically fulfilled by the software upon acknowledgement of a particular input. At their most basic, smart contracts are 'a set of promises, specified in digital form, including protocols within which the parties perform on these promises' (Szabo, 1996, cited in Murphy & Cooper, 2016). Whilst the concept was first articulated in 1996, the immutability and distributed nature of DLT/Blockchain has brought renewed attention to the concept. Although they are commonly cited in the literature as a potential application of DLT/Blockchain, questions remain over the legal status, enforceability and technological feasibility of such contracts.

Source: Murphy and Cooper (2016)

19 'Use case' is a term that originates in software engineering, where it refers to a list of actions or sequence of steps which usually define the interaction between the actors and the (software) system. As used in common parlance and also in this document, use case refers to a scenario, set of scenarios, or examples of scenarios in which various stakeholders interact, mostly in relation to a technology or technological ecosystem for specific outcomes; e.g. a commonly cited Internet of Things use case is the Internet-enabled smart meter, which, by keeping record of when and how much the utility in question (e.g. energy, gas, or water) is consumed, can give end-users better control over their consumption (Tracy, 2016).

3.2.1. Lack of clarity on the terminology and perceived immaturity of the technology

The difficulty in understanding what DLT and Blockchain stand for, and what the technology can actually do, is reiterated by multiple sources (see, for example, Andreasyan, 2016; Taylor, 2015; SWIFT Institute, 2016; Parliamentary Office of Science and Technology, 2016). The use of the terms 'Distributed Ledger Technology' and 'Blockchain' is often conflated (Mainelli & Mills, 2016).[20,21] 'The Blockchain' is also common shorthand to refer specifically to the Blockchain implementation which underpins the Bitcoin cryptocurrency and payment system, which is one of the most prominent implementations of the technology (Iansiti & Lakhani, 2017; The Economist, 2016). Variants on these terms are also used, including mutual distributed ledger (MDL) (Mainelli, 2017) and cryptotechnologies (Euro Banking Association Working Group on Electronic Alternative Payments [EBAWGEAP], 2016).

> *The description of Blockchain tends to pre-determine peoples' understanding and to very quickly go into Bitcoin, and suddenly we are not talking about Blockchain implementations of particular solutions. We are now looking at something that is very similar to Bitcoin.* [INT01]

Given the diversity of DLT/Blockchain solutions under development, it is unclear whether similar issues will arise for specific technical terms (such as the choice of consensus mechanism) or other aspects or applications of DLT/Blockchain which are as yet un- or underdeveloped.

Contributing to the lack of clarity regarding terminology is the variety of approaches and differences in the technical implementation of DLT/Blockchain. The SWIFT Institute (2016) argues that the variety of approaches is indicative of the relative immaturity of the technology. This suggests that it will be a while before full-scale adoption becomes a consideration. DLT/Blockchain is seen as an 'immature' technology (Pinna & Ruttenberg, 2016), and few applications are beyond proof-of-concept stage (INT01; INT06; INT13; Accenture Consulting, 2016). As such, there appears to be a lack of understanding among businesses, consumers and authorities about the way the technology operates, the potential use cases for DLT/Blockchain and the likely short- and medium-term market development potential (Brandman & Thampapillai, 2016; Deloitte, 2016; EBAWGEAP, 2016; McKinsey & Company, 2015). This is exacerbated by the lack of a visible 'killer' application[22] for DLT/Blockchain (INT10); unestablished cases of best practice for the technology (Morrison, 2016e); a lack of agreed performance criteria (Mainelli & Mills, 2016); and the risk that prominent DLT/Blockchain failures[23] may diminish the technology (Mainelli & Mills, 2016). Moreover, given the current hype related to DLT/Blockchain (INT01;

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20 Among the 15 interviewees, two thought DLT and Blockchain was the same thing, nine differentiated between them but in varying terms, and the remaining four saw a distinction between the terms, but acknowledged that these terms are used interchangeably and perhaps irreversibly so. Despite the relatively small sample of interviewees, this variation is perhaps an indicator of how the prevailing perceptions of DLT and Blockchain differ significantly.

21 In Appendix A, we provide a list of some of the definitions of DLT and Blockchain cited in publicly available literature to further illustrate the varied understanding of the terminology.

22 A 'killer' application (also killer app) is a feature, function or application of a new technology or product which is presented as virtually indispensable or much superior to rival products.

23 The two most prominent examples are the Bitcoin hack (Shin, 2016) and the Ethereum hack (Siegel, 2016). Bitcoin has been subject to multiple hacks since its inception (Nakamura, 2016).

INT02; INT05), one of the key challenges will be to demonstrate viable, realistic and achievable real-world use cases.

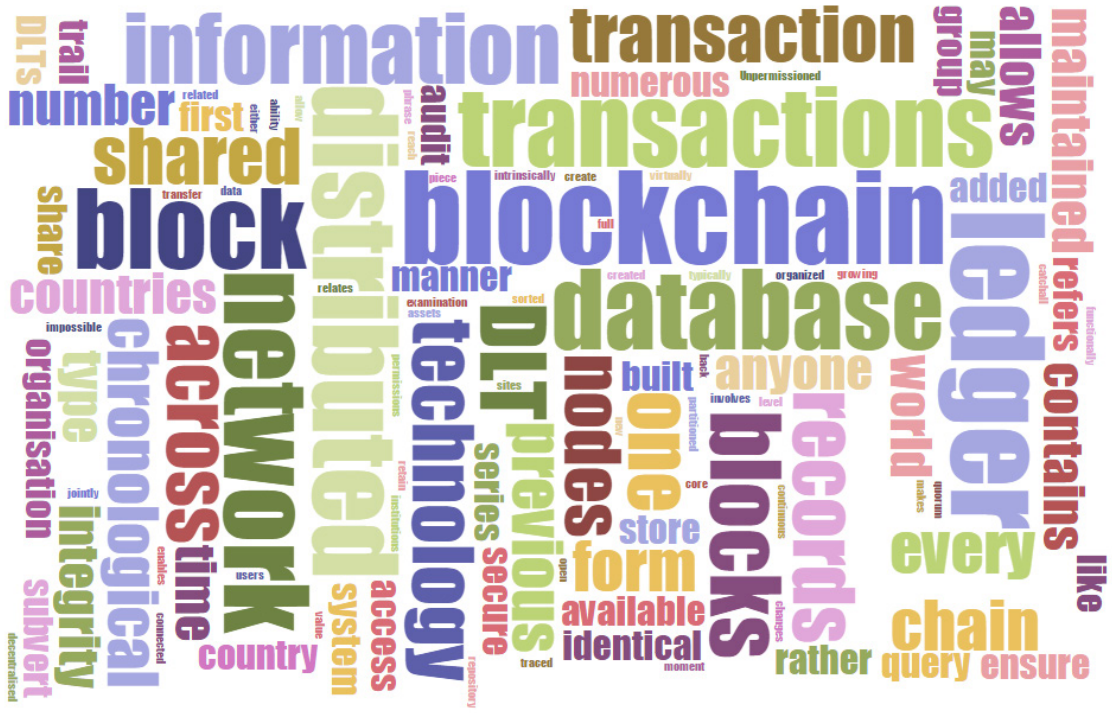
> *The main challenge is people are just seeing an exciting buzzword about [in DLT/Blockchain] without really fundamentally understanding it. If you really want to do something properly and invest properly into it… you have to become clear about how it will transform your business before you invest. The problem is people don't have the underlying knowledge.* [INT02]

> *I think the hype is at a level where you don't know what to believe anymore. The joke is that Blockchain can do everything, including cure cancer.* [INT05]

The perceived immaturity of the technology also creates challenges for businesses that potentially want to use DLT/Blockchain. The unavailability of human resources with the appropriate knowledge and skills to effectively develop and implement DLT/Blockchain solutions limits the extent to which DLT/Blockchain solutions can be developed (INT14). Moreover, insufficient understanding of DLT/Blockchain among existing staff could pose challenges to widespread adoption (European Securities and Markets Authority [ESMA], 2016b; Shah, 2016).

In Figure 4, we show a word cloud that highlights the most frequently occurring words within the definitions of DLT and Blockchain listed in Appendix A. We recognise that the word cloud provides only a high-level visual representation of the most recurring words. Nevertheless, it highlights the diversity of topics that the definitions listed in Appendix A cover and further illustrates the varied interpretations of DLT and Blockchain among stakeholders.

Figure 4: Word cloud showing the most frequently occurring words in the definitions of DLT and Blockchain listed in Appendix A.



Section take-away: Insufficient clarity regarding and inconsistent understanding of the terminology, combined with the perception that DLT/Blockchain is an immature technology, poses challenges to wider adoption of DLT/Blockchain.

3.2.2. Perceived risks in early adoption and the likely disruption to existing industry practices

Even if economic benefits are expected, the costs of adoption and implementation of DLT/Blockchain for existing businesses in the short term may be considerable. This is particularly the case for incumbents with large existing back-office processes, complex legacy IT systems, or the processes created to comply with existing standards which could require costly redesign (INT06; INT05; Crosby et al., 2015; Deloitte, 2016; McKinsey & Company, 2015). Early adopters may also run the risk of investing in models which later do not prove interoperable with a more widely adopted variant of DLT/Blockchain (INT05; McKinsey & Company, 2015). Moreover, capital costs associated with acquiring specialist 'mining'[24] hardware may be substantial (Deloitte, 2016). In addition, the running costs associated with the adoption of DLT/Blockchain are as yet unclear (Kakavand et al., 2017; Krawiec et al., 2016; Maye, 2016). This may discourage early adopters and hinder the development of a 'critical mass' of organisations potentially required to meaningfully collaborate in order to develop a cross-industry DLT/Blockchain solution (Deloitte, 2016; EBAWGEAP, 2016; ESMA, 2016b; Mills et al., 2016; McKinsey & Company 2017; Mainelli & Milne, 2016; World Economic Forum, 2016b).

Some back-office processes may not be easily removed or replaced by DLT/Blockchain solutions in the near term. The intermediaries (including systems and/or people) that are part of the legacy processes may act in parallel with DLT/Blockchain solutions. In some cases, those intermediaries may even accelerate the adoption of DLT/Blockchain by implementing DLT/Blockchain solutions themselves (Mainelli & Milne, 2016).

DLT/Blockchain solutions may have to implement established sector-specific business practices (both technical and operational) and standards, and they may have to overcome cultural resistance by market incumbents to achieve wider market acceptance (INT10; Crosby et al., 2015; McKinsey & Company, 2015; Shackelford & Myers, 2016). In some cases, the established systems, processes and architectures may be extensively deployed; examples include the existing financial infrastructure, messaging protocols (such as Society for Worldwide Interbank Financial Telecommunication [SWIFT]),[25] and reference data used in financial services (World Economic Forum, 2016b). At an operational level, financial institutions looking to adopt DLT/Blockchain solutions may have to rethink their strategies with regard to 'workforce optimization, data centre requirements, storage, networking and security' (Accenture Consulting, 2017). DLT/Blockchain may need to be interoperable with such existing processes otherwise the markets may face a period of uncertainty as existing practices are disrupted by new DLT/Blockchain solutions (INT03; INT04; Deloitte, 2016). We discuss the further implications of (the lack of) interoperability in Section 3.2.6.

24 Mining is the process of spending computing power to process transactions, secure the network and keep everyone in the system synchronized. For an explanation in the context of Bitcoin cryptocurrency, please see https://bitcoin.org/en/faq#what-is-bitcoin-mining

25 SWIFT is a global, member-owned cooperative, and it is the world's leading provider of secure financial messaging services. https://www.swift.com/about-us/discover-swift

Section take-away: The potential high costs of initial implementation, perceived risks associated with early adoption of DLT/Blockchain, and possibility of disrupting existing practices may pose significant challenges to businesses.

3.2.3. Insufficient evidence on business gains and wider economic impact

Given the challenges of adoption, it is unclear in some cases whether a DLT/Blockchain solution is an improvement over a more traditional, centralised ledger (for example, in terms of performance or other transactional parameters, such as security or throughput) (INT11; Deloitte, 2016; Maye, 2016; McKinsey & Company, 2017; Morrison, 2016e; Tierion, 2016). Until further proofs of concept are piloted and tested, uncertainty regarding which use cases are viable and realistic may remain. Although the available proof of concept studies and solutions are useful for sharing opinions and thoughts, and for stimulating the debate surrounding what DLT/Blockchain can do, in order to achieve wider adoption and critical mass in the market, Dunker and Krasniqui (2016) suggest that the technology is not yet ready. Currently, the return on investment for businesses is unclear, which could make it more difficult to argue a case for investing in DLT/Blockchain solutions (Accenture, 2016; Barclays, 2016; The Economist, 2015). Additional factors that indicate that DLT/Blockchain technology is still immature include the lack of extensive testing, absence of a regulatory framework,[26] and the lack of clarity regarding how the technology would interact with existing systems (Lamarque, 2016). In this context, Brennan and Lunn (2016) identify the following two threats to achieving critical mass of adoption: (a) fragmentation of platforms, and (b) institutional and social inertia to transition to and/or agree on a platform.

> *The big obstacle … in adopting Blockchain is 'What are you going to use it for and if you do, are you going to save money with it or make more money than you currently do?' Existing systems may be old, but if they do the job, why would we pay to decommission them and do something new? Technology doubt is a massive obstacle for new technology, and especially Blockchain.* [INT12]

In the absence of wider adoption among businesses, it is not easy to make a sufficiently clear assessment of DLT/Blockchain's broader economic impact in the medium to long term. Some of the main concerns are as follows:

- The automation of processes previously conducted by intermediaries could lead to the loss of jobs (INT06; McKinsey & Company, 2016).
- The adoption of permissioned ledgers by existing industry incumbents could serve to shut out new market entrants or to create significant barriers to market entry (ESMA, 2016a; Millar & Brunet, 2015; Brandman & Thampapillai, 2016).
- As is the case with the introduction of any potentially disruptive innovation, DLT/Blockchain could result in some market incumbents going out of business entirely (INT10).

The removal of intermediaries, as well as efficiency gains and automated contract processing, may open up new areas of unforeseen risk – particularly in the financial sector – by

26 There is also insufficient clarity on how DLT/Blockchain may have to adapt to variations in the regulatory environments of different industries

encouraging herding behaviours,[27] changing the nature of financial interactions in sectors currently considered low risk (e.g. insurance Investopedia (2015) or government treasury bonds Simpson (2017)), or making the monitoring of systemic risk more difficult for regulators (Deloitte, 2016; ESMA, 2016b). In addition, the placing of assets on DLT/Blockchain or the widespread use of smart contracts may have consequences for liquidity[28] in the market, although there are differing opinions about whether this would serve to release liquidity (e.g. by increasing the speed of settlement) or decrease liquidity (e.g. by 'locking in' collateral in a smart contract or requiring higher collateral by reducing position netting,[29] a role currently played by intermediaries) (ESMA, 2016a, 2016b; Mills et al., 2016; Mainelli & Mills, 2016).

Section take-away: There is lack of clarity about the improvements the technology offers over existing solutions. In the absence of widespread DLT/Blockchain adoption, the broader economic impact of the technology in the medium and long term is difficult to determine.

3.2.4. Lack of clarity on how the technology is/would be governed

Given the distributed nature of ledgers and their function as an immutable record, setting out clear rules for the governance of the ledger will be a key challenge for both permissioned and permissionless ledgers (ESMA, 2016a, 2016b; Mills et al., 2016; Kakavand et al., 2017; Mainelli & Mills, 2016). Part of this governance challenge may be a result of establishing off-ledger agreements setting out the responsibilities and terms of use for participants. In addition, as part of off-ledger agreements, certain permissions automatically may (or may not) be granted to ledger users by virtue of their user status. This may involve establishing procedures for certain aspects of governance, such as:

- Identity verification of users and establishing appropriate permissions (ESMA, 2016b; Financial Industry Regulatory Authority (FINRA), 2017; SWIFT, 2016);
- Methods of error correction which would be employed should incorrect data be added to the ledger or transactions be deemed in need of reversal (Brandman & Thampapillai, 2016; The Depository Trust & Clearing Corporation (DTCC), 2016; ESMA, 2016a, 2016b; Mainelli & Mills, 2016; McKinsey & Company, 2015);
- Dispute arbitration (Bogart & Rice, 2015; Mainelli & Mills, 2016) and applicable law (ESMA, 2016b);
- Compliance with legislation and regulation (such as know-your-customer (KYC)/anti–money laundering (AML) processes), particularly in the case of anonymous users (ESMA, 2016a); and
- Assigning responsibility for maintaining the integrity of the system.

27 Herding, herding behaviour, or herd behaviour refers to a situation in which individuals' private information is overwhelmed by the influence of public information about the decisions of a herd or group. In an uncertain world, if an individual realises that their own judgement is fallible, then the individual is likely to think that it may be rational to assume that others are better informed, and thus this individual follows these others. See Baddeley et al. (2012) for details of herding behaviour in financial industry.

28 Liquidity refers to cash, cash equivalents and other assets (liquid assets) that can be easily converted into cash (i.e. liquidated). For more details, see: http://lexicon.ft.com/Term?term=liquidity

29 Position netting (more generally netting) refers to the process by which the value of multiple positions or payments due to be exchanged between two or more parties are offset. Netting can be used to determine which party is owed remuneration in a multiparty agreement. For more details, see: http://www.investopedia.com/terms/n/netting.asp

DLT/Blockchain is likely to require individual users to interact with the ledger and transact using their private key. Therefore, the management of keys – and protocols for key loss or theft – will be important (Mills et al., 2016; Oates & Samudrala, 2016; Peters & Panayi, 2015; SWIFT, 2016), and they must be designed to avoid introducing additional vulnerabilities through a 'back door' (Tierion, 2016).

While permissioned ledgers are in a better position to set out rules as a criterion of joining the ledger, in the case of permissionless ledgers or open ledgers (e.g. peer-to-peer (P2P) asset transfer), careful consideration is required as to how to set up the governing structure in order to mandate nodes to undertake critical steps, such as downloading software updates or ensuring that a critical mass of nodes does not 'take control' of the ledger (Shackelford et al., 2016).[30] In particular, depending on the ledger design, inefficiencies may arise from the difficulty of achieving consensus to validate peer-to-peer transaction as the network grows, leading to high aggregated costs. Deloitte (2016) estimates the total running costs of the Bitcoin network to be as much as $600 million a year. The lack of consensus between parties involved in the network could lead to periodic 'forks',[31] especially in permissionless ledgers, and thus slow down decision making and transaction processing[32] (Kakavand et al., 2017).

For ledgers that are shared between multiple legal entities – whether permissioned or permissionless – a key challenge will be establishing liability among partners for the activities taking place on the ledger – for example, liability for losses experienced by businesses in the event of an operational failure or compromised keys, or legal responsibility in the event of data loss or theft (ESMA, 2016a, 2016b; Mainelli & Mills, 2016; World Economic Forum, 2016b).

Section take-away: Because of the nascent nature of the technology, there is a lack of clarity with regard to the governance of DLT/Blockchain systems.

3.2.5. Uncertainty around regulation

Understanding how operations on DLT/Blockchain relate to the wider regulatory environment – or to the development of specific regulation in light of DLT/Blockchain – will be a key element in the development and adoption of DLT solutions (Accenture Digital, 2016; Deloitte, 2016; McKinsey & Company, 2017). This is particularly the case for operations which involve the transfer of assets or data across different jurisdictions or for ledgers involving anonymous interaction (FINRA, 2017; McKinsey & Company, 2017; Brandman & Thampapillai, 2016). The current regulatory environment (from a wider international perspective) is unclear in this regard (Deloitte, 2016; EBAWGEAP, 2016; SWIFT, 2015; World Economic Forum, 2016b). In some sectors, such as insurance and banking, there may also be a change in the type and role of market players, giving rise to new market structures – but with associated implications for regulation, such as software companies taking on functions traditionally fulfilled by licensed financial services companies (INT05; INT06; INT10; Mills et al., 2016).

Smart Contracts Alliance and Deloitte (2016) highlight that, from a regulatory perspective,

30 The 'Ethereum fork' is a prominent example of the difficulty of managing unforeseen problems in a permissionless ledger. See Siegel (2016).

31 In software engineering, a 'fork' is said to occur when a set of developers take a copy of the source code and start to develop distinct and separate piece of software. See Dash (2010).

32 This could also limit the effectiveness of permissionless ledgers for some use cases.

the functions and impact of DLT/Blockchain will be more important than the technology itself.[33] Particularly in relation to the financial sector, which is highly regulated, standards for a new technology can be crucial. However, Lamarque (2016) notes that 80 per cent of the focus on DLT/Blockchain implementation is likely to be on business processes and only 20 per cent on the technology. Due to the expected change in business norms, the challenge is for the regulator to decide when to intervene (Broby & Karkkainen, 2016; Elliott et al., 2016) to ensure that innovation is not stifled and that, at the same time, end-user rights are protected.

Furthermore, regulatory bodies themselves will need to develop the skills required to understand and interpret the activity taking place on the ledger, to identify potential risks, and to ensure user compliance with existing regulation (Deloitte, 2016). In the case of financial services, this may also involve understanding how certain patterns of behaviours by users of DLT/Blockchain relate to wider, system-wide risk (ESMA, 2016a).

Section take-away: The uncertainty of the current regulatory environment with respect to DLT/Blockchain technologies is perceived as an obstacle to its widespread adoption.

3.2.6. Multiple non-interoperable implementations and resulting fragmentation

To realise the full benefits of DLT/Blockchain, it will be critical for ledgers to be able to exchange information with other ledgers and with legacy IT systems (INT04; INT05; EBAWGEAP, 2016; ESMA, 2016a; Mills et al., 2016; Mainelli & Mills, 2016; Shah, 2016; SWIFT, 2016). In the short and medium term, it is unclear whether large businesses would be prepared to overhaul their existing operating procedures; DLT/Blockchain solutions will, in many cases, be required to co-exist with legacy IT structures and business processes (Morrison 2016e; Mills et al., 2016; INT12; The Select Committee on Economic Affairs, 2016),[34] and different types of ledgers may develop in silos (ESMA 2016b). De Meijer (2016) highlights how there are at least dozens of fragmented DLT/Blockchain systems competing, each with their proprietary, non-interoperable standards and protocols, which raises challenges for interoperability and competition (e.g. in the form of barriers to entry for new entrants). Kakavand et al. (2017) also highlight the potential inconsistent development of the technology, which could lead to a fragmented market. Wider adoption for DLT/Blockchain depends on enabling seamless interaction, not just between DLT/Blockchain systems, but also between current (eventually to be legacy) systems and those based on DLT/Blockchain. A regulatory and legal intervention, Lamarque (2016) argues, may be necessary to ensure that DLT/Blockchain has 'a meaningful and concrete impact'.

> *There will not be one big Blockchain (like the mobile network). Banks will have tens of thousands of ledgers. Millions of Blockchains will exist. These will need to speak with each other and interconnect.* [INT03]

Similarly, enabling interoperability between ledgers in order to share data or enact

33 This was also suggested by an interviewee (INT10).

34 Oral evidence provided by Simon Taylor in the House of Lords select committee on Economic Affairs inquiry on Distributed Ledger technologies on Tuesday, 19 July 2016. See The Select Committee on Economic Affairs (2016) for more details.

transfers across multiple ledgers may become crucial to fully realise the benefits of DLT/Blockchain (Deloitte, 2016).

Section take-away: The emergence of multiple, non-interoperable DLT/Blockchain implementations could lead to a fragmented ecosystem and limit widespread adoption.

3.2.7. Maintaining security and privacy of data

Organisations will need to think carefully about maintaining the integrity and security of data stored on a ledger – and of the data relating to the transaction and ledger activity itself (Deloitte, 2016; EBAWGEAP, 2016; ESMA, 2016a, 2016b; Mills et al., 2016; Mainelli & Milne, 2015; SWIFT, 2016). In the context of Bitcoin, although transactions are in theory anonymous,[35] the record of transactions itself is visible and permanent, and so transactions can be traced if a particular user's wallet address is known (ESMA, 2016b; SWIFT, 2016). For many ledgers, a transparent record may actually be preferred or purposeful – although with the ability to restrict users' ability to access sensitive or commercial data. Organisations will need to ensure that data can be accessed only by those with appropriate permissions, and in line with prevailing data protection legislation (EBAWGEAP, 2016; Mainelli & Milne, 2016). This may present a particular challenge for ledgers for which data is transferred across jurisdictions and thereby through different data protection regimes (ESMA, 2016a).

Assigning and verifying ownership of digitised assets on a ledger

Applications which seek to facilitate the transfer of assets will have to establish a system that clearly represents assets on the ledger and possibly verifies their off-ledger storage and transfer (ESMA, 2016a; Mills et al., 2016; McKinsey & Company, 2015). This will include agreement among actors on various aspects of the digitisation, such as terms of transaction, description of assets, terms of transfer and link to real-world assets (such as fiat currency or goods) (McKinsey & Company, 2015).

Similarly, for asset-based ledgers, a system of verifying ownership before it is added to the ledger is needed. While ledgers can be used to track and transfer ownership of assets, such as property titles, copyright or diamonds, the ownership of the assets will have to be adequately established before they are added to the ledger. A related challenge will be the representation of fiat currency on the ledger and linking to off-ledger accounts.[36] In the absence of a viable system of linking cash, DLT/Blockchain users will require the use of traditional third-party intermediaries – such as banks – or the use of dedicated digital currencies (which may be ledger-specific or more widely used cryptocurrencies, such as Ether or Bitcoin (see O'Dair, 2016)).

35 Data can be used in some cases to identify probable users. See Meiklejohn et al. (2013).

36 DLT solutions in this field are being developed. See for example: http://www.billoncash.com/

The potential anonymity offered by DLT/Blockchain is perceived to be both an advantage and a potential challenge, since it can be used for illegal activity (Bartlam & Kantor, 2016; Crosby et al., 2015; Government Actuary's Department, 2016; Shackelford & Myers, 2016). Although distributed ledgers are perceived to be more secure than centralised systems, this does not always translate into the security of every account (Kakavand et al., 2017; Parliamentary Office of Science & Technology, 2016). The challenges of social engineering,[37] application vulnerability and account takeovers equally apply to DLT implementation, as seen in the example of Bitcoin hacks (Schepers, 2016; Shackelford & Myers, 2016). An additional security risk comes from the possibility for any miners[38] controlling more than 51 per cent of the computing power to modify the transactions on the ledger (Accenture, 2016; Shackelford & Myers, 2016; The Economist, 2015).

An associated concern is related to the immutability of the record and the management and removal of data should any participating individuals wish for their data to be removed (INT11). In this regard, longer-term concerns have been raised about the potential for a 'Panopticon' – an intrusive and immutable record of individuals' actions – should the use of connected ledgers become widespread (Mainelli & Mills, 2016). Mainelli and Gupta (2016) suggest that an important challenge to maintaining privacy of data is likely to be end-user errors. For example, end-users are likely to (either accidentally or by mistake) reveal their (private) cryptography keys, and to deal with such scenarios, schemes to kill the cryptography key and replace it while maintaining the users' identity would need to be developed (see also FINRA, 2017). The Ethereum hack highlights that any possible implementation cannot guarantee complete security (INT02) and that 'blockchains are only immutable when consensus wants them to be' (Brennan & Lunn, 2016).

Section take-away: Potential security vulnerabilities and concerns about data privacy are seen to be significant challenges, particularly if users are entrusting DLT/Blockchain solutions with personal data.

3.2.8. Ensuring integrity of data and strong encryption

Ensuring the integrity of the data is a key issue for DLT/Blockchain-based applications. Whereas DLT/Blockchain may present opportunities in this regard, such as multiple copies of a ledger in the event of a cyberattack or computer failure (as detailed in Section 3.3.4), the distribution of access and management rights across multiple nodes may in itself present a security risk, in that malevolent entities have multiple 'back doors' through which to attack the system (INT02; ESMA, 2016a). Ensuring that software updates are correctly and swiftly installed will be important in this regard (although such seamless updating presents a particular challenge for permissionless, large-scale ledgers; see SWIFT, 2016).

A related concern is the integrity of encryption used to protect data stored on the ledger, particularly in the longer term, given that potential quantum computing technologies could render current encryption practices insufficient for

37 'Social engineering' is a technique used by hackers or other attackers to gain access to information technology systems by getting the needed information (for example, a username and password) from a person rather than breaking in to the system through electronic or algorithmic hacking methods. See Orgill et al. (2004) for further explanation.

38 'Miners' refers to either individuals or machines engaged in the mining activity. See footnote 24 for an explanation on mining,

secure data storage (Crosby et al., 2015; ESMA, 2016b; The Select Committee on Economic Affairs, 2016).[39] For this reason, some experts advise that no data be stored directly on the ledger itself, but, rather, that it be 'hashed'[40] and stored in a secure off-ledger location (The Select Committee on Economic Affairs, 2016).[41] The issue of trust in the system, ascertaining integrity of other users in the distributed ledger, and carrying out transactions in a consistently secure manner are thus key challenges to wider DLT/Blockchain adoption (Brennan & Lunn, 2016; Christidis & Devetsikiotis, 2016). As Brennan and Lunn (2016) suggest, although identity can be effectively encrypted in a DLT/Blockchain implementation, to enable transaction data to be verified, the nodes in the distributed ledger need to see the transaction data. This suggests a potential issue for data privacy in the specific case of permissionless ledgers.

> *Currently identity is being viewed as being a human factor, but if we want to attest the composition of a network, for instance, then we need to start identifying the devices that participated in that network. This is going to be worth [a lot of value] in the IoT [Internet of things] space – 'How do I believe that what this device is telling me is correct?'* [INT01]

Section take-away: Safeguarding data integrity and ensuring strong encryption mechanisms are perceived as key challenges to the wider adoption of DLT/Blockchain.

3.2.9. Energy-intensive nature of the technology

The distributed nature of DLT/Blockchain (in which changes are made to multiple copies of the ledger simultaneously) means that certain ledger designs may be significantly more energy-intensive than centralised alternatives (INT06; ESMA, 2016a; McKinsey & Company, 2015, 2016). The Bitcoin blockchain, as an example of a fully operational ledger, is alleged to be highly energy intensive (Deetman, 2016; Malmo, 2015). Under current Bitcoin operating processes, transactions can take several minutes to be completed while new blocks are mined. The operational performance and ability to scale the ledger will rely heavily on ledger design, in particular the choice of consensus mechanism, if the potential for future scaling of operations is to be preserved (Deloitte, 2016; ESMA, 2016b; SWIFT, 2016). This is likely to be a more significant problem for permissionless ledgers than for permissioned ones, in which scaling can be planned and managed (ESMA, 2016b).

Distributed technologies, such as DLT/Blockchain, push the maintenance costs away from the centre of the network (Lamarque, 2016). With large numbers of stakeholders and technologies (with different approaches to DLT/Blockchain implementation), the energy costs of running such a system and ensuring that effective cost-estimation mechanisms are in place (particularly on the server side to manage demand) may pose a significant challenge. Lamarque (2016) also suggests that compared

39 Oral evidence provided by Cathy Mulligan and Blythe Masters in the House of Lords Select Committee on Economic Affairs Inquiry on Distributed Ledger Technologies on Tuesday, 19 July 2016.

40 Hashing refers to a computer programming function (also called hash function) which scrambles input data to derive their output. The value returned by the hash function is called hash value, hash code or sometimes just hash. The term 'hash' itself is based on its non-technical meaning, i.e. to make a mess. See Knuth (2000) for more details.

41 Oral evidence provided by Cathy Mulligan and Blythe Masters in the House of Lords Select Committee on Economic Affairs Inquiry on Distributed Ledger Technologies on Tuesday, 19 July 2016. Efforts are underway to develop 'quantum-proof' encryption techniques.

with existing centralised ledger systems, the costs of running DLT/Blockchain systems may be significantly higher. For a distributed system with an ever-increasing number of nodes and thus a wider network footprint, the energy consumption (and related costs) could rise quickly, and the resultant energy requirement is difficult to predict at this stage.

Section take-away: The distributed nature of DLT/Blockchain systems and the need for increased computing power could potentially result in high energy consumption and associated costs.

3.2.10. Lack of clarity regarding smart contracts and how to implement them through DLT/Blockchain

The development of smart contracts remains at a nascent stage. The available evidence suggests there are significant challenges to the use of DLT/Blockchain in implementing smart contracts. The extent to which 'code' can be considered a legal agreement between parties remains unclear and untested in court (INT11). Similarly, a related challenge will be writing code that is clear and free of loopholes or errors, in which key legal terms are adequately represented, that is understood by relevant parties, that is consistent with broader legal practice (which does not use code), and that includes clear identification of individuals or business entities responsible in case of code failure (INT12; ESMA, 2016b)[42]. At the current stage of development, this lack of clarity may restrict smart contracts to simple agreements in which there is minimal subjectivity as to whether terms have been fulfilled and in which those terms can be represented in a simpler, binary fashion (i.e. the contract is either fulfilled or not fulfilled) (INT10; Mainelli & Milne, 2016). In this regard, another challenge for the legal profession will be acquiring the skills that are necessary to adequately deal with potential cases involving complex computer code (Morrison, 2016e).

> *"There is a lot of confusion in the smart contract space. Too many people think a smart contract is an e-contract, a digital version of a contract that used to be on paper. It is a set of rules of engagement; it is not an electronic version of a legal document.* [INT01]

A number of these challenges stem from the perceived lack of clarity and varying definitions of smart contracts themselves, rather than from DLT/Blockchain as a technology. As Christidis and Devetsikiotis (2016) suggest, legal enforceability of smart contracts can be limited based on the definition considered. The extent to which smart contracts can be deemed binding as existing contracts as a matter of law is also unclear (Murphy & Cooper, 2016). Smart Contracts Alliance and Deloitte (2016) highlight that applying contract law to smart contracts written entirely in code would be challenging in terms of determining when or whether a contract has formed, whether a party had performed its obligations, or whether there had been any breaches. Particularly in the context of DLT/Blockchain, as Mainelli and McDowall (2016) observe, smart contracts (when implemented to be fully autonomous) are by their very nature difficult to 'rein in' once they have been put in place. The Ethereum hack is cited as exposing flaws in smart contracts (INT02) when implemented with DLT/Blockchain (Brennan & Lunn, 2016).

42 A related challenge will be finding auditors who can audit the code that was/is used to implement the smart contracts. This is likely to be necessary if smart contracts become commonplace.

Section take-away: Key obstacles remain with respect to the legal enforceability of smart contracts, primarily related to the lack of clarity regarding the definition of smart contracts and how to implement them through DLT/Blockchain.

3.3. Opportunities offered by DLT/Blockchain

Having outlined the challenges of DLT/Blockchain, in this section we discuss some of the key opportunities that the development and adoption of DLT/Blockchain could present. This includes improvements to business practices, such as cost reduction at the operational level and increased resilience in transactional systems, and facilitating particular applications, such as digital identity management and smart contracts. As the discussion in the following sections show, the adoption of the technology could also increase end-users' trust and allow efficiency gains.

> *I think from what I'm hearing from the market was that it was cool to look at, and people have done that. But people have been waiting for demonstrable value and what the technology can do. People have been experimenting, and people are starting to see the benefits. I think it's just a matter of time until there is a big uptake that makes a big impact that allows others to follow*. [INT05]

3.3.1. Providing efficiency gains (including cost savings) for businesses and end-users

DLT/Blockchain can help automate a number of processes which are currently done through human action or that require third-party involvement, thus presenting opportunities for efficiency gains (Brandman & Thampapillai, 2016; Tandulwadikar, 2016; Deloitte, 2016; ESMA, 2016a, 2016b; EBAWGEAP, 2016; McKinsey & Company, 2015; Government Office for Science, 2016). DLT/Blockchain can remove the need for actively intermediated data synchronisation and concurrency control by a trusted third party in a supply chain, and this could also translate into efficiency gains (Mattila et al., 2016).

Similar observations are made by Brennan & Lunn (2016), who argue that the opportunity for sectors which currently rely on trusted third-party intermediation could be in the form of cost removal, improved transactional efficiency and novel revenue streams. We have collated the following key opportunities for efficiency gains across industries:

- DLT/Blockchain can closely link usage with costs and value, which would allow companies to pay for infrastructure in real time according to their usage and value attained. This could reduce the costs associated with massive up-front investments in infrastructure (Bogart & Rice, 2015).

Cloud-based Blockchain technology and support for national and local public bodies

Crown Commercial Services, the central procurement and commercial services agency for the UK government, has signed agreements with DLT/Blockchain service providers to provide national and local public bodies with access to cloud-based Blockchain technology and support. Current agreements include a Specialist Cloud Service agreement with Capgemini to provide DLT/Blockchain-related consultancy services (Gov.uk, n.d.a), and a Platform-as-a-Service agreement with Credits to provide a cloud-based Blockchain platform and related development (Gov.uk, n.d.b; Credits, n.d.).

- The adoption of permissioned DLT/Blockchain technology could replace certain paper-based processes, thereby reducing cost and reliance on paper and increasing the speed and transparency of data-intensive transactions (Taylor, 2015).
- DLT/Blockchain could undertake a number of the functions currently performed by third parties (for example, traditional third-party reconciliation in financial payments), thus increasing efficiency (Brandman & Thampapillai, 2016; Deloitte, 2016; ESMA, 2016a; Mills et al., 2016).
- DLT/Blockchain may facilitate transactions without a reliance on proprietary infrastructure, therefore reducing costs (Tandulwadikar, 2016).
- The adoption of DLT/Blockchain technology to an enterprise or across multiple stakeholders in a sector may bring significant efficiency gains, because it can link together fragmented parts of organisations (Bogart & Rice, 2015).

> *The driving forces, I'd say, are the efficiency gains, which are removing the need for reconciliation in the transfer of valued information assets. If companies can derive significant competitive advantage from doing that, naturally that would drive adoption. And also taking the valid products that are attractive to end-users – that would definitely drive adoption*. [INT06]

Section take-away: By automating processes and removing the need for third-party intermediaries, DLT/Blockchain solutions have the potential to provide significant efficiency gains and cost savings for businesses and end-users.

3.3.2. Enabling new revenue sources

The adoption of DLT/Blockchain could lead to new revenue streams, products and services for businesses (Brennan & Lunn, 2016; EBAWGEAP, 2016; Government Office for Science, 2016). Bogart and Rice (2015) present the following examples when discussing new potential revenue sources:

- The high quality and accessibility of data on the DLT/Blockchain could lead to high-quality data analysis, business improvements and the creation of new business models that rely on such analytic capabilities.
- Public and permissionless ledgers could be leveraged, leading to innovative processes, services and applications that build on existing fair-trade, ethical business practices for open and transparent transactions of goods and services.
- The development of sidechains[43] could allow businesses to develop new functionality and innovations on top of existing DLT/Blockchain implementations and could be used to develop new applications across sectors.

43 A sidechain is a blockchain that validates data from other blockchains (Back et al., 2014).

E-money: Licences for Blockchain-based providers to issue digital currency

The UK Financial Conduct Authority (FCA) has recently begun granting licences for Blockchain-based providers to directly issue e-money. The Small Electronic Money Institution (EMI) license permits businesses to issue digital currency and receive payments under certain conditions and reporting requirements. Current EMI licenses have been awarded to Tramonex, a cross-border payments provider whose model was developed in part with a £248,000 grant from Innovate UK (Research Councils UK, 2015) and utilising the FCA regulatory 'sandbox' (Financial Conduct Authority, 2016); and Circle, a payments provider (Popper, 2016).

More efficient transaction processes may also create additional revenue opportunities by facilitating an improved cash flow and reducing the amount of collateral required for transactions, thus facilitating the use of this capital elsewhere in the economy (Brandman & Thampapillai, 2016; McKinsey & Company, 2015; EBAWGEAP, 2016; Deloitte, 2016; ESMA, 2016a); however, the extent of this predicted impact on liquidity is debated (see Section 3.2.3).

Section take-away: The adoption of DLT/Blockchain technologies could potentially enable new revenue sources for businesses.

3.3.3. Enabling new economic and business models

The adoption of DLT/Blockchain could also enable new business and economic models. The ability to transfer assets without a third-party intermediary could create opportunities for peer-to-peer transactions and thus facilitate the growth of the 'sharing economy' (Tapscott & Tapscott, 2016a). New forms of business collaboration may also be possible, such as multiple participants being able to contribute individual lines of code to a programme while retaining copyright for their discrete contribution (INT09; O'Dair, 2016), or creating ledger-based organisations which are governed on the basis of smart contracts.[44]

Royal Mint Gold: A Blockchain-based platform for trading of 'digital gold'

In 2017, The Royal Mint will launch Royal Mint Gold (RMG), a Blockchain-based platform for the trading of 'digital gold', a digitised representation of physical gold bullion stored off-ledger (Royal Mint, n.d.; Reuters, 2016). Investors will be able to directly purchase and trade digitised gold bullion at a rate of 1 'RMG' for 1 gramme of gold held in The Royal Mint's vault, with the stated intended benefit being to increase transparency and reduce counterparty risk by facilitating direct ownership. (Royal Mint, n.d.).

44 The most prominent example of this has been the establishment of the decentralised autonomous organisation (also known as DAO) in Ethereum. However, this encountered a number of problems in implementation due to problems with the code. See Siegel (2016).

There may also be opportunities for the wider financial and economic system, such as bringing greater numbers of people into the mainstream financial system (Mills et al, 2016; Tapscott & Tapscott, 2016a; Government Office for Science, 2016) and the creation of new forms of financial institutions (INT10). Should cryptocurrencies or ledger-based asset transfers become more widely adopted, this may facilitate novel forms of taxation, given the record of transactions and the ability to better understand the quantity of money in the system (The Select Committee on Economic Affairs, 2016)[45] and, with buy-in from relevant stakeholders, it may facilitate the collection of VAT (Government Office for Science, 2016). Similarly, the emergence of Bitcoin has demonstrated the viability of cryptocurrencies using a ledger-based platform; further development of cryptocurrencies or digitised assets could create new methods of online transaction (ESMA, 2016a; Government Office for Science, 2016).

Section take-away: The growth of the DLT/Blockchain ecosystem could result in the creation of novel business and economic models, such as new forms of business collaboration and cryptocurrencies.

3.3.4. Improving resilience and security in transactional systems

DLT/Blockchain has the potential to increase the resilience of systems and data storage due to its distributed nature and its lack of a central point of failure (Deloitte, 2016; ESMA, 2016a; Mills et al., 2016). The Bank of England (2017), in a report on its FinTech Accelerator proof of concept, suggests that the risks of failure are proportionately spread in DLT/Blockchain rather than being concentrated at a single point; this, in turn, can make the system resilient and more secure. In the same report, however, the author(s) strike a note of caution by stating that the technology is still relatively immature and that any such use cases need further testing in the real world before such capabilities can be operationalised.

The opportunities provided by the distributed nature of the technology are also highlighted by Mainelli (2017), who suggests that DLT/Blockchain provides a technology that is not owned by a single entity and that therefore in the event of failure everyone can keep their own copy of data and transactions. This form of resilience and security provides the opportunity to create new identity systems where users own the data, which remains universally consistent and cannot be destroyed (INT02; Mainelli & Gupta, 2016). Furthermore, and as noted previously, DLT/Blockchain-based systems can potentially eliminate third parties (Lehdonvirta, 2016). The disintermediation of trust[46] enabled by DLT/Blockchain is thus a key differentiator when compared with existing or legacy systems (Brennan & Lunn, 2016), which often have single-point, centralised mechanisms of verification and security.

Section take-away: The decentralised nature of DLT/Blockchain and the lack of a central point of failure could facilitate transactional systems to become more resilient and secure.

45 Oral evidence provided by Michael Mainelli to the House of Lords Select Committee on Economic Affairs Inquiry on Distributed Ledger Technologies on Tuesday, 19 July 2016.

46 In the context of DLT/Blockchain, disintermediation of trust refers to the lack of third parties (intermediaries) being needed for authenticating trust or transactions that have traditionally relied on third parties to establish trust. See Stubbs and Akmeemana (2016).

3.3.5. Empowering end-users and improving trust in transactions

DLT/Blockchain can improve trust in transactions without the need for third-party intermediation (INT05; INT10; INT11; Bogart & Rice, 2016; Brandman & Thampapillai, 2016; Deloitte, 2016; Oates & Samudrala, 2016). It can put end-users in control of their own data and transactions, as their personal information is not stored on a centralised database that is more vulnerable to being hacked (Nesta, 2017; Shackelford & Myers, 2016). Bogart and Rice (2015) argue that, since a public DLT/Blockchain provides a transparent trail of transactions, it could reduce the need for some of the existing regulatory controls on the auditing and logging of transactions, services and goods.

> *Blockchain really allows a trusted and proven mechanism to exchange data safely with external and internal bodies whilst validating integrity of data. It gives the human-to-human trust we need as a society.* [INT05]

As highlighted recently (Government Office for Science, 2016), key areas of opportunity for DLT/Blockchain are in relation to cybersecurity, authentication of trust, identification and verification of user identities, and doing so through a transparent mechanism (also INT02). Mattila et al. (2016) suggest that this opportunity could be in the form of disintermediated, censorship-resistant and tamper-proof digital platforms of distributed trust. In addition to such platforms, providing trust and security in the Internet of Things[47] is also identified as an opportunity for DLT/Blockchain. Consider for example, the suggestion by Atzori (2015) to add a computational layer through DLT/Blockchain which can allow data to be safely analysed and processed in an IoT environment.

> *I think the key driving force will be operating in environments where there are problems with trust, and especially centralised trust.* [INT02]

Section take-away: DLT/Blockchain has the capability to empower users by putting them in control of their own information, and it has the potential to improve users' trust in carrying out transactions.

3.3.6. Offering benefits for recording and reporting of data and activities through immutability capabilities

As mentioned in Chapter 1, DLT/Blockchain is able to offer an immutable record of transactions: that is, transactions cannot be deleted or altered. This immutability of DLT/Blockchain records may have additional benefits for recording and reporting of data and activities (ESMA, 2016a; McKinsey & Company, 2015; O'Dair, 2016; Oates & Samudrala, 2016; Government Office for Science, 2016; Mainelli & Manson, 2016).

Govcoin Systems: Blockchain-based system to issue benefits payments

The UK Department for Work and Pensions in conjunction with GovCoin Systems has begun piloting a Blockchain-based system to issue benefit payments through an app (Plimmer, 2016). The trial, which began in 2016, is currently in the second phase with 1000 volunteers, with plans for a more extensive roll-out later in 2017 (Green, 2016).

47 The IoT can be regarded as an extension of today's Internet, consisting of 'a pervasive and self-organising network of connected, identifiable and addressable physical objects … [that use] embedded chips and microprocessors' (Schindler et al., 2013).

Examples of potential benefits offered by immutable record of transactions include, (a) providing a clear financial trail for auditors (Deloitte, 2016; ESMA, 2016a; Mills et al., 2016; McKinsey & Company, 2015; World Economic Forum, 2016b); (b) enabling regulatory compliance through 'smart code' rather than just legal code (Government Office for Science, 2016); (c) improving transparency by providing a trail of transactions in permissionless ledgers; and (d) reducing error and fraud in data by enabling tamper-proof distributed platforms (Brandman & Thampapillai, 2016; Deloitte, 2016; Government Office for Science, 2016).

Section take-away: The immutability of DLT/Blockchain transactions offers a number of benefits, including providing a clear audit trail and reducing the propensity for fraud.

3.3.7. Enabling management of digital identity through public key cryptography

Subject to the specific requirements of a use case, DLT/Blockchain can enable efficient and cost-effective management of digital identity by relying on the use of public key cryptography as part of the solution,[48] leading to significant security improvements (INT08; Nesta, 2016). DLT/Blockchain can allow users to retain control over their personal information. This could lead to lowered cost of identity verification and more efficient ways of doing business-to-consumer (B2C) transactions (Bogart & Rice, 2016). More efficient identity management can result in improved transparency with respect to audit processes (INT01), compliance with privacy laws and regulations (Crawford et al., 2016), and compliance with know your customer (KYC)[49] and anti–money laundering (AML) processes (ESMA, 2016b; Mainelli & Manson, 2016). Improved security for users also means improved trust, which could unlock the ability for businesses to have access to more data and improve their business analytics capabilities.

Section take-away: Depending on the use case, DLT/Blockchain could enable efficient and cost-effective management of digital identity through the use of public key cryptography.

3.3.8. Providing the underlying mechanism for smart contracts and enabling smart auditing capabilities

Smart contracts implemented through DLT/Blockchain can allow self-enforcement and self-execution of mutual agreements among businesses, individuals or machines. This can help businesses and end-users reduce administrative costs and lower risks in transactions (particularly in online transactions) (Bogart & Rice, 2016; Deloitte, 2016; EBAWGEAP, 2016; ESMA, 2016a; Guo & Liang, 2016; McKinsey & Company, 2015; Peters & Panayi, 2015; Schatsky & Muraskin, 2016). Smart contracts could be crucial for connected devices that may power the future machine-to-machine (M2M)[50] economy (Huckle et al., 2016). Smart contracts can also be used for property and land registry (INT11) or for financial transactions, facilitating disintermediated transactions

48 Public key cryptography is intended to enable an individual to send messages in such a way that only the person who receives them can understand them even if the method of encryption is discovered by 'an enemy' who intercepts the messages. See Beardon (2011).

49 KYC is the process of a business identifying and verifying the identity of its clients. See PwC (2015).

50 M2M communications refers to 'technology that allows for the automatic exchange of data or information from one device to another through wired and wireless communications links… [and] could be considered to be an integral part of the IoT' (Gunashekar et al., 2016).

(Kakavand et al., 2017). Smart contracts enabled by DLT/Blockchain could be easier to audit and could help identify failures in operation and reconciliation processes more efficiently (Accenture Digital, 2016).

As DLT/Blockchain based systems become more widespread, this could enable the use of 'smart audits',[51] thereby reducing the need for third-party verification to a great extent (INT01; Schatsky & Muraskin, 2016). Such use of smart audits could facilitate improved analysis of complex value chains and reduce the possibility of fraud, including in the food sector (INT07) or the pharmaceutical (INT02; INT03; INT04), luxury items, diamond (INT01; INT02), fashion, and electronics industries (Crosby et al., 2015). This is because DLT/Blockchain technology can provide alternatives to existing anti-counterfeiting mechanisms, enable tracking of items through complex supply chains, and verify their origin and composition (Nesta, 2016).

Section take-away: DLT/Blockchain technology could be used to implement the underlying mechanism for smart contracts and enable the use of smart auditing capabilities across different sectors.

3.4. Sector-specific observations on the challenges and opportunities of DLT/Blockchain

The available evidence on the sector-specific potential and uses of DLT/Blockchain varies. It indicates that some areas, such as financial services and supply chain management, have invested more resources in proof-of-concept studies than have others areas. Several interviewees noted that highly regulated sectors, such as financial services, healthcare and pharmaceutical industries, may find the adoption of DLT/Blockchain more beneficial owing to its ability to provide an audit trail (INT01; INT02; INT04; INT06; INT10). For sectors that rely heavily on international supply chain and logistic coordination, the case for international norms and discussion between global stakeholders was seen as more important than engagement with national or regional stakeholders (INT07; INT12; INT13). Security, interoperability and identity management were seen as a priority for the healthcare sector (INT02; INT05; Krawiec et al., 2016). In addition, Krawiec et al. (2016) suggest that the following two aspects would be important for DLT/Blockchain adoption in the healthcare sector: (a) common architecture for sharing healthcare records; and (b) rules related to storing data (e.g. whether data should be on-chain or off-chain).

For the financial industry, to build a network effect that would benefit consumers and various industry stakeholders in equal measures, interoperability was deemed to be a priority (INT06; INT10; Accenture Digital, 2016). Tapscott and Tapscott (2016a) discuss specific uses and suggest that reconciliation and asset safekeeping within the financial industry would be important. Tapscott and Tapscott (2016a) also argue a role for DLT/Blockchain in the IoT to address privacy and payments-related concerns in a M2M economy. The potential role of DLT/Blockchain in addressing security issues in IoT is also mentioned by some interviewees (INT01; INT05; INT06).

In the table below, we present further details on the challenges and opportunities for DLT/Blockchain adoption – and examples of potential key stakeholders – for some notable sectors.

51 'Smart auditing' refers to automated auditing of goods and services using computing methods and additional technology, such as smart sensors and intelligent data analysis. See Rezaee et al. (2002) and Bukhsh & Weigand (2011, 2013) for further details.

Table 3: Sector-specific observations on the challenges and opportunities related to DLT/Blockchain, and potential stakeholders within each sector

Sector	Opportunities/Drivers	Challenges	Key stakeholders
Financial services (including banking and payments)	• Increased efficiency through interlinked, interoperable distributed ledgers • Faster, more efficient, and transparent handling of reconciliation and auditability in financial transactions • Reducing duration of clearing and settlement processes • Increased speed of execution in securities settlement • Decommissioning of back office infrastructure and improving efficiency of middle office functions • Cutting costs in the processing of trades in securities, trade finance, and also in payments, particularly international payments • New applications and business models based on micropayments and nanopayments	• Without interoperable DLT implementations, the current challenges of reconciliation processes cannot be resolved. • Standardisation to ensure 'straight-through processing (also known as STP)', interoperability and backward compatibility • Banking infrastructure currently limited to proofs of concept studies or pilots • Many existing implementations limited to virtual currencies.	• Merchant acquirers, card issuers and financial payments processors • Companies creating the platforms and software to facilitate the exchange of other digital assets • Financial institutions: large banks, e.g. MorganStanley, CreditSuisse • Financial regulation authorities, e.g. Financial Conduct Authority (FCA) • Technology companies building parallel banking services, e.g. Apple Pay, Android Pay • Incumbent banks and financial services organisations • Central banking authorities and financial regulators • Government • End-users / organisations representing end-user interests and rights • Payment gateway services that currently interact with banking infrastructure, e.g. PayPal • Fintech, Finserv start-ups, e.g. InnovateFinance • Consumer and investment banks, e.g. Barclays, HSBC • Anti–money laundering (AML) services (including financial audit and investigation authorities)

Sector	Opportunities/Drivers	Challenges	Key stakeholders
Music	• New business models relying on direct-to-consumer, real-time, pay-as-you-go services • Directly connecting content producers (including artists) and consumers, and aligning media consumption with price paid • Simplification of royalty payments, better data protection, and reduced costs for intellectual property protection • Reduced fragmentation in distribution of content and revenue collection	• Lack of a single interoperable data format • Multiple content databases and resulting fragmentation • Proliferation of the same content across multiple (non-interoperable) streaming platforms • Resistance from current intermediaries, and potential loss of jobs	• Music distributors • Streaming platforms, e.g. Spotify, Apple Music • Music download platforms, e.g. Apple iTunes, Google Play • Record labels/publishers, e.g. Universal Music Group, Sony Music Entertainment, Warner Music Group • Musicians and artists • Owners and distributors of existing music catalogues, e.g. Faber Music Distribution • End-users / organisations representing end-user interests and rights, e.g. Consumer Direct, National Consumer Council, Which?
Public sector	• Synchronisation of data and better coordination across multiple departments • Access and verification of data in real time • Reduced centralisation • Use of smart contracts to automatically enforce legal and regulatory compliance • Reducing fraud in government transactions	• Lack of norms (possibly standards) or platforms for DLT/Blockchain-based inter-departmental government processes and transactions • Lack of platforms for non-governmental entities (including citizens, businesses and third-sector organisations) to transact with public sector	• Government departments, e.g. Department of Work and Pensions • Government licensed registries, e.g. Land Registry for England & Wales • Government contractors, sub-contractors • Citizens/organisations representing citizen interests and rights, e.g. Citizen Advice Bureau • Businesses • Independent third-party auditors, e.g. KPMG, PwC • Government auditors, e.g. the UK National Audit Office
Healthcare	• New revenue streams and business models based on patient health data records • Reducing transaction costs through disintermediation • Enabling patients to retain control over individual data	• Vendor lock-in • Untested in large healthcare infrastructure deployments • Greater security risk in the absence of viable real-world use cases	• National healthcare providers, e.g. National Health Service • Government departments of health, e.g. Department of Health (England) • Independent/private healthcare providers • Patients/organisations representing patient interests and rights, e.g. Patients Association (UK) • Professional carers or relatives of patients • Healthcare insurers, e.g. BUPA, Aviva

Sector	Opportunities/Drivers	Challenges	Key stakeholders
Pharma-ceuticals	• Provenance important for Intellectual Property (IP) protection and recording supply chain data • Improving efficiency of drug distribution • Reducing counterfeiting	• Potential conflicts or differences with existing approaches to clinical trials, drug testing and regulatory compliance • Usage currently limited to proof of concept for pharmaceutical supply chains	• Pharmaceutical companies, e.g. AstraZeneca, GlaxoSmithKline • Pharmaceutical sector regulators, e.g. Medicines and Healthcare Products Regulatory Agency • Organisations involved in pharmaceutical distribution, e.g. Pharmaceuticals Direct • End-users/organisations representing end-user interests and rights, e.g. National Consumer Council • Healthcare professionals • Manufacturers part of pharmaceutical supply chain • Pharmaceutical retailers, e.g. Boots, Lloyds Pharmacy • Pharmaceutical industry bodies, e.g. Association of British Pharmaceutical Industry, British Association of European Pharmaceutical Distributors

Sources: Interviews; Accenture Digital (2016); Bogart and Rice (2015); Brandman & Thampapillai (2016); Brennan and Lunn (2016); Cordwell (2016); EBAWGEAP (2016); ESMA (2016a, 2016b); Government Office for Science and Technology (2016); Guo and Liang (2016); Kakavand (2016); Kakavand et al. (2017); Krawiec et al. (2016); Millar and Brunet (2015); Nesta (2016); Oates and Samudrala (2016); O'Dair (2016); O'Dair et al. (2016); Pinna and Ruttenberg (2016); Schatsky and Muraskin (2016); Shah (2016); Shelkonvikov (2016); Stanganelli (2016); SWIFT (2016); Tapscott and Tapscott (2016a, 2016b); The Economist (2016); Tierion (2016); World Economic Forum (2016b)

3.5. Conclusion

In this chapter we have presented evidence on the challenges and opportunities with regard to the wider development and adoption of DLT/Blockchain technologies. In Table 4, we summarise the key observations with regard to these challenges and opportunities. Clearly, the opportunities for DLT/Blockchain are vast; however, the challenges remain significant.

Furthermore, the DLT/Blockchain landscape is complex and varied, and therefore not all challenges and opportunities will be applicable to all DLT/Blockchain designs. The next chapter builds on these observations to present the prospects for developing standards in relation to DLT/Blockchain technologies.

Table 4: Key challenges and opportunities in relation to DLT/Blockchain

Challenges	Insufficient clarity regarding and inconsistent understanding of the terminology, combined with the perception that DLT/Blockchain is an immature technology, poses challenges to wider adoption of DLT/Blockchain. The potential high costs of initial implementation, perceived risks associated with early adoption of DLT/Blockchain, and possibility of disrupting existing practices may pose significant challenges to businesses. The lack of clarity about the improvements the technology offers over existing solutions may delay its adoption by businesses. In the absence of widespread DLT/Blockchain adoption, the broader economic impact of the technology in the medium and long term is difficult to determine. Because of the nascent nature of the technology, there is a lack of clarity with regard to the governance of DLT/Blockchain systems. There is uncertainty related to the way current regulatory frameworks would apply to DLT/Blockchain and the changes that might be needed in the event of wider DLT/Blockchain adoption across sectors. The emergence of multiple non-interoperable DLT/Blockchain implementations could lead to a fragmented ecosystem and limit widespread adoption. Potential security vulnerabilities and concerns about data privacy are seen to be significant challenges, particularly if users are entrusting DLT/Blockchain solutions with personal data. Safeguarding data integrity and ensuring strong encryption mechanisms are perceived as key challenges to the wider adoption of DLT/Blockchain. The distributed nature of DLT/Blockchain systems and the need for increased computing power could potentially result in high energy consumption and associated costs. Key obstacles remain with respect to the legal enforceability of smart contracts, primarily related to the lack of clarity regarding the definition of smart contracts and how to implement them through DLT/Blockchain.
Opportunities	By automating processes and reducing the need for third-party intermediaries, DLT/Blockchain solutions have the potential to provide significant efficiency gains and cost savings for businesses and end-users. The adoption of DLT/Blockchain technologies could potentially enable new revenue sources for businesses. The growth of the DLT/Blockchain ecosystem could result in the creation of novel business and economic models, such as new forms of business collaboration and cryptocurrencies. The decentralised nature of DLT/Blockchain and the lack of a central point of failure could facilitate transactional systems to become more resilient and secure. DLT/Blockchain has the capability to empower users by putting them in control of their own information, and it has the potential to improve users' trust in carrying out transactions. The immutability of DLT/Blockchain transactions offers a number of benefits, including providing a clear audit trail and reducing the propensity for fraud. Depending on the use case, DLT/Blockchain could enable efficient and cost-effective management of digital identity through the use of public key cryptography. DLT/Blockchain technology could be used to implement the underlying mechanism for smart contracts and enable the use of smart auditing capabilities across different sectors.

4 The prospective role of standards to support DLT/Blockchain

Summary box: Key points related to the prospective role of standards to support DLT/Blockchain

- Standards could play an important role in ensuring interoperability between multiple DLT/Blockchain implementations and, in doing so, could help reduce the risk of a fragmented ecosystem.
- Using standards to establish a stronger consensus on consistent terminology and vocabulary could improve understanding of the technology and help progress the market.
- Establishing standards to address the security and resilience of, and the privacy and data governance concerns related to DLT/Blockchain could help create trust in the technology.
- Standards could play a role in digital identity management and foster end-user trust in the technology.
- There are potential opportunities for standards to play a role in sectors where provenance tracking is important.
- It may be too early to think about standards related to the technical aspects of DLT/Blockchain.

4.1. Introduction

In the previous chapter, we discussed the challenges and opportunities facing the development and wider adoption of DLT/Blockchain. This chapter synthesises the challenges, opportunities and issues in order to assess the role that standards could play in supporting DLT/Blockchain. In doing so, we identify several areas for action where we believe it would be valuable to carry out further constructive dialogue related to the potential role of standards to support the growth of the DLT/Blockchain ecosystem in the UK.

> *I think the main obstacle is convincing UK stakeholders why they need [DLT/Blockchain].... A significant barrier to adoption … is change. People have to change their way of working and their investments, so it will be quite hard. Trusting the technology to ensure that it's scalable will be key, and reliability has to be proven.* [INT05]

The list of topics we have highlighted is not definitive, and our intention is not to be prescriptive; rather, the list is a spectrum of wide-ranging topics that would benefit from further exploration and consideration by the DLT/Blockchain community. While the focus of the study has been on the UK perspective, we note that some of the insights we have presented in the discussion below are likely to also

The role of standards in the context of innovations

Standards may have positive impact on innovation by creating 'common vocabularies and agreed definitions of terms, increasing the confidence of investors and consumers, increasing the speed at which companies can bring their products to market and reducing the technical barriers to trade' (Allen & Sriram, 2000; van Merkerk & Robinson, 2006; Swann, 2010, in O'Sullivan & Brévignon-Dodin, 2012). Standards may encourage interoperability and cooperation, and introduction of standards can lead to enhanced economies of scale (Tait & Banda, 2016). Standards may be introduced in the early stage of the technology life cycle, as a way to encourage development of a new technology, or at a later stage, to go with the adoption of the technology, leading to new opportunities and improved efficiency (O'Sullivan & Brévignon-Dodin, 2012).

The appropriate level and type of standardisation is likely to be dependent on the stage of the technology emergence (O'Sullivan & Brévignon-Dodin, 2012). Premature standardisation could lock innovation, which could potentially affect the adoption of other technologies; conversely, delayed standardisation in key stages of technological development may result in economic inefficiency (Tassey, 2000, in O'Sullivan & Brévignon-Dodin, 2012). Standards can result in premature selection of technologies and may be potentially constraining if they are overly prescriptive (Tait & Banda, 2016).

have relevance for the global DLT/Blockchain community. The findings presented here are based on a triangulation of the evidence from the desk research and stakeholder interviews against the discussion at the internal workshop to identify the prospects for standards. In the next section, we discuss our key findings, and we follow this with a short discussion on the role that the UK could play in supporting the technology by potentially developing standards in different areas related to DLT/Blockchain.

> *I think the technology is quite immature. So I think it will take a long time while industry and solutions themselves develop. But I think it's important that we put a framework in place now. As the technology is quite nascent and will change quite rapidly, so will stakeholders' understanding about technology. But it's a technology that is predicated on collaboration, and interoperability needs to be achieved, and people need to be speaking the same language and have the same understanding, so I really think standards have a strong role to play in driving forward adoption.* [INT06]

4.2. The potential role of standards in supporting DLT/Blockchain

Based on our analysis of the literature and the interviews, we have identified several priority areas for further consideration in which the development of appropriate standards could potentially overcome the challenges and harness the benefits and opportunities in relation to DLT/Blockchain. Each of these topics is discussed in turn below. Before we examine these topics in detail, in the box below we highlight a selection of quotes from the stakeholder interviews we conducted to contextualise the discussions related to the prospective role of standardisation activities in the DLT/Blockchain ecosystem.

The potential role of standards to support DLT/Blockchain: Views from the ground

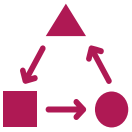
> *I think all the bodies will start looking into standards because it just makes sense for wider adoption. Having some kind of standards would make people a little less scared. Then it would also be useful for everyone knowing that it's compliant with that standard, so provides these features, etc. There's a lot of confusion, so anything that helps with that is useful.* [INT08]

> *I think the current challenge is the lack of standards; people are not ready to commit millions of pounds in changing their system or using DLT/Blockchain.* [INT05]

> *Based on what I've seen, I would say, yes, this is the right time [for developing standards] and … where I see the risk is across the whole of the system. I would say that risks are where there is a hand-off from one organisation to another or one geography to another or an area to another; this is where the risks are and this is where standards would be needed the most.* [INT07]

> *For the moment, there is too much 'hype' around blockchain, and actors are looking at the context rather than at what the technology can actually do. It would be easier to come back to the main function of Blockchain before starting to think about standardisation ...* [INT11]

> *I think standards are going to be really important to some issues related to portability and interoperability. These are going to be really important to give some kind of confidence as to how this would work and ensure that by starting there is some resilience in the systems.* [INT02]



4.2.1. Standards could play an important role in ensuring interoperability between multiple DLT/Blockchain implementations and, in doing so, could help reduce the risk of a fragmented ecosystem

The main prospect for standardisation mentioned by the majority of interviewees (INT01; INT04; INT05; INT06; INT07; INT09; INT10; INT13) is to ensure interoperability between the multiple implementations of DLT/Blockchain that currently exist or that will exist in the future. As the technology finds broader use cases, it is crucial that the various systems be able to 'talk' to each other using a 'language' that is universally understood (INT01; INT04; INT05; INT06; INT08; INT09) and to ensure the integrity of data exchanged (INT05).[52] In particular, interoperability could be important in scenarios that may require permissioned and permissionless DLT/Blockchain implementations to 'talk' to each other (INT05).[53] Standards addressing interoperability could help reduce the risk of fragmentation in the DLT/Blockchain landscape, where numerous use cases, applications and systems otherwise would not be able to interact with each other. Standards could also help to establish interoperability within and across sectors as use

52 For example, so that data are not corrupted when transferred from one ledger to another.

53 For example, in cases where permissioned ledgers would need to talk to permissionless ledgers, and vice versa.

cases develop to find cross-sector applications, thus helping to create a competitive market (INT04; INT05; INT07; INT09; Mills et al., 2016; Lamarque, 2016; Oates & Samudrala, 2016).

> *One key thing that has to work for [DLT/Blockchain] to take off is that the technology has to be interoperable. Otherwise, it won't work. That's where standards should be concentrated.* [INT10]

Interoperability would also be needed when it comes to the interaction of the new DLT/Blockchain architecture with legacy systems (INT01; INT04; INT05). This would enable businesses to make plans for transitioning existing systems, and it would also facilitate the newer systems to interact with a wider network as well as with the previous architecture in place at third-party stakeholders' systems and infrastructure (INT04; INT05; INT09). For example, in practice, market participants would need to agree on the messaging/communications standards for financial transactions to interact with the distributed ledger by relying on standards that would span the entire industry (Oates & Samudrala, 2016).

> *Standardisation is a first step to [realise Blockchain opportunities], because we need all Blockchains to talk to each other and we need other networks and systems to talk to each other and to Blockchains.* [INT05]

Despite the consensus that emerged from the participants we interviewed, the actual role of interoperability and the extent to which interoperability would need to be achieved is not yet clear. Standards for interoperability would need to be coherent and proportional to the objectives of the stakeholders to ensure that innovation can flourish (INT01). Two interviewees suggested that it would not be necessary for all applications to obey the same protocols for data transactions, but that standards would be relevant in ensuring the interaction between 'systems' (e.g. countries, manufacturers, industries) and between the new architecture and legacy systems (INT01; INT04). This position is echoed by an article in the literature (Mainelli & Mills, 2016) in which more than 60 individuals representing developers, the legal profession, accountancy practices, the financial services industry, regulators and standards agencies were surveyed. Despite agreeing on the role of interoperability in standards, the participants interviewed for the Mainelli & Mills (2016) report suggest that interoperability may be a low priority for standardisation. Similarly the SWIFT Institute (2016) contends that in the long term full technical standardisation may be more useful than interoperable standards that cater to different implementations.

4.2.2. Using standards to establish a stronger consensus on consistent terminology and vocabulary could improve understanding of the technology and help progress the market

The perceived immaturity of the technology and the resulting lack of clarity over the various terms used in the DLT/Blockchain community in relation to DLT/Blockchain (including the use of 'DLT' versus 'Blockchain') were seen as potential challenges to the wider adoption of the technology. The lack of understanding of what DLT/Blockchain is and what it can do are perceived as obstacles to growing the market (INT02; INT14). In this regard, several interviewees suggested developing a broader consensus on the definition and terminology for DLT/Blockchain (INT02; INT04; INT06; INT09; INT13). Similar observations are made in the literature (Mainelli & Mills, 2016), stating the need to adopt taxonomies and performance standards that contain outcome-focused sets of definitions and categorisations in relation to DLT/Blockchain. Mainelli (2017) has also argued the need for outcome-focused

definitions as a way for regulators and actors in the ecosystem to assess DLT/Blockchain on outputs 'rather than the mechanics of how they operate'.

> *I think that is one of the big things where standards would be needed is that they could help make a stronger taxonomy about what the different terms actually mean. This would ensure people are speaking the same language.* [INT12]

However, standardising terminology could prove to be a difficult process, as a number of companies developing systems, protocols and services based on DLT/Blockchain already have their own definitions and implementations.[54] One interviewee noted that it might be difficult to reconcile these differences in the near term (INT04). Furthermore, the use of DLT/Blockchain implementations and their potential role in a business could vary significantly depending on the business sector. Thus, instead of attempting to create a fully standardised and agreed-upon list of definitions, a simpler framework and guidance about the technology, signifying, for example, how it could be used (including good-practice advice) emerged as a possible alternative (INT04; INT09). Instead of attempting to develop a canonical definition of terms, a 'glossary' of terms and definitions which could contribute to further clarity on understanding the technology among stakeholders has also been suggested as a way forward (INT02).

4.2.3. Establishing standards to address the security and resilience of, and the privacy and data governance concerns related to DLT/Blockchain could help create trust in the technology

As we noted in Chapter 3, organisations relying on DLT/Blockchain would need to carefully consider the security and integrity of end-users' data stored on the ledger. For example, the decentralised nature of DLT/Blockchain and the distributed access and management rights across multiple nodes in the network could present a serious security risk, with malicious entities potentially having multiple 'back doors' through which to attack the system. In this regard, several interviewees suggested that standardisation would be needed to ensure security and resilience of the networks and to facilitate trust, and that this would be important in determining the wider adoption of the technology in the medium to long term (INT02; INT05; INT08; INT10). Furthermore, standards on data governance were identified as being key to ensuring that the data held on DLT/Blockchain systems cannot be easily manipulated and that their integrity is protected, and that in doing so, standards would mitigate data privacy concerns (INT02; INT05; INT08; Mainelli & Mills, 2016). Standards related to data governance could cover how individuals' records are maintained, as well as data ownership and data transfer principles (Mainelli & Mills, 2016). Mainelli (2017) furthers this argument and presents the need for data governance and liability standards to carefully take into account 'the civil liberty implications of data aggregation,

54 A useful example would be three cryptocurrency-related platforms – Bitcoin, Ethereum and Ripple. Although the Bitcoin and Ethereum platforms are both based on DLT/Blockchain, their purposes are different. Bitcoin is a payment network. Ethereum allows any kind of data to be stored on DLT/Blockchain and provides an agreement (i.e. smart contract) on how that data will be updated. Both are intended to be trustless systems. Although often seen as competing systems, Bitcoin and Ethereum are intended for different purposes. In contrast, Ripple provides a marketplace for trust – giving the end-user control over whom they trust. In addition, Ripple uses a somewhat different mechanism for ledger security, called trust graph. For more details, see https://bitcoin.org/en/faq; https://ethereum.org/ether and https://ripple.com/technology/

sharing and mining'. Thinking about other aspects of governance, Kakavand et al. (2017) highlight the need for standards on governance to foster the implementation of DLT/Blockchain, while enhancing the resilience of the system to privacy and cybersecurity risks. In this regard, one interviewee (INT08) suggested that: (a) standards on data governance could prove to be essential to cultivate end-user and business trust in the technology and foster its adoption; and (b) data governance standards can potentially play a role in the way DLT/Blockchain works in terms of consensus and control mechanisms, as well as audit processes.

Standards on data governance could also be aimed at security to protect end-users' data (INT08; INT12). In addition, two interviewees contended that standards would enable protocols to be defined for encryption or how to handle user nodes, for instance, and thus help to embed cybersecurity controls into DLT/Blockchain services (INT05; INT08; Brandman & Thampapillai, 2016). The development of standards in these areas could also serve to confirm the authenticity of transactions and, consequently, to serve as another enabler of trust and resilience in the system (INT07). However, given that the technology is still at a nascent stage, when thinking about developing standards, it may be necessary to exercise due diligence (including the possibility of building on existing standards) on the role that standards could play and to conduct further research in order to understand the spectrum of activities that security standards could focus on.

> *I think anywhere where data is being used, consumed, shared and distributed, standards are important from a basic control point of view and security standpoint.* [INT12]

4.2.4. Standards could play a role in digital identity management and foster end-user trust in the technology

In order to foster end-user trust in the technology, allowing end-users and businesses to manage and verify whom they are transacting with was cited as an important area for standards (INT05; INT10). However, a number of existing processes (including several proprietary processes) for authentication and digital identity management exist.[55] This suggests that, in order for standards related to digital identity to be useful, the nature of identities (i.e. sovereign, national or worldwide identities) being targeted and the objectives of the authentication process would need to be carefully defined.

Some interviewees drew parallels with the Internet/web and reflected on the erosion of end-user trust in various Internet/web platforms (INT05; INT10). For DLT/Blockchain to achieve cross-sectoral adoption, they argued, it needs to have robust norms to protect end-users' digital identity. One interviewee (INT10) contended that, given the distributed nature of the technology, schemes for authenticating not only the platform providers but also the other end-users in the system would be crucial to build trust in the system (see also the discussion on authentication and interoperability in Government Office for Science, 2016). This would be notably different from the current mainstream security/trust mechanisms, in which end-users authenticate themselves while interacting with a central authority (e.g. public sector or business) through the web. For this reason, another interviewee posited that for DLT/Blockchain implementations, digital identity authentication may need to

55 E.g. 3SKey for Banks by SWIFT, Authentication schemes provided by CA Technologies, or open standard, decentralised authentication protocol such as OpenID.

mirror one-to-one human trust mechanisms in the offline world (INT05). This suggests that existing security, e-identity and e-signature standards may need to be revisited to reflect the operational complexities of the future DLT/Blockchain systems.

Standards could help manage risks associated with identity, liability, responsibility and compliance from a cross-sector perspective (Mainelli & Mills, 2016). In particular, authentication of digital identities for financial transactions implemented through DLT/Blockchain-based solutions (Shrier et al., 2016) to ensure KYC/AML compliance may differ from the existing processes. This highlights the importance of being able to assess and verify transacto/transactee identities in a DLT/Blockchain implementation (INT01) and of the possible need for changes to existing standards to reflect evolving business practices. Standards could also play a role in informing the end-users about how specific DLT/Blockchain solutions/platforms rate on such features as 'privacy by design', strength of hashing approaches used, and measures to protect their digital identities. In this context, one interviewee (INT02) suggested that standards may have to be specifically developed to address requirements of the sectors in which a DLT/Blockchain solution is being implemented.

4.2.5. There are potential opportunities for standards to play a role in sectors where provenance tracking is important

Several interviewees mentioned provenance and DLT/Blockchain's capability to deliver provenance tracking (i.e. the ability to provide a complete trail of transactions) as essential to unlocking its innovation potential (INT02; INT05; INT06; INT10; INT11; INT12). Particularly in sectors which trade in physical goods, DLT/Blockchain's provenance capabilities would be crucial to effectively linking the digital identity (and history) of the product with its physical attributes to provide tracking of goods (Greenspan & Zehavi, 2016). Such sectors as pharmaceuticals (INT02; INT10),[56] supply chains for single-source products (INT07),[57] and diamond trading and transfer (INT01; INT02; INT11) could potentially benefit from standards (including sector-specific standards where applicable) which provide a way for different regional and national stakeholders to verify, transfer and transact products and services across the entire lifecycle of those products and services.

The key to effectively implementing provenance tracking would be the data – and how data exchange across multiple stakeholders (which could be either humans or automated systems, i.e. machines) takes place (INT01; INT11). This suggests an opportunity for standards, particularly in terms of the type of data, how it should be stored, possibly cryptographic requirements and levels based on the type of product, and also the length of time the data could be and should be stored (INT01). An additional aspect for consideration would be the tokenisation

56 Possible benefits suggested but yet to be fully demonstrated in relation to the pharmaceuticals industry are anticounterfeiting measures, limiting distribution of fake drugs, and more efficient and effective drug testing and piloting (INT02; INT07).

57 A useful example is the pilot of the Provenance system for tuna fisheries in Indonesia and across the wider stakeholder supply chain. See Provenance (2016).

mechanisms[58] (Christidis & Devetsikiotis, 2016) and whether the complexity of the transactions permits the use of DLT/Blockchain effectively (Greenspan, 2016). However one interviewee suggested that before the widespread use of DLT/Blockchain for provenance tracking is considered, the norms for DLT/Blockchain-based supply chain transactions would need to be established (INT11). The use cases of DLT/Blockchain for provenance tracking have been limited to small pilots, and the extent to which DLT/Blockchain-based solutions would scale is not fully established. This suggests that further research on the use cases and ontologies that could contribute to a robust DLT/Blockchain design[59] for provenance tracking may be required before a discussion takes place on the role of standards.

4.2.6. It may be too early to think about standards related to the technical aspects of DLT/Blockchain

Currently, there is limited consensus on the potential for standards on technical aspects (e.g. format in which data is stored, size of blocks, communications protocols) and their impact on DLT/Blockchain adoption. Some interviewees (INT01; INT04; INT09) questioned the need for a standardised approach to DLT/Blockchain technology itself. They suggested that such an approach would be suitable only for particular applications within DLT/Blockchain and would not necessarily be adopted by others. Developing and adopting standards on technical aspects could restrict applications from being developed in the future (INT01; INT09). Such standards may not prove useful, since the technology is still under active development and its use cases are still evolving (INT09).

> *I don't think we should be setting standards about the technical aspects. High-level standards on what those standards should look like – for example, interoperability and interaction with other providers – but don't set standards about how many characters should be in this field.* [INT10]

Nevertheless, a contrasting view was expressed by one interviewee, who suggested that standards on technical aspects may be needed to improve the performance of the technology, especially when it comes to transactions processing time (INT02). Furthermore, standardisation of technical aspects, such as standard messaging structure, could be required, for instance, in financial services, in order to harmonise the information to be exchanged to, ultimately, satisfy KYC requirements (INT04). The same interviewee suggested that a cautious approach should be adopted when it comes to technical standards, as not all technical aspects may need to be standardised.

Finally, a crucial perspective in the context of developing (or not developing) standards on technical aspects is the role of the markets in supporting the growth of the technology. Considering the relative immaturity of the technology, aiming for standards on technical aspects could prove counter-productive at this stage. Interviewees (INT03; INT04; INT10) emphasised that markets and industry-based stakeholders could play a stronger role in relation to standards that focus on technical aspects. This position is reflected in an article in the literature which suggests that consensus

58 Tokens are entries on the ledger. Tokenisation mechanisms refer to the way tokens are created, maintained and exchanged. See Lewis (2015).

59 See Kim and Laskowski (2016) for a more detailed discussion on ontologies that could enable provenance tracking using Ethereum. See also Kim (2016).

on standards on technical aspects will emerge 'naturally' as some software becomes dominant, with technical standards emerging from their application programming interfaces (APIs) (Mainelli & Mills, 2016).

4.3. UK-specific observations on the development of DLT/ Blockchain standards

In this section we cover some initial observations in the context of the role that the UK could play as the prospects for DLT/Blockchain standards develop further and the interests of stakeholders become clearer. This discussion is primarily informed by the insights provided by the experts we interviewed, and we acknowledge that further research is needed to validate and build on these observations. Where relevant, evidence from the desk research has been cited. Highlighting the extent of consensus building that would be essential to any future standards-based activity, this discussion indicates that further stakeholder engagement will be critical in order to inform UK's approach to standards to support DLT/Blockchain.

4.3.1. The influence of the UK's position as an important financial hub

London's position as a financial capital and a hub for Fintech start-ups was mentioned by several interviewees as being potentially relevant when the future development and adoption of DLT/Blockchain-based platforms and solutions is considered (INT03; INT04; INT05; INT06; INT10; INT12; INT13; see also World Economic Forum, 2016a; Yeandle et al., 2005). This is partly an acknowledgement of the extent to which the financial services (including banking) industry has been at the forefront of the piloting, testing and developing of solutions for DLT/Blockchain (INT03; INT05; INT10; INT14). When comparing the UK landscape and the overall international landscape, one interviewee (INT14) spoke highly of the strength and quality of the technology workforce in the UK in relation to the financial services sector.

The willingness of UK businesses to experiment with emerging technologies and potentially disruptive innovations was also cited as a strength by more than one interviewee (INT05; INT10; INT14). Given a relatively vibrant Fintech sector and the availability of start-up funding in London (Ernst & Young, 2014), the UK is well positioned to play a notable role in influencing the discourse on standardisation of DLT/Blockchain. This could be important for the UK's participation in future international standards-making activities, particularly if a sector-specific approach emerges for DLT/ Blockchain standards.

> *London is a pre-eminent global hub for finance. DLT/Blockchain can have a global application. The UK has an opportunity for export.* [INT04]

4.3.2. The advantages of a market-led regulatory regime in the UK

The UK regulatory regime was cited as an advantage by several interviewees (INT05; INT06; INT10; INT12; INT13). In particular, the ability to balance market-led activities against enabling competition to thrive was mentioned as a strength for the UK (INT05; INT10). Since regulation varies significantly depending on the sector, the evidence in the literature limits the extent to which a viable assessment of the overall UK regulatory regime can be presented.[60] However, the UK approach to technology regulation in particular is seen to be more

60 For a discussion of the UK regulatory regime from a 'commerce' perspective and for a comparison with the EU regime, see Ambler et al. (2010) and Ambler & Chittenden (2009), respectively.

effective due to its focus on outcomes[61,62] (INT10). For example, the 'forward-looking' approach taken by the Bank of England and the FCA, not only on cryptocurrency but also on DLT/Blockchain as the underlying technology, was noted as being a factor that would strengthen the wider DLT/Blockchain ecosystem in the UK beyond financial services (INT05; INT06). A specific example of this pragmatic, market-led approach is the FCA's 'regulatory sandbox', an initiative by which organisations can pilot innovations (such as products, technologies or delivery mechanisms) in the 'real world' without having to meet the full regulatory requirements for a mature product, but while ensuring protection for end-users (INT05; INT10; FCA, 2015). This has provided assurance to companies, and as one interviewee noted, has helped foster the development of DLT/Blockchain in the UK by facilitating the testing of a product (INT03). Consider, for example, how, of the 18 innovations selected in 2016 for the first sandbox cohort, 9 were DLT/Blockchain-based technologies (FCA, 2016).

The tacit knowledge gained through such initiatives can provide the UK with a distinctive advantage if the use of standardisation to influence DLT/Blockchain adoption is considered. This could be particularly crucial if a cross-sectoral approach to standards on DLT/Blockchain were to take precedence.

> *"The UK has a fairly strong position, largely driven by organic growth of the industry to solving private sector needs. Many FinTech firms are trialling the use of DLT, for example, through the regulatory sandbox. Local councils are also beginning to drive the way forward in the use of DLT for government services.* [INT15]

4.4. Conclusions

The evidence from the literature review and interviews on the role for standards suggests the need for a measured approach to developing standards in the near and medium terms. Although a majority of interviewees agreed that standards have a role to play in shaping the development and adoption of DLT/Blockchain in the long term, most of them were also of the opinion that additional time may be needed to enable a more informed approach to deciding which aspects and uses of the technology should be prioritised (INT02; INT03; INT04; INT05; INT06; INT10; INT12; INT13). Similar analysis is presented in the literature, with De Meijer (2016), and SWIFT Institute (2016) suggesting that further clarity is needed on the overall technological landscape for a stronger case for standards to emerge. At a House of Lords Select Committee on Economic Affairs' Inquiry on Digital Ledger Technologies conducted in July 2016, it was suggested that the case for standards would become clearer after commercial applications are available more widely to the industry and the market is more evolved in terms of the use of DLT/Blockchain (The Select Committee on Economic Affairs, 2016).[63]

In arguing for a better prospect for standards in the medium and long term, one interviewee (INT11) suggested that once the technology is

61 Although it is limited to the financial industry perspective, for an interesting discussion on what constitutes effective regulation, see Isencko et al. (2016).

62 For details of the UK approach to regulation, particularly the emphasis on outcomes as part of non-economic regulation, see Department for Business, Innovation & Skills (2014) and Department for Business, Energy & Industrial Strategy (2016).

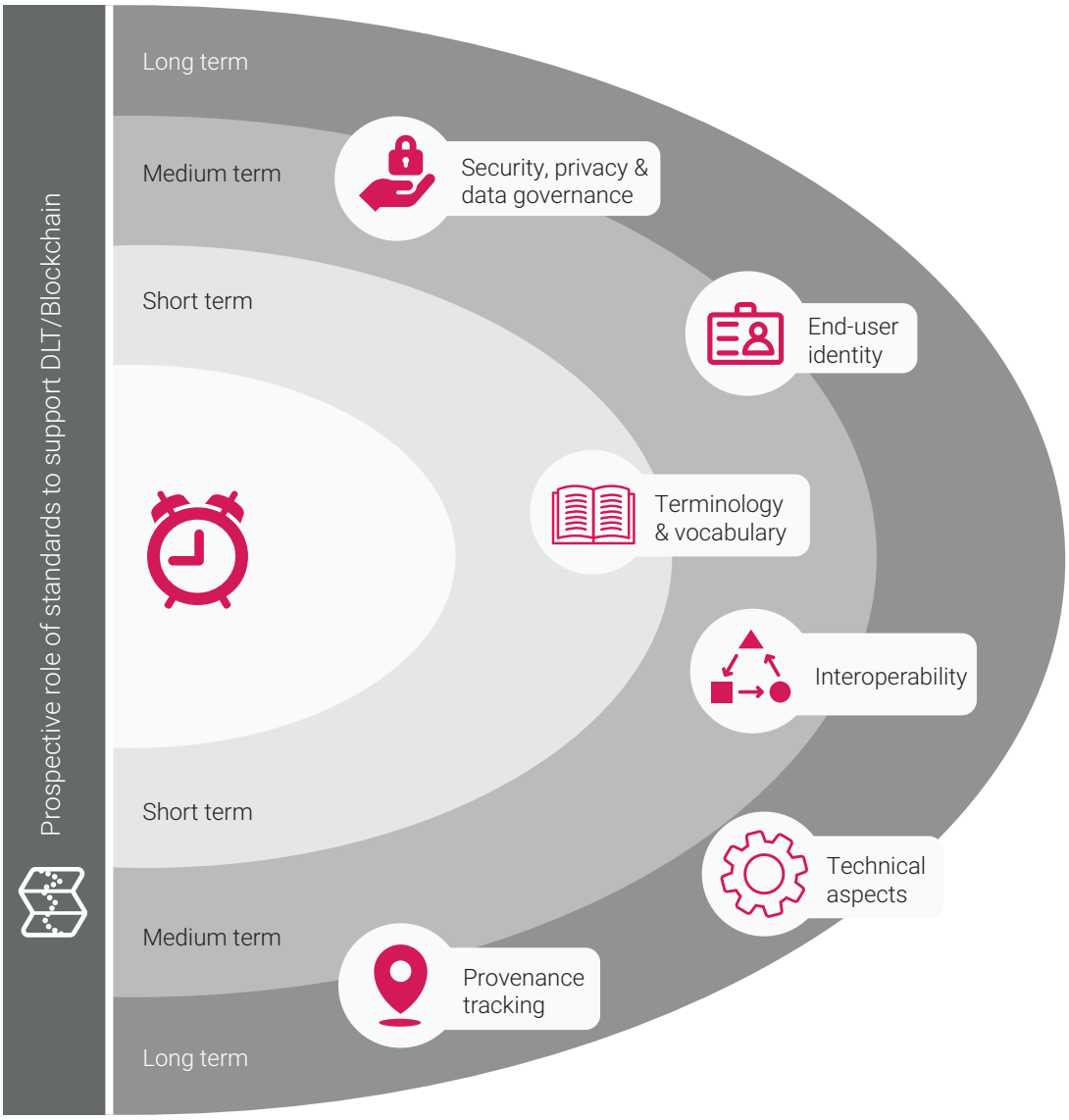
63 Oral evidence provided by Simon Taylor in the House of Lords select committee on Economic Affairs inquiry on Distributed Ledger technologies on Tuesday, 19 July 2016.

more mainstream and a better understanding of its strengths and weaknesses emerges, the priorities for standards will become clearer. While discussing medium-term possibilities, another interviewee (INT10) emphasised interoperability as a key outcome to be targeted. It was also suggested that, given the likely disruptive influence of the technology, some aspects (e.g. technical aspects of DLT/Blockchain) of standardisation may develop in a longer time frame than others (INT10). The same interviewee suggested that in the near term, initiating and fostering a discussion with various stakeholder groups on standards could be crucial to developing a shared understanding of their needs.

Our analysis suggests that standards could prove to be important to the wider development and adoption of DLT/Blockchain. We have identified several areas where standards could – to varying degrees – potentially overcome the challenges and could support innovation, growth and competitiveness in the DLT/Blockchain ecosystem. Some of these areas, such as standards in the context of provenance tracking and management of digital identities, are more specific than others (e.g. standards to ensure interoperability and consensus on terminology). Generally, standards were seen as being important to facilitate trust and support innovation and thus the development of new applications. In addition, standards were also seen to have a role in coordinating and 'defragmenting' a market constituted of 'piecemeal initiatives' and to 'unlock network effects' (Digital Catapult & Open Data Institute, 2016; also INT01; INT09; Mainelli & Milne, 2016). This would help to build market confidence and to allow the coordination of various actors within and across sectors to foster convergence (INT09). The process of standardisation enables stakeholders to 'stop and think' about the use of technology to solve social problems and to enable 'legibility' (Narayanan as quoted in Schepers 2016).

As mentioned previously, the priority areas we have proposed in our analysis are not intended to be definitive or prescriptive. The aim is to provoke further exploration of these topics in a collaborative manner by stakeholders within the wider DLT/Blockchain community about the potential role of standards in supporting the development and adoption of the technology. In Figure 5, we illustrate these priority areas and provide an approximate indication of the relative timelines for potentially developing standards in relation to these areas. To reiterate, our analysis suggests that, despite the consensus on the overall importance of standards to support the growth of DLT/Blockchain, views differ with regard to the areas for potential standardisation and the timelines for developing and implementing the standards. The timelines shown in Figure 5 are indicative at this stage and are based on our examination of the DLT/Blockchain ecosystem established through the rapid scoping study we have undertaken. Further research and continued engagement with the stakeholder communities that would input to them is needed to establish a better understanding of the timelines for developing standards.

Figure 5: Areas where standards could potentially play a role in supporting DLT/Blockchain and an indication of the prospective timelines[64]



Source: RAND Europe

64 Note that the 'vertical axis' in the figure does not carry any meaning; that is, provenance could just as easily go at the top of the visualisation as at the bottom. What the figure attempts to present is the relative position of the different topics in relation to the 'time axis'. For example, to help progress the market, the DLT/Blockchain community could, in the short term, focus on developing standards related to establishing a consensus on consistent terminology. In the medium to long term, after having addressed issues related to inconsistent definitions and terminology, standards development could be focussed on other areas, such as security, privacy and data governance, and interoperability.

5 Concluding remarks

DLT/Blockchain is an exciting new area of technological innovation that has significant potential. Over the past few years, there have been a growing number of DLT/Blockchain-related activities across different sectors with potential impact on industry, government and society. Using a mixed methods approach involving a focused review of the literature and interviews with a selected set of stakeholders, we analysed the current landscape of DLT/Blockchain developments and closely examined the issues that are central to the development of DLT/Blockchain.

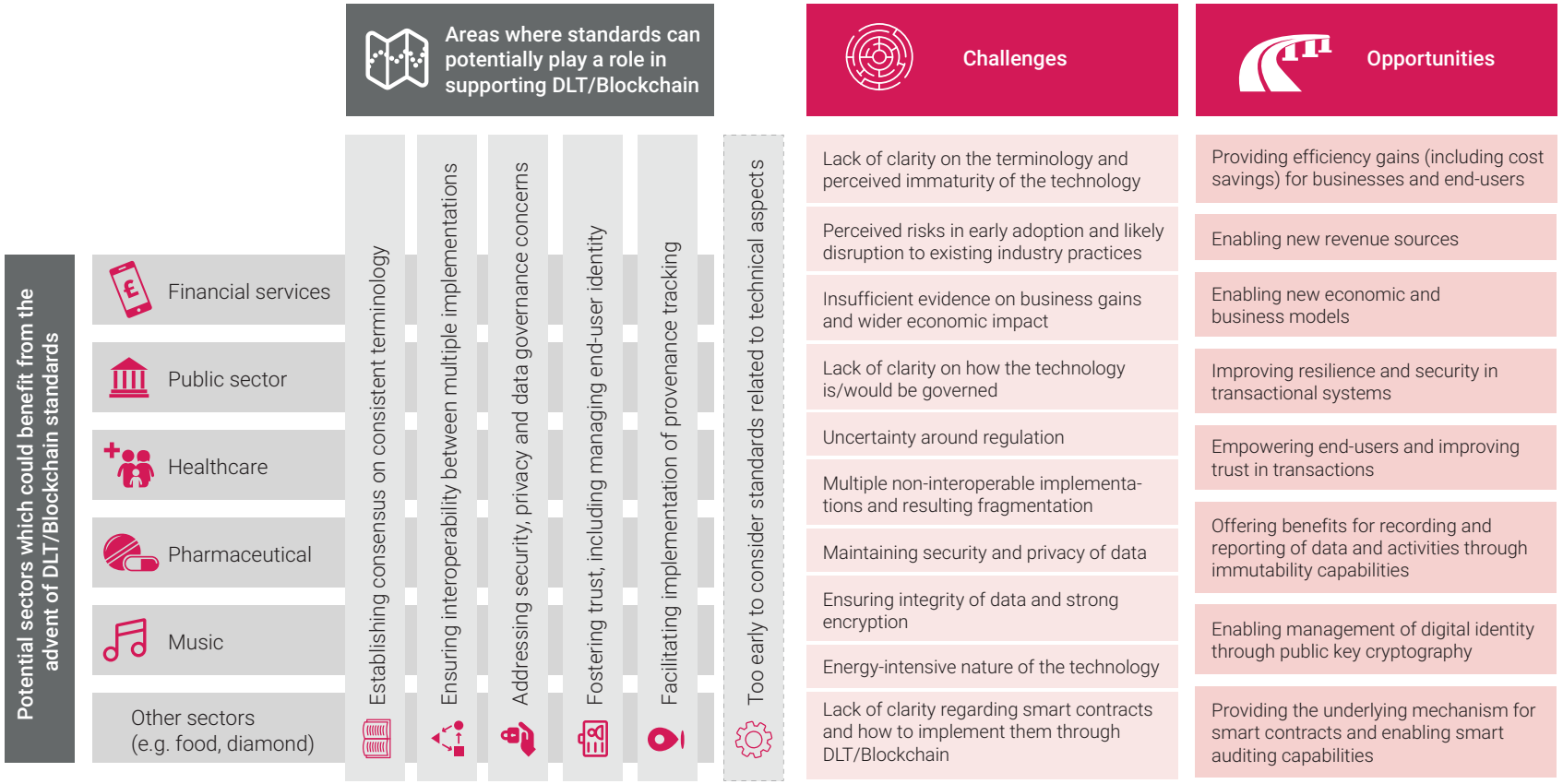
Our analysis suggests that the opportunities arising from DLT/Blockchain are vast; however, there are also many challenges to contend with. Although it is a field characterised by rapid change and uncertainties, steps can be taken to better understand the current realities, drivers of change and impacted sectors. In this regard, the analysis in this report notes that there is scope for standards to play a role in supporting the technology, for example, to act as an enabler to create the necessary space for the development and adoption of Blockchain/DLT and its market.

However, as is generally the case with emerging technologies, the timing for developing and introducing standards (which may build on existing standards) is critical. An intervention that occurs too early could run the risk of locking in stakeholders to solutions that, in the long run, might not be the most effective and, in the process, potentially stifle innovation. A standards strategy that occurs too late with regard to a technology potentially risks missing opportunities to maximise the benefits the technology could deliver.

The analysis we have undertaken aims to provide a rounded perspective on the evidence base that could be used for future discussion and decision making related to the role for standards to support DLT/Blockchain. In Figure 6, we show an all-encompassing visualisation that depicts: (a) the areas we have identified where standards could play a role in supporting DLT/Blockchain, (b) the potential sectors which could benefit from the advent of DLT/Blockchain standards, and (c) the overarching challenges and opportunities identified in relation to DLT/Blockchain.

> *Developing standards is useful because the development for the acceptance by the BSI or ISO community will take some time. I think it's important to start considering this now. What you don't want to do is … stifle innovation, nor do you want to release standards before fully understanding the direction of the standards. It is important to get the conversation started right now.* [INT02]

Figure 6: Visualisation depicting (a) the areas where standards could play a role in supporting DLT/Blockchain, (b) the potential sectors that could benefit from the advent of DLT/Blockchain standards, and (c) the challenges and opportunities identified in relation to DLT/Blockchain[65]



Source: RAND Europe

65 Note: This visualisation provides a very high-level 'summary' of the analyses presented in the report. The DLT/Blockchain landscape is complex and varied; therefore, not all the areas for standards and not all the challenges and opportunities identified in our study will be applicable to all DLT/Blockchain designs and sectors.

Bibliography

Accenture. 2016. *Blockchain-Enabled Distributed Ledgers: Are Investment Banks Ready?* New York: Accenture. As of 14 March 2017: https://www.accenture.com/t20160203T200922__w__/us-en/_acnmedia/PDF-6/Accenture-Blockchain-Enabled-Distributed-Ledgers.pdf#zoom=50

Accenture Consulting. 2017. *Banking on Blockchain: A Value Analysis for Investment Banks*. New York: Accenture. As of 14 March 2017: https://www.accenture.com/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Consulting/Accenture-Banking-on-Blockchain.pdf

Accenture Digital. 2016. *Blockchain Technology: How Banks Are Building a Real-Time Global Payment Network*. New York: Accenture. As of 14 March 2017: https://www.accenture.com/t20161019T015506__w__/us-en/_acnmedia/PDF-35/Accenture-Blockchain-How-Banks-Building-Real-Time-Global-Payment-Network.PDF

Allen, Robert H., & Ram D. Sriram. 2000. 'The Role of Standards in Innovation'. *Technological Forecasting and Social Change* 64 (2–3): 171–181. doi:10.1016/S0040-1625(99)00104-3

Ambler, Tim, & Francis Chittenden. 2009. *Worlds Apart: The EU and British Regulatory Systems*. London: British Chambers of Commerce. As of 14 March 2017: http://www.britishchambers.org.uk/assets/downloads/policy_reports/BCC_report_Worlds_Apart.pdf

Ambler, Tim, Francis Chittenden & Andrea Miccini. 2010. *Is Regulation Really Good for Us?* As of 14 March 2017: http://www.britishchambers.org.uk/assets/downloads/policy_reports_2010/is_regulation_really_good_good_for_us.pdf

Andreasyan, Tanya. 2016. 'ISITC Europe and Oasis to Define Technical Standards for Blockchain'. Banking Technology, 13 October. As of 14 March 2017: http://www.bankingtech.com/608572/isitc-europe-and-oasis-to-define-technical-standards-for-blockchain/

Armstrong, Patrick. 2016. 'Regulation and DLT: Working to Strike the Right Balance'. [presentation text, 22 November] Paris: ESMA. As of 14 March 2017: https://www.esma.europa.eu/sites/default/files/library/2016-1613_1.pdf

Atzori, Marcella. 2015. 'Blockchain Technology and Decentralized Governance: Is the State Still Necessary?' As of 14 March 2017: http://www.the-blockchain.com/docs/Blockchain%20Technology%20and%20Decentralized%20Governance%20-%20Is%20the%20State%20Still%20Necessary.pdf

———. 2017. 'Blockchain-based Architectures for the Internet of Things: A Survey'. [abstract] As of 14 March 2017: https://ssrn.com/abstract=2846810

Back, Adam, Matt Corallo, Luke Dashjr, Mark Friedenbach, Gregory Maxwell, Andrew Miller, Andrew Poelstra, Jorge Timón & Pieter Wuille. 2014. *Enabling Blockchain Innovations with Pegged Sidechains*. As of 14 March 2017: https://blockstream.com/sidechains.pdf

Baddeley, Michelle, C. Burke, W. Schultz & P. Tobler. 2012. *Herding in Financial Behaviour: A Behavioural and Neuroeconomic Analysis of Individual Differences*. Cambridge Working Papers in Economics 1225. Cambridge: University of Cambridge. doi:10.17863/CAM.1041

Bank of England. 2017. *FinTech Accelerator Proof of Concept*. London: Bank of England. As of 14 March 2017: http://www.bankofengland.co.uk/Documents/fintech/fintechpocdlt.pdf

Barclays. 2016. 'Cash Cows - How Blockchain Is Transforming Trade Finance'. London: Barclays. 1 November. As of 14 March 2017: https://www.home.barclays/news/2016/11/how-blockchain-is-transforming-trade-finance.html

Bartlam, Martin, & Mikaela Kantor. 2016. *Can Blockchain Live Up To the Hype?* London: DLA Piper. As of 14 March 2017: http://pdf.dlapiper.com/pdfrenderer.svc/v1/ABCpdf9/GetRenderedPdfByUrl//Can%20blockchain%20live%20up%20to%20the%20hype.pdf/?url=https://www.dlapiper.com:443%2fen%2fuk%2finsights%2fpublications%2f2016%2f07%2fglobal-financial-markets-insight-issue-10%2fcan-blockchain-live-up-to-the-hype%2f%3f%26-pdf%3d1&attachment=false

Beardon, Toni. 2011. *Public Key Cryptography*. Cambridge: University of Cambridge NRICH Project. As of 14 March 2017: https://nrich.maths.org/2200

Biondi, Daniel, Tom Hetterscheidt & Björn Obermeier. 2016. *Blockchain in the Financial Services Industry*. Hewlett Packard Enterprise [business white paper]. As of 14 March 2017: https://www.hpe.com/h20195/v2/GetPDF.aspx/4AA6-5864ENW.pdf

Bitcoin. 2017. 'Frequently Asked Questions'. As of 14 March 2017: https://bitcoin.org/en/faq#what-is-bitcoin

Blockcerts. 2017. 'The Open Standard for Blockchain Certificates'. As of 14 March 2017: http://www.blockcerts.org

Bogart, Spencer, & Kerry Riche. 2015. *Blockchain Report: Welcome to the Internet of Value*. New York: Needham & Company LLC. As of 14 March 2017: https://needham.bluematrix.com/sellside/EmailDocViewer?encrypt=4aaafaf1-d76e-4ee3-9406-7d0ad3c0d019&mime=pdf&co=needham&id=sbogart@needhamco.com&source=mail&utm_content=buffer0b432&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

Brandman, G., and S. Thampapillai. 2016. 'Blockchain – Considering the Regulatory Horizon'. Oxford Business Law Blog, 7 July. As of 14 March 2017: https://www.law.ox.ac.uk/business-law-blog/blog/2016/07/blockchain-%E2%80%93-considering-regulatory-horizon

Brennan, Charles, & William Lunn. 2016. *Blockchain: The Trust Disrupter*. London: Credit Suisse. As of 14 March 2017: https://www.finextra.com/finextra-downloads/newsdocs/document-1063851711.pdf

Broby, Daniel, & Tatja Karkkainen. 2016. 'FINTECH in Scotland: Building a Digital Future for the Financial Sector'. [abstract] As of 14 March 2017: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2839696

BSI (British Standards Institution). 2017. *What Is a standard? & What Does It Do?* London: BSI. As of 14 March 2017: https://www.bsigroup.com/en-GB/standards/Information-about-standards/what-is-a-standard/

Bukhsh, Fazia Allah, & Hans Weigand. 2011. Evaluating the Application of Service-oriented Auditing in the B2G Domain: A Case Study. In *Perspectives in Business Informatics Research*, edited by J. Grabis & M. Kirikova, –. BIR 2011. Lecture Notes in Business Information Processing 90. Berlin & Heidelberg: Springer.

———. 2013. Smart Auditing – Innovating Compliance Checking in Customs Control. In *2013 IEEE 15th Conference on Business Informatics*, 131–138. doi:10.1109/CBI.2013.27

Chain Protocol. 2017. *Chain Protocol Whitepaper*. As of 14 March 2017: https://chain.com/docs/protocol/papers/whitepaper

Christidis, Konstantinos, & Michael Devetsikiotis. 2016. Blockchains and Smart Contracts for the Internet of Things. IEEE Access 4: 2292–2303. doi:10.1109/ACCESS.2016.2566339

Cordwell, Jonathan. 2016. *Blockchain in Healthcare: SWOT Analysis*. CSC Blogs, 22 January. As of 14 March 2017: https://blogs.csc.com/2016/01/22/blockchain-in-healthcare-swot-analysis/

Crawford, Shaun, Ian Meadows & David Piesse. 2016. *Blockchain Technology as a Platform for Digitization: Implications for the Insurance Industry*. London: EYGM. As of 14 March 2017: http://www.ey.com/Publication/vwLUAssets/EY-blockchain-technology-as-a-platform-for-digitization/$FILE/EY-blockchain-technology-as-a-platform-for-digitization.pdf

Credits, n.d. 'Credits Blockchain-as-a-Service'. As of 08 March 2017: http://credits.vision/p/g-cloud-blockchain-platform-as-a-service

Crosby, Michael, Nachiappan, Pradhan Pattanayak, Sanjeev Verma & Vignesh Kalyanaraman. 2015. *BlockChain Technology: Beyond Bitcoin*. Sutardja Center for Entrepreneurship & Technology Technical Report. Berkeley: University of California Berkeley. As of 14 March 2017: http://scet.berkeley.edu/wp-content/uploads/BlockchainPaper.pdf

Dash, Anil. 2010. 'Forking Is a Feature'. Anil Dash [blog], 10 September. As of 14 March 2017: http://anildash.com/2010/09/forking-is-a-feature.html

Davies, Sam. 2016. 'Building Smart Contracts for UK Games Development'. Digital Catapult Centre Blog, 12 October. As of 14 March 2017: https://www.digitalcatapultcentre.org.uk/building-smart-contracts-uk-games-development/

De Meijer, Carlo R.W. 2016. 'Blockchain and Standards: First Things First!' FinExtra [blog], 20 September. As of 14 March 2017: https://www.finextra.com/blogposting/13114/blockchain-and-standards-first-things-first

Deetman, Sebastiaan. 2016. *Bitcoin Could Consume as Much Electricity as Denmark by 2020*. Motherboard. 29 March. As of 14 March 2017: https://motherboard.vice.com/en_us/article/bitcoin-could-consume-as-much-electricity-as-denmark-by-2020

del Castillo, Michael. 2016. 'ISITC Europe Proposes 10 Blockchain Standards Benchmarks'. CoinDesk, 18 July. As of 14 March 2017: http://www.coindesk.com/isitc-blockchain-standards-benchmarks/

Deloitte. 2016. *Blockchain: Enigma. Paradox. Opportunity*. London: Deloitte LLP. As of 14 March 2017: https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/Innovation/deloitte-uk-blockchain-full-report.pdf

Department for Business, Energy & Industrial Strategy. 2016. *Regulatory Delivery Model: Outline Presentation*. As of 14 March 2017: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/560797/regulatory-delivery-model-outline.ppt

Department for Business, Innovation & Skills. 2014. *Regulators' Code*. Birmingham: Department for Business, Innovation & Skills Better Regulation Delivery Office. As of 14 March 2017: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/300126/14-705-regulators-code.pdf

Devine, Peter. 2015. 'Blockchain Learning: Can Crypto-Currency Methods Be Appropriated to Enhance Online Learning?' In *ALT Online Winter Conference 2015, 7–10 December 2015*. As of 14 March 2017: http://oro.open.ac.uk/44966/1/Devine2015-altc-blockchainlearning.pdf

Digital Catapult & Open Data Institute. 2016. *Response to the Government Chief Scientific Advisor's Report on Distributed Ledger Technologies*. As of 14 March 2017: http://www.digitalcatapultcentre.org.uk/wp-content/uploads/2016/01/Digital-Catapult-ODI-Response.pdf

The Depository Trust & Clearing Corporation. 2016. *Embracing Disruption: Tapping the Potential of Distributed Ledgers to Improve the Post-Trade Landscape*. As of 16 March 2017: http://www.dtcc.com/news/2016/january/25/new-dtcc-white-paper-calls-for-leveraging-distributed-ledger-technology

Dong, He, Karl Habermeier, Ross Leckow, Vikram Haksar, Yasmin Almeida, Mikari Kashima, Nadim Kyriakos-Saad, Hiroko Oura, Tahsin Saadi Sedik, Natalia Stetsenko & Concepcion Verdugo-Yepes. 2016. Virtual Currencies and Beyond: Initial Considerations. [IMF staff discussion note SDN/16/03] As of 14 March 2017: https://www.imf.org/external/pubs/ft/sdn/2016/sdn1603.pdf

Dunker, Paul, & Monique Krasniqui. 2016. Deloitte Survey: Blockchain Reaches Beyond Financial Services with some Industries Moving Faster. 13 December. [press release] As of 14 March 2017: https://www2.deloitte.com/us/en/pages/about-deloitte/articles/press-releases/deloitte-survey-blockchain-reaches-beyond-financial-services-with-some-industries-moving-faster.html

Elliott, Karen, Fabio Massacci, Chan Nam Ngo & Julian Williams. 2016. 'Unruly Innovation: Distributed Ledgers, Blockchains and the Protection of Transactional Rents'. [abstract] As of 14 March 2017: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2888872

EBAWGEAP (Euro Banking Association Working Group on Electronic Alternative Payments). 2015. *Cryptotechnologies, a major IT innovation and catalyst for change: 4 categories, 4 applications and 4 scenarios: An exploration for transaction banking and payments professionals*. As of 14 March 2017: https://www.abe-eba.eu/downloads/knowledge-and-research/EBA_20150511_EBA_Cryptotechnologies_a_major_IT_innovation_v1_0.pdf

———. 2016. *Applying Cryptotechnologies to Trade Finance: Information Paper*. As of 14 March 2017: https://www.abe-eba.eu/downloads/knowledge-and-research/EBA_May2016_eAPWG_Applying_cryptotechnologies_to_Trade_Finance.pdf

Ernst & Young. 2014. *Landscaping UK Fintech*. London: Ernst & Young LLP. As of 14 March 2017: http://www.ey.com/Publication/vwLUAssets/Landscaping_UK_Fintech/$FILE/EY-Landscaping-UK-Fintech.pdf

ESMA (European Securities and Markets Authority). 2016b. *Report: The Distributed Ledger Technology Applied to Securities Markets*. As of 14 March 2017: https://www.esma.europa.eu/sites/default/files/library/2016-773_dp_dlt.pdf

———. 2016a. *Discussion Paper: The Distributed Ledger Technology Applied to Securities Markets*. As of 14 March 2017: https://www.esma.europa.eu/sites/default/files/library/2016-773_dp_dlt.pdf

FCA (Financial Conduct Authority). 2015. *Regulatory Sandbox*. London: Financial Conduct Authority. As of 14 March 2017: https://www.fca.org.uk/publications/documents/regulatory-sandbox

———. 2016. 'Financial Conduct Authority Unveils Successful Sandbox Firms on the Second Anniversary of Project Innovate'. London: Financial Conduct Authority. [press release] As of 14 March 2017: https://www.fca.org.uk/news/press-releases/financial-conduct-authority-unveils-successful-sandbox-firms-second-anniversary

FINRA (Financial Industry Regulatory Authority). 2017. *Distributed Ledger Technology: Implications of Blockchain for the Securities Industry*. Washington, DC: FINRA. As of 14 March 2017: http://www.finra.org/sites/default/files/FINRA_Blockchain_Report.pdf

Forest, H., & D. Rose. 2015. *Delighting Customers and Democratising Finance: Digitalisation and the Future of Commercial Banking*. Frankfurt am Main: Deutsche Bank. As of 14 March: http://cib.db.com/docs_new/Digitalisation_and_the_Future_of_Commercial_Banking.pdf

Gov.uk, n.d.a. 'Capgemini UK plc: Blockchain Distributed Ledger Technology (DLT)'. As of 08 March 2017: https://www.digitalmarketplace.service.gov.uk/g-cloud/services/648004309233749

Gov.uk, n.d.b. 'Credits: UK plc: Credits Blockchain as a Service (BaaS)'. As of 08 March 2017: https://www.digitalmarketplace.service.gov.uk/g-cloud/services/378759923386821

Government Actuary's Department. 2016. *Investment News*, October. As of 14 March 2017: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/558408/Sep_2016_update.pdf

Government Office for Science. 2016. *Distributed Ledger Technology: Beyond Block Chain: A Report by the UK Government Chief Scientific Adviser*. London: Government Office for Science. As of 14 March 2017: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/492972/gs-16-1-distributed-ledger-technology.pdf

Glance, David. 2015. 'What Is Bitcoin? It Is not that Complicated if You Ignore the Geek Speak'. The Conversation US [blog], 23 August. As of 14 March 2017: http://theconversation.com/what-is-bitcoin-it-is-not-that-complicated-if-you-ignore-the-geek-speak-46512

Green, H., 2016. 'Govcoin's co-founder Robert Kay explains why his firm is using blockchain to change the lives of benefit claimants'. *City A.M.* [online], October 10, 2016. As of 10 March 2017: http://www.cityam.com/250993/govcoins-co-founder-robert-kay-explains-why-his-firm-using

Greenspan, Gideon. 2016. 'Four Genuine Blockchain Use Cases'. MultiChain [blog], 10 May. As of 14 March 2017: http://www.multichain.com/blog/2016/05/four-genuine-blockchain-use-cases/

Greenspan, Gideon, & Maya Zehavi. 2016. *Will Provenance Be the Blockchain's Break Out Use Case in 2016?* CoinDesk, 7 January. As of 14 March 2017: http://www.coindesk.com/provenance-blockchain-tech-app/

Gunashekar, Salil, Anton Spisak, Kevin Dean, Nathan Ryan, Louise Lepetit & Paul Cornish. 2016. *Accelerating the Internet of Things in the UK: Using Policy to Support Practice*. Santa Monica, CA: RAND Corporation. As of 14 March 2017: http://www.rand.org/pubs/research_reports/RR1492.html

Guo, Y., & C. Liang. 2016. 'Blockchain Application and Outlook in the Banking Industry'. *Financial Innovation* 2: 24. doi:10.1186/s40854-016-0034-9

Hong Kong Applied Science and Technology Research Institute Company. 2016. *Whitepaper on Distributed Ledger Technology*. As of 14 March 2017: http://www.hkma.gov.hk/media/eng/doc/key-functions/finanical-infrastructure/Whitepaper_On_Distributed_Ledger_Technology.pdf

Horizon Scanning Working Group. 2016. *The Horizon for Payments: A New Vision for UK Payments*. Payments Strategy Forum. As of 14 March 2017: https://www.paymentsforum.uk/sites/default/files/documents/HSWG%20Report.pdf

Huckle, Steve, Rituparna Bhattacharvya, Martin White & Natalia Beloff. 2016. 'Internet of Things, Blockchain and Shared Economy Applications'. *Procedia Computer Science* 98: 461–466. doi:10.1016/j.procs.2016.09.074

Hyperledger (homepage). 2017. As of 14 March 2017: https://www.hyperledger.org/

Iansiti, Marco, & Karim R. Lakhani. 2017. 'The Truth about Blockchain'. *Harvard Business Review*, 1 January. As of 14 March 2017: https://hbr.org/product/the-truth-about-blockchain/R1701J-PDF-ENG

Interledger (homepage). 2017. As of 14 March 2017: https://interledger.org/

Investopedia. 2015. 'Why Is the Insurance Sector Considered a Low-Risk Investment?' As of 14 March 2017: http://www.investopedia.com/ask/answers/051915/why-insurance-sector-considered-lowrisk-investment.asp

———. 2017. 'Fiat Money'. As of 14 March 2017: http://www.investopedia.com/terms/f/fiatmoney.asp

Iscenko, Zanna, Peter Andrews, Kristine Dambe & Peter Edmonds. 2016. *Economics for Effective Regulation*. As of 14 March 2017: https://www.fca.org.uk/publication/occasional-papers/occassional-paper-13.pdf

ISO (International Organization for Standardization). 2017a. 'ISO/TC 307: Blockchain and Electronic Distributed Ledger Technologies: About'. As of 14 March 2017: http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=6266604

———. 2017b. 'ISO/TC 307: Blockchain and Electronic Distributed Ledger Technologies: Participation'. As of 14 March 2017: https://www.iso.org/committee/6266604.html?view=participation

ITU (International Telecommunication Union). 2017. 'ITU Workshop on "Security Aspects of Blockchain"'. As of 14 March 2017: http://www.itu.int/en/ITU-T/Workshops-and-Seminars/201703/Pages/default.aspx

Kakavand, H., N. Kost De Sevres & B. Chilton. 2017. 'The Blockchain Revolution: An Analysis of Regulation and Technology Related to Distributed Ledger Technologies'. [abstract] As of 14 March 2017: https://ssrn.com/abstract=2849251

Kim, Henry M. 2016. 'IoT and Blockchain Aware Ontologies for Supply Chain Provenance'. [abstract] As of 14 March 2017: https://ssrn.com/abstract=2818557

Kim, Henry M., & Marek Laskowski. 2016. 'Towards an Ontology-driven Blockchain Design for Supply Chain Provenance'. [abstract] doi:10.2139/ssrn.2828369

Knuth, Donald E. 2000. *Sorting and Searching*. 2nd ed. Boston: Addison-Wesley.

Krawiec, R.J., Dan Housman, Mark White, Mariya Filipova, Florian Quarre, Dan Barr, Allen Nesbitt, Kate Fedosova, Jason Killmeyer, Adam Israel & Lindsay Tsai. 2016. *Blockchain: Opportunities for Health Care*. Deloitte Consulting LLP. As of 14 March 2017: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/public-sector/us-blockchain-opportunities-for-health-care.pdf

Lamarque, Mélodie. 2016. *The Blockchain Revolution: New Opportunities in Equity Markets*. Boston: Massachusetts Institute of Technology. As of 14 March 2017: https://dspace.mit.edu/handle/1721.1/104522

Lehdonvirta, Vili. 2016. 'The Blockchain Paradox: Why Distributed Ledger Technologies May Do Little to Transform the Economy'. Internet Policy Blog, 21 November. As of 14 March 2017: https://www.oii.ox.ac.uk/the-blockchain-paradox-why-distributed-ledger-technologies-may-do-little-to-transform-the-economy/

Lewis, Anthony. 2015. 'A Gentle Introduction to Digital Tokens'. Bits of Blocks [blog], 28 September. As of 14 March 2017: https://bitsonblocks.net/2015/09/28/a-gentle-introduction-to-digital-tokens/

Lielacher, Alexander. 2016. *UK Financial Regulator Unveils Fintech 'Sandbox' Filled with Blockchain Startups*. 8 November. As of 14 March 2017: https://btcmanager.com/uk-financial-regulator-unveils-fintech-sandbox-filled-with-blockchain-startups/

Mainelli, Michael, & A. Milne. 2015. The Impact and Potential of Blockchain on the Securities Transaction Lifecycle. SWIFT Group. [SWIFT Institute Working Paper 2015-007] As of 14 March 2017: https://www.swiftinstitute.org/wp-content/uploads/2016/05/The-Impact-and-Potential-of-Blockchain-on-the-Securities-Transaction-Lifecycle_Mainelli-and-Milne-FINAL.pdf

Mainelli, Michael, & Bernard Manson. 2016. Chain Reaction: How Blockchain Technology Might Transform Wholesale Insurance. [Long Finance report] London: Z/Yen Group. As of 14 March 2017: http://www.zyen.com/Publications/LongFinance_How_Blockchain_Technology_Might_Transform_Wholesale_Insurance_July2016.pdf

Mainelli, Michael, & Bob McDowall. 2016. 'Why Smart Contracts Need Shrewder People'. *Banking Technology*, March/April. As of 14 March 2017: http://www.zyen.com/Articles/Michael%20Mainelli%20and%20Bob%20McDowall%20BT%202016.pdf

Mainelli, Michael, & Simon Mills. 2016. *The Missing Links in the Chains? Mutual Distributed Ledger (aka Blockchain) Standards*. [Long Finance report] London: Z/Yen Group. As of 14 March 2017: http://www.zyen.com/PDF/The_Missing_Links_In_The_Chain_Mutual_Distributed_Ledger_(aka_blockchain)_Standards_2016.11_v2.4.pdf

Mainelli, Michael, & Vinay Gupta. 2016. 'Misplaced Trust'. *Banking Technology*, February. As of 14 March 2017: http://www.zyen.com/Articles/Banking%20Technology%20-%20Misplaced%20Trust%20In%20Identity%20-%20Mainelli%20and%20Gupta%202016.02.pdf

Mainelli, Michael. 2017. 'Which Way for Blockchain Standards in 2017?' As of 14 March 2017: http://www.coindesk.com/which-way-for-blockchain-standards-in-2017/

Malmo, Christopher. 2015. *Bitcoin Is Unsustainable*. Motherboard. As of 14 March 2017: https://motherboard.vice.com/en_us/article/bitcoin-is-unsustainable

Mattila, Juri, Timo Seppälä, Catarina Naucler, Riitta Stahl, Marianne Tikkanen, Alexandra Bådenlid & Jane Seppälä. 2016. *Industrial Blockchain Platforms: An Exercise in Use Case Development in the Energy Industry*. [ETLA Working Papers 43] As of 14 March 2017: http://www.etla.fi/wp-content/uploads/ETLA-Working-Papers-43.pdf

Maye, Niall. 2016. 'Overcoming the Blocks to Blockchain: Banks and Financial Institutions Get Practical'. The CoinTelegraph, 20 April. As of 14 March 2017: https://www.cointelegraph.uk/news/overcoming-the-blocks-to-blockchain-banks-and-financial-institutions-get-practical

McKinsey & Company. (2015). *Beyond the Hype: Blockchains in Capital Markets*. As of 14 March 2017: http://www.mckinsey.com/industries/financial-services/our-insights/beyond-the-hype-blockchains-in-capital-markets

———. 2016. *How Blockchains Could Change the World*. As of 14 March 2017: http://www.mckinsey.com/industries/high-tech/our-insights/how-blockchains-could-change-the-world

———. 2017. *Blockchain Technology in the Insurance Sector*. As of 14 March 2017: https://www.treasury.gov/initiatives/fio/Documents/McKinsey_FACI_Blockchain_in_Insurance.pdf

Meiklejohn, Sarah, Marjori Pomarole, Grant Jordan, Kirill Levchenko, Damon McCoy, Geoffrey M. Voelker & Stefan Savage. 2013. 'A Fistful of Bitcoins: Characterizing Payments Among Men with No Names'. In *Internet Measurement Conference 2013*. doi:10.1145/2504730.2504747

Mersch, Y. 2016. 'Distributed Ledger Technology: Role and Relevance of the ECB'. Speech at the 22nd Handelsblatt Annual Conference Banken-Technologie, 6 December. Frankfurt am Main: European Central Bank. As of 14 March 2017: https://www.ecb.europa.eu/press/key/date/2016/html/sp161206.en.html

Millar, Jeremy, & Etienne Brunet. *Blockchain & Bitcoin 2016: A Survey of Global Leaders*. London: Magister Advisors. As of 14 March 2017: http://www.slideshare.net/jeremysmillar/magister-advisors-blockchain-bitcoin-in-2016-a-survey-of-global-leaders

Mills, David, Kathy Wang, Brendan Malone, Anjana Ravi, Jeff Marquardt, Clinton Chen, Anton Badev, Timothy Brezinski, Linda Fahy, Kimberley Liao, Vanessa Kargenian, Max Ellithorpe, Wendy Ng & Maria Baird. 2016. *Distributed Ledger Technology in Payments, Clearing, and Settlement*. [Finance and Economics Discussion Series 2016-095] Washington: Board of Governors of the Federal Reserve System. doi:10.17016/FEDS.2016.095

Morrison, Alan. 2016a. 'Blockchain and Smart Contract Automation: Introduction and Forecast'. As of 14 March 2017: http://www.pwc.com/us/en/technology-forecast/blockchain/introduction.html

———. 2016b. 'Blockchain and Smart Contract Automation: Blockchains Defined'. As of 14 March 2017: http://www.pwc.com/us/en/technology-forecast/blockchain/definition.html

———. 2016c. 'Blockchain and Smart Contract Automation: Why Are Blockchains Important?' As of 14 March 2017: http://www.pwc.com/us/en/technology-forecast/blockchain/importance.html

———. 2016d. 'Blockchain and Smart Contract Automation: Private Blockchains, Public, or Both?' As of 19 May 2017: http://usblogs.pwc.com/emerging-technology/private-blockchains-public-or-both/

———. 2016e. 'Blockchain and Smart Contract Automation: How Smart Contracts Automate Digital Business'. As of 19 May 2017: http://usblogs.pwc.com/emerging-technology/how-smart-contracts-automate-digital-business/

Murphy, Sean, & Charley Cooper. 2016. *Can Smart Contracts Be Legally Binding Contracts?* London: Norton Rose Fulbright LLP. As of 14 March 2017: https://sites-nortonrosefulbright.vuturevx.com/596/14051/uploads/r3-and-norton-rose-fulbright-white-paper-full-report-144581.pdf

Nakamura, Yuji. 2016. 'The Wretched, Endless Cycle of Bitcoin Hacks'. Bloomberg Technology, 17 August. As of 14 March 2017: https://www.bloomberg.com/news/articles/2016-08-17/the-wretched-endless-cycle-of-bitcoin-hacks

Nesta. 2017. '2017 Will Be the Year Blockchain Is Harnessed by Individuals to Take Back Control of Their Online Lives, Says Eddie Copeland'. As of 14 March 2017: http://www.nesta.org.uk/2017-predictions/blockchain-powers-personal-data-revolution?gclid=CKSei93-4dECFZG6Gwod2wsG0w#sthash.OJQ0Cnf5.dpuf

———. 2016 'Why You Should Care about Blockchains: The Non-Financial Uses of Blockchain Technology'. Nesta Blogs, 24 March. As of 14 March 2017: http://www.nesta.org.uk/blog/why-you-should-care-about-blockchains-non-financial-uses-blockchain-technology

Nugent, Timothy, David Upton & Mihai Cimpoesu. 2016. 'Improving Data Transparency in Clinical Trials Using Blockchain Smart Contracts'. *F1000Research* 5:2541. doi:10.12688/f1000research.9756.1

O'Dair, M, 2016. *The Networked Record Industry: How Blockchain Technology Could Transform the Consumption and Monetisation of Recorded Music*. Guildford: New Economic Models in the Digital Economy. As of 14 March 2017: http://www.nemode.ac.uk/wp-content/uploads/2012/12/ODair-The-networked-record-industry-REPORT-1.pdf

O'Dair, M., Zuleika Beaven, David Neilson, Richard Osborne & Paul Pacifico. 2016. *Music on the Blockchain*. London: Middlesex University. As of 14 March 2017: https://www.mdx.ac.uk/__data/assets/pdf_file/0026/230696/Music-On-The-Blockchain.pdf

O'Sullivan, Eoin, & Laure Brévignon-Dodin. 2012. *Role of Standardisation in Support of Emerging Technologies*. Cambridge: University of Cambridge Institute for Manufacturing. As of 14 March 2017: http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/OSullivan_Dodin_Role_of_Standardisation_June_2012__2_.pdf

Oates, Roger, & Raghavasuresh Samudrala. 2016. *Industrialisation of Distributed Ledger Technology in Banking and Financial Services*. Mumbai: Tata Consultancy Services. As of 14 March 2017: https://www.techuk.org/component/techuksecurity/security/download/8691?file=B37583_Blockchain_Paper_4.pdf&Itemid=181&return=aHR0cHM6Ly93d3cudGVjaHVrLm9yZy9pbnNpZ2h0cy9yZXBvcnRzL2l0ZW0vODY5MS10ZWNodWstdGNzLXBhcGVyLWJsb2NrY2hhaW4=

Orgill, Gregory L., Gordon W. Romney, Michael G. Bailey & Paul M. Orgill. 2004. The Urgency for Effective User Privacy-Education to Counter Social Engineering Attacks on Secure Computer Systems. In *Proceedings of the 5th Conference on Information Technology Education*, 177–181. doi:10.1145/1029533.1029577

Parliamentary Office of Science & Technology. 2016. *Distributed Ledgers – Closed POST Breakfast Event*. London: Parliamentary Office of Science & Technology. As of 14 March 2017: https://www.parliament.uk/documents/post/061216_Distributed-Ledgersv3.pdf

Peter, G. M. 2010. *International Standards and Trade: A Review of the Empirical Literature*. [OECD Trade Policy Papers] doi:10.1787/18166873

Peters, G.W., & E. Panayi. 2015. 'Understanding Modern Banking Ledgers through Blockchain Technologies: Future of Transaction Processing and Smart Contracts on the Internet of Money'. As of 14 March 2017: https://pdfs.semanticscholar.org/0a84/a077ada2acb6918e7764fafcd28f667dae28.pdf

Pinna, Andrea, & Wiebe Ruttenberg. 2016. *Distributed Ledger Technologies in securities Post-Trading: Revolution or Evolution?* Frankfurt am Main: European Central Bank. As of 14 March 2017: https://www.ecb.europa.eu/pub/pdf/scpops/ecbop172.en.pdf

Plimmer, G. 2016. 'Use of bitcoin tech to pay UK benefits sparks privacy concerns'. *The Financial Times* [online], July 12, 2016. As of 10 March 2017: https://www.ft.com/content/33d5b3fc-4767-11e6-b387-64ab0a67014c

Popper, N., 2016. 'Bitcoin Start-Up Gets an Electronic Money License in Britain'. *The New York Times* [online], April 6, 2016. As of 10 March 2017: https://www.nytimes.com/2016/04/06/business/dealbook/bitcoin-start-up-gets-an-electronic-money-license-in-britain.html?_r=0

Provenance. 2016. *From Shore to plate: Tracking Tuna on the Blockchain*. As of 14 March 2017: https://www.provenance.org/tracking_tuna_on_the_blockchain

PwC. 2015. *Know Your Customer: Quick Reference Guide*. New York: PwC. As of 14 March 2017: http://www.pwc.co.uk/assets/pdf/anti-money-laundering-quick-reference-guide-2015.pdf

R3CEV (home page). 2017. As of 14 March 2017: http://www.r3cev.com/

Redman, Jamie. 2016. 'Estonian Health Records to Be Secured by Blockchain'. 4 March. Bitcoin.com. As of 14 March 2017: https://news.bitcoin.com/estonian-health-records-secured-by-blockchain/

Reed Smith LLP. 2016. *Beyond Bitcoin: Blockchain: The Essential Building Block in Designing the Future*. As of 14 March 2017: http://documents.jdsupra.com/69ae8c7f-0461-4f44-a542-fdb65b9ab748.pdf

Research Councils UK, 2015. 'Settlement using blockchain to Automate Foreign Exchange in a Regulated environment (SAFER)'. As of 10 March 2017: http://gtr.rcuk.ac.uk/projects?ref=720735

Reuters, 2016. 'UK's Royal Mint, CME Group launch blockchain-based gold trading platform'. Tue Nov 29, 2016. As of 08 March 2017: http://www.reuters.com/article/us-gold-blockchain-royal-mint-idUSKBN13O0M4

Rezaee, Zabihollah, Ahmad Sharbatoghlie, Rick Elam & Peter L. McMickle. 2002. Continuous Auditing: Building Automated Auditing Capability. *Auditing* 21 (1): 147–163. doi:10.2308/aud.2002.21.1.147

Royal Mint n.d., 'RMG® The New Digital Gold Standard'. As of 08 March 2017: http://www.royalmint.com/rmg

Schatsky, David, & Craig Muraskin. 2016. *Beyond Bitcoin: Blockchain Is Coming to disrupt Your Industry*. Deloitte University Press. As of 14 March 2017: https://dupress.deloitte.com/dup-us-en/focus/signals-for-strategists/trends-blockchain-bitcoin-security-transparency.html

Schepers, Doug. 2016. 'Building Blocks to Blockchains: A Report on the W3C Blockchains and the Web Workshop'. W3C Blog, 26 August. As of 14 March 2017: https://www.w3.org/blog/2016/08/building-blocks-to-blockchains/

Schindler, Helen Rebecca, Jonathan Cave, Neil Robinson, Veronika Horvath, Petal Hackett, Salil Gunashekar, Maarten Botterman, Simon Forge & Hans Graux. 2013. *Europe's Policy Options for a Dynamic and Trustworthy Development of the Internet of Things*. SMART 2012/0053. Santa Monica, CA: RAND Corporation. As of 14 March 2017: http://www.rand.org/pubs/research_reports/RR356.html

Seibold, S., & G. Samman. 2016. *Consensus Immutable Agreement for the Internet of Value*. KPMG. As of 14 March 2017: https://assets.kpmg.com/content/dam/kpmg/pdf/2016/06/kpmg-blockchain-consensus-mechanism.pdf

Shackelford, Scott, & Steven Myers. 2016. 'Block-by-Block: Leveraging the Power of Blockchain Technology to Build Trust and Promote Cyber Peace'. [abstract] As of 14 March 2017: https://ssrn.com/abstract=2874090

Shah, Sooraj. 2016. 'Can The UK Government Really Benefit from Blockchain?' Silicon.co.uk, 24 November. As of 14 March 2017: http://www.silicon.co.uk/data-storage/uk-government-blockchain-benefits-bitcoin-199868

Shelkovnikov, Alexander. 2016. *Blockchain Applications in the Public Sector*. London: Deloitte LLP. As of 14 March 2017: https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/innovation/ch-en-innovation-deloitte-blockchain-app-in-public-sector.pdf

Shin, Laura. 2016. *Hackers Have Stolen Millions of Dollars in Bitcoin Using Only Phone Numbers*. Forbes, 20 December. As of 14 March 2017: https://www.forbes.com/sites/laurashin/2016/12/20/hackers-have-stolen-millions-of-dollars-in-bitcoin-using-only-phone-numbers/#175a3b2038ba

Shrier, David, Weige Wu & Alex Pentland. 2016. *Blockchain & Infrastructure (Identity, Data Security)*. Part 3. Boston: Massachusetts Institute of Technology. As of 14 March 2017: http://inpluslab.sysu.edu.cn/files/Paper/Summary/Blockchain___Infrastructure__Identity__Data_Security_.pdf

Siegel, David. 2016. *Understanding the DAO Attack*. CoinDesk, 25 June. As of 14 March 2017: http://www.coindesk.com/understanding-dao-hack-journalists/

Silver, J. 2016. *Blockchain or the Chaingang? Challenges, Opportunities and Hype: The Music Industry and Blockchain Technologies*. [CREATe Working Paper 2016/05] doi:10.5281/zenodo.51326

Simpson, Stephen D. 2017. *Low vs. High-Risk Investments for Beginners*. Investopedia. As of 14 March 2017: http://www.investopedia.com/financial-edge/0512/low-vs.-high-risk-investments-for-beginners.aspx

Smart Contracts Alliance & Deloitte. 2016. *Smart Contracts: 12 Use Cases for Business & Beyond*. Chamber of Digital Commerce. As of 14 March 2017: http://bloq.com/assets/smart-contracts-white-paper.pdf

Stanganelli, Joe. 2016. 'How Blockchain Is Helping Genomics Research'. BioITWorld, 4 May. As of 14 March 2017: http://www.bio-itworld.com/2016/5/4/how-blockchain-is-helping-genomics-research.aspx

Stubbs, Evan, & Chami Akmeemana. 2016. 'Blockchain, Cryptoeconomics, and the Disintermediation of Trust'. 10 May. As of 14 March 2017: https://www.linkedin.com/pulse/blockchain-cryptoeconomics-disintermediation-trust-akmeemana-14-000-

SWIFT (Society for Worldwide Interbank Financial Telecommunications) Institute. 2016. *Distributed Ledgers, Smart Contracts, Business Standards and ISO 2002*. SWIFT. As of 14 March 2017: https://www.swift.com/node/39911

SWIFT Institute & Accenture. 2016. *SWIFT on Distributed Ledger Technologies*. SWIFT. As of 14 March 2017: http://www.ameda.org.eg/files/SWIFT_DLTs_position_paper_FINAL1804.pdf

Szabo, Nick. 1996. 'Smart Contracts: Building Blocks for Digital Markets'. As of 8 March 2017 (Copy): http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart_contracts_2.html

Tait, Joyce, & Geoffrey Banda. 2016. *Proportionate and Adaptive Governance of Innovative Technologies: The Role of Regulations, Guidelines and Standards*. [Main Report] Edinburgh: Innogen Institute, University of Edinburgh. As of 14 March 2017: http://www.innogen.ac.uk/downloads/Innogen_Institute_BSI_Standards_Project_Main_Report.pdf

Tandulwadikar, Akhil. 2016. *Blockchain in Banking: A Measured Approach*. As of 14 March 2017: https://www.cognizant.com/whitepapers/Blockchain-in-Banking-A-Measured-Approach-codex1809.pdf

Tapscott, D., & A. Tapscott. 2016a. 'The Impact of the Blockchain Goes Beyond Financial Services'. *Harvard Business Review*, 10 May. As of 14 March 2017: https://hbr.org/2016/05/the-impact-of-the-blockchain-goes-beyond-financial-services

———. 2016b. *Blockchain Revolution: How the Technology Behind Bitcoin is Changing Money, Business, and the World*. New York: Penguin Random House.

Tassey, Gregory. 2000. 'Standardisation in Technology-based Markets'. Research Policy 29: 587–602. As of 14 March 2017: http://www.sciencedirect.com/science/article/pii/S0048733399000918

Taylor, Simon. 2015. *Blockchain: Understanding the Potential*. London: Barclays. As of 14 March 2017: https://www.barclayscorporate.com/content/dam/corppublic/corporate/Documents/insight/blockchain_understanding_the_potential.pdf

The Economist. 2016. 'Better with Bitcoin'. *The Economist*, 21 May. As of 14 March 2017: http://www.economist.com/news/science-and-technology/21699099-blockchain-technology-could-improve-reliability-medical-trials-better

———. 2015. 'Blockchains: The Great Chain of Being Sure about Things'. *The Economist*, 31 October. As of 14 March 2017: http://www.economist.com/news/briefing/21677228-technology-behind-bitcoin-lets-people-who-do-not-know-or-trust-each-other-build-dependable

The Select Committee on Economic Affairs. 2016. Inquiry on Distributed Ledger Technologies. Revised transcript of evidence. Evidence session 1. 19 July. As of 14 March 2017: http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/economic-affairs-committee/distributed-ledger-technologies/oral/35390.html

Tierion. 2016. *Blockchain Healthcare 2016 Report: Promise & Pitfalls*. Tierion. As of 14 March 2017: https://tierion.blob.core.windows.net/blogcontent/2016/10/Blockchain-Healthcare-2016.pdf

Tracy, Philip. 2016. 'Top 5 Industrial IoT Use Cases'. RCRWirelessNews [blog], 20 September. As of 14 March 2017: https://www.ibm.com/blogs/internet-of-things/top-5-industrial-iot-use-cases/

Trautman, Lawrence J. 2016. Is Disruptive Blockchain Technology the Future of Financial Services? *The Consumer Finance Law Quarterly Report* 232. [abstract] As of 14 March 2017: https://ssrn.com/abstract=2786186

Van Merkerk, Rutger O., & Douglas K.R. Robinson. 2006. 'Characterizing the Emergence of a Technological Field: Expectations, Agendas and Networks in Lab-on-a-Chip technologies'. *Technology Analysis & Strategic Management* 18 (3–4): 411–428. doi:10.1080/09537320600777184

W3C. 2016. 'Blockchains and the Web: A W3C Workshop on Distributed Ledgers on the Web'. W3C. As of 14 March 2017: https://www.w3.org/2016/04/blockchain-workshop/

———. 2016b. 'Compact View of the Results of Blockchains and the Web Workshop Expression of Interest'. As of 14 March 2017: https://www.w3.org/2016/04/blockchain-workshop/interest/expressions-of-interest.html#Wunsche

Walch, Angela. 2015. 'The Bitcoin Blockchain as Financial Market Infrastructure: A Consideration of Operational Risk'. *NYU Journal of Legislation and Public Policy* 837. [abstract] As of 14 March 2017: https://ssrn.com/abstract=2579482

Whitechapel Think Tank. 2016b. *Distributed Ledger Technology: Clearing Away the Debris?* Whitechapel Think Tank. As of 14 March 2017: http://www.paymentsuk.org.uk/sites/default/files/DLT%20-%20Clearing%20away%20the%20debris.pdf

World Economic Forum. 2016b. *The Future of Financial Infrastructure: An Ambitious Look at How Blockchain Can Reshape Financial Services*. Cologny, Switzerland: World Economic Forum. As of 14 March 2017: http://www3.weforum.org/docs/WEF_The_future_of_financial_infrastructure.pdf

———. 2016a. *The Complex Regulatory Landscape for FinTech: An Uncertain Future for Small and Medium-sized Enterprise Lending*. As of 14 March 2017: http://www3.weforum.org/docs/WEF_The_Complex_Regulatory_Landscape_for_FinTech_290816.pdf

Yeandle, Mark, Michael Mainelli & Adrian Berendt. 2005. *The Competitive Position of London as a Global Financial Centre*. London: Z/Yen. As of 14 March 2017: http://www.zyen.com/PDF/LCGFC.pdf

Zerado. 2016. 'Blockchain Standards Matter'. Zerado, 23 November. As of 14 March 2017: http://zerado.com/en/news/blockchain-standards-matter/

Zyskind, Guy, Oz Nathan & Alex Pentland. 2015. 'Decentralizing Privacy: Using Blockchain to Protect Personal Data'. In *2015 IEEE Security and Privacy Workshops*, 180–184. doi:10.1109/SPW.2015.27

Appendix A: Overview of definitions of DLT/Blockchain

The table below provides a list of some of the definitions of DLT/Blockchain cited in the publicly available literature. We note that this is not an exhaustive list of definitions and serves only to illustrate the varied understanding of the terminology being used by stakeholders.

Table 6: Overview of definitions of DLT/Blockchain cited in the literature

Source	Definition of DLT	Definition of Blockchain
Accenture consulting (2017)	No definition provided	'Blockchain – a catchall phrase for distributed ledger technology – is a new type of database system which enables multiple parties to share access to the same data, at virtually the same time, with an unprecedented level of confidence.'
Bogart & Rice (2016)	No definition provided	'Generically, a blockchain is a distributed ledger: a chronological chain of "blocks" where each "block" contains a record of valid network activity since the last block was added to the chain. The Bitcoin blockchain is a distributed chronological ledger of valid network transactions that anyone can review, anyone can add to (by transacting on the network), but nobody can change. '
Brennan & Lunn (2016)	No definition provided	'A shared ledger requiring consensus to update, with tamper-evident properties that is economically unfeasible for any single entity to retrospectively alter is a bigger disruptive threat.'
The Economist (2016)	No definition provided	'A database that contains the payment history of every bitcoin in circulation, the blockchain provides proof of who owns what at any given juncture. This distributed ledger is replicated on thousands of computers – bitcoin's "nodes" – around the world and is publicly available.'

Source	Definition of DLT	Definition of Blockchain
Elliott et al. (2016)	'DLTs are databases that are distributed across a large number of computing nodes in some form of network. The interesting feature of a DLT is that no one component of the network controls the overall information on the DLT, but can dynamically query it. This technology allows a ledger to be maintained that tracks transactions and attempts to ensure that no (small) group of individuals can subvert the ledgers' integrity.'	'Blockchain is a sequence of applications of a hash function to a sequence of transactions. Every block contains the information of the current transaction and a reference to its previous block header's hash. The blockchain is shared by all nodes of the network and every transaction is stored within the blockchain so that it is transparent for everyone to know the balance of each account in the network.'
FINRA report (2017)	'Distributed ledger technology involves a distributed database maintained over a network of computers connected on a peer-to-peer basis, such that network participants can share and retain identical, cryptographically secured records in a decentralized manner.'	No definition provided
Government Office of Science (2016)	'Distributed ledgers are a type of database that is spread across multiple sites, countries or institutions, and is typically public. Records are stored one after the other in a continuous ledger, rather than sorted into blocks, but they can only be added when the participants reach a quorum.'	'A block chain is a type of database that takes a number of records and puts them in a block (rather like collating them on to a single sheet of paper). Each block is then "chained" to the next block, using a cryptographic signature. This allows block chains to be used like a ledger, which can be shared and corroborated by anyone with the appropriate permissions.'
Hong Kong Applied Science and Technology Research Institute Company (2016)	'DLT is built upon a series of networks of databases that allow participants to create, disseminate and store information in an efficient and secure manner. At the same time, these networks make constantly available for examination a full audit trail of information history, which can be traced back to the moment when a piece of information was created for the first time.'	'Structurally speaking, a blockchain may be considered as a series of blocks of information that are securely chained together.... All blocks newly formed after the first block are securely chained to the previous one, thus ensuring their authenticity and creating a trustworthy audit trail.'
Kakavand et al. (2017)	'Distributed ledger technology refers to the ability for users to store and access information or records related to assets and holdings in a shared database (i.e., the ledger) capable of operating without a central validation system and based on its own standards and processes.'	'Blockchain is "a database that consists of chronologically arranged bundles of transactions known as blocks," against which any proposed transaction can be checked with confidence in the integrity of any particular block. '

Source	Definition of DLT	Definition of Blockchain
McKinsey & Company (2016)	No definition provided	'An open-source distributed database using state-of-the-art cryptography.'
McKinsey & Company (2015)	Same definition as for Blockchain.	'A blockchain is a cryptographic, or encoded, ledger comprising a digital log of transactions shared across a public or private network.'
Murphy & Cooper (2016)	'Distributed ledger is a collection of records (making up a database), where identical copies of each record are held on numerous computers across an organisation, a country, multiple countries, or the entire world, either jointly or partitioned by the parties to which each record relates.'	'Blockchain is a distributed ledger taking the form of an electronic database that is replicated on numerous nodes spread across an organisation, a country, multiple countries, or the entire world.'
Peters & Panayi (2015)	No definition provided	'In its most crude form, one may consider a blockchain to be a ledger or, more simply, a chronological database of transactions recorded by a network of computers. The term "blockchain" refers to these transactions being grouped in blocks, and the chain of these blocks forms the accepted history of transactions since the inception of the blockchain.'
Taylor (2015)	No definition provided	'An Unpermissioned blockchain is an open, decentralised ledger which records the transfer of value. Every transaction is cryptographically chained to the previous transaction. The result is a permanent, immutable and verifiable record of truth that everyone can see.'
World Economic Forum (2016b)	'At its core, DLT is a growing repository of transactions organized in chronological blocks where the technology intrinsically makes changes to previous transactions functionally impossible.'	No definition provided

Appendix B: List of search terms used in the accelerated evidence assessment

Table 7: List of search terms used in the accelerated evidence assessment

Blockchain challenges, Distributed ledger technologies challenges
Blockchain barriers, Distributed ledger technologies barriers
Blockchain different sectors, Distributed ledger technologies different sectors
Blockchain key stakeholders, Distributed ledger technologies key stakeholders
Blockchain forecasts, Distributed ledger technologies forecasts
Blockchain predictions, Distributed ledger technologies predictions
Blockchain long-term predictions, Distributed ledger technologies long-term predictions
Blockchain + [specific year] e.g. Blockchain 2017; Blockchain 2018; Blockchain 2019; Blockchain 2020
Distributed ledger technologies + [specific year] e.g. Distributed ledger technologies 2017; Distributed ledger technologies 2018; Distributed ledger technologies 2019; Distributed ledger technologies 2020
Blockchain breakthroughs, Distributed ledger technologies breakthroughs
Blockchain standards, Distributed ledger technologies standards
Blockchain R3CEV, Distributed ledger technologies R3CEV
Blockchain chain, Distributed ledger technologies chain
Blockchain hyperledger, Distributed ledger technologies hyperledger
Blockchain ethereum, Distributed ledger technologies ethereum
Blockchain Chinaledger, Distributed ledger technologies Chinaledger
Blockchain music, Distributed ledger technologies music
Blockchain creative industries, Distributed ledger technologies creative industries
Blockchain finance, Distributed ledger technologies finance
Blockchain banking, Distributed ledger technologies banking

Blockchain healthcare, Distributed ledger technologies healthcare
Blockchain education, Distributed ledger technologies education
Blockchain McKinsey, Distributed ledger technologies McKinsey
Blockchain Deloitte, Distributed ledger technologies Deloitte
Blockchain PwC, Distributed ledger technologies PwC
Blockchain Barclays, Distributed ledger technologies Barclays
Blockchain KPMG, Distributed ledger technologies KPMG
Blockchain Harvard Business Review, Distributed ledger technologies Harvard Business Review
Blockchain smart contracts, Distributed ledger technologies smart contracts
Blockchain identity management, Distributed ledger technologies management
Blockchain code verification, Distributed ledger technologies code verification
Blockchain security, Distributed ledger technologies security
Blockchain IoT, Distributed ledger technologies IoT
Blockchain survey, Distributed ledger technologies survey
Blockchain McKinsey survey, Distributed ledger technologies McKinsey survey, Blockchain Deloitte survey, Distributed ledger technologies Deloitte survey
Decentralised autonomous organisation; Digital autonomous organisation
Additional searches using the term 'Blockchain' were done at following web sites: medium.com; wired.com; coindesk.com; theconversation.com
Additional searches using the term 'Distributed ledger technologies' were done at following web sites: medium.com; wired.com; coindesk.com; theconversation.com

Appendix C: Protocol for semi-structured interviews

I. [Introductory questions]

Q1. Could you please tell me a bit about your current role and how this relates to DLT/ Blockchain?

II. [General understanding of DLT/ Blockchain and the UK context]

We would like to ask you some questions about your general perception of DLT/Blockchain, as well as your understanding of developments taking place in the UK.

Q2. How would you define (a) Distributed Ledger Technology (DLT) and (b) Blockchain?

Q2.1 Do you feel there is any confusion or overlap in the terminology, or do people use the terms clearly?

Q3. What is your general understanding of the DLT/Blockchain landscape in the UK?

Q3.1 How has the wider DLT/Blockchain landscape been evolving in the UK over the last few years? Where is it heading (a) over the next 2-5 years and (b) beyond?

Q3.2 How does the evolution of DLT/ Blockchain in the UK compare to that of other countries active in this space? (E.g. Australia, Singapore, Estonia, Slovenia, US, China …)

Q4. Are there particular areas of DLT/ Blockchain where the UK has a global competitive advantage?

Q4.1 How do you see these specific areas evolving (a) over the next 2-5 years and (b) beyond?

III. [Perceptions of the challenges and opportunities]

We would now like to ask you some questions about your perceptions of the current and future barriers/challenges and drivers, as well as the potential opportunities in relation to DLT/ Blockchain.

Q5. What do you think are some of the main challenges currently faced in relation to the wider development and adoption of DLT/ Blockchain technologies (in the UK), and why?

Q5.1 Are any of these challenges specific to certain sectors? Are there different challenges you see for the area as a whole versus sector-specific challenges?

Q5.2 Are any of these challenges specific to certain aspects of DLT/Blockchain – e.g. smart contracts, code verification, anything else?

Q6. What do you think are some of the main driving forces for developing and adopting DLT/ Blockchain technologies (in the UK), and why?

Q6.1 Are any of these drivers specific to certain sectors? Are there different drivers you see for the sector as a whole versus sector-specific drivers?

Q6.2 Are any of these drivers specific to certain aspects of DLT/Blockchain – e.g. smart contracts, code verification, anything else?

Q7. Looking to the future, what do you perceive as some of the main opportunities in relation to the wider DLT/Blockchain ecosystem (in the UK) over the next 2-5 years and beyond?

Q7.1. Which sectors do you think present the greatest opportunities for the application of DLT/Blockchain technologies (in the UK), and why?

Q7.2. According to you, who are the main stakeholders (individuals/organisations) in relation to DLT/Blockchain (in the UK)?

Q7.3 What do you think would need to happen to realise these opportunities?

Q7.4 What would be the barriers preventing these future opportunities?

IV. [Perceptions of standardisation-related issues]

As we mentioned at the start of the interview, we are examining some of the main (market/business) issues behind which BSI (and others) can pull in key stakeholders to develop a standards strategy for DLT/Blockchain technologies. We would like to ask you some questions now about the potential role of standards in relation to the challenges and opportunities we just discussed.

Q8. What is your understanding of a standard?

Q9. Are you aware of any efforts to explore the potential for standards in this field?

Q10. Do you think developing standards for DLT/Blockchain would be useful at this time, and why?

Q11. In your opinion, what are the main areas where DLT/Blockchain standards (in the UK) could help nurture this developing technology and address some of the challenges you have talked about?

Q11.1 What are the sectors (in the UK) that could benefit most from the advent of standards in DLT/Blockchain, and why? (Which sectors are important for the UK's economy when we think of DLT/Blockchain?)

Q11.2 Who/what are the key stakeholders/ stakeholder groups that would need to work together to grow this area?

Q11.3 How does DLT/Blockchain relate to existing standards, i.e. are there any existing standards that are sufficient to cover emerging DLT applications (e.g. standards relating to information security, data handling, etc.)?

Q11.4. Are there any areas/sectors where the introduction of standards would potentially hinder growth?

Q12. What do you foresee as the main barriers and challenges in designing and adopting standards in this field?

Q13. According to you, which aspects of DLT/Blockchain are likely to be priorities while designing standards?

Q13.1 Which aspects of DLT/Blockchain standardisation should be a priority for the UK?

Q14. When do you think would be right time to start thinking about developing and delivering DLT/Blockchain standards?

Wrap-up

Q15. Based on your expertise and experience of working in this field, is there anything else you would like to add that we have not yet discussed?

Q16. Are there any other individuals that you think we should be speaking to – particularly those who would be able to provide expert assessment of the current/future outlook in the context of developing DLT/Blockchain standards?