The Evolution and Design of Digital Economies

Melvyn Weeks*
Faculty of Economics and Clare College
University of Cambridge

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Abstract

The technology of the distributed ledger, the so-called blockchain, is expanding beyond the creation of efficiencies in financial intermediation to include the management of consumption data originating from IoT micro devices, the trading of surplus renewable energy, and programmable transactions in the form of so-called smart contracts. Although the majority of current applications involve payments of some form, the key question going forward is whether the two technologies which underpin bitcoin, namely a digital token and the blockchain, can serve as a basis for other use cases.

In this paper we examine the evolution and design of marketplaces for digital economies. We first introduce a simple economic model which we use to understand the dynamics of firm boundaries, and the organisation of economic activity more generally. In examining how the contrasting forces of scale and scope economies, together with the relative costs of transacting within firms and markets have facilitated the emergence of decentralised marketplaces, we make use of a number of core economic principles. These include the economics of transaction costs, ownership and control, the principal-agent problem, bounded rationality, information asymmetry and trust relations. We also consider the technological antecedents of blockchain technology, including the Internet protocols and the fundamental distinction between a distributed database and ledger.

Against this backdrop we consider the motivation behind the FETCH protocol which provides a set of tools for the dynamic creation of intelligent marketplaces for an agent-based economy.

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Keywords: blockchain; distributed ledger; smart contracts; mechanism design; theory of the firm; digital economies, autonomous agents; FETCH.

*Contact Author: Dr. M. Weeks, Faculty of Economics, University of Cambridge, Cambridge CB3 9DD, UK. Email: mw217@econ.cam.ac.uk. We have benefited from comments provided by Arthur Meadows, Humayun Sheikh, Toby Simpson, and speakers and participants at the Indepen Forum *Disruptive and enabling or just disruptive? What will blockchain do for customers of utilities?*

Disclaimer

In this paper we provide a first overview of how we see the evolution and design of digital economies. Given that decentralised markets are emerging, economists and computer scientists are learning how to adapt the tools developed to build and understand the dynamics of centralised marketplaces. As such we see this project as on-going and will provide the necessary updates to this paper.

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Blockchain is not only useful in moving money, it's useful in moving any asset - whether that's a unit of energy or a unit of computing power - in a very transparent and reliable way.

David Bartlett, Chief Technology Officer for General Electric's
digital power services business.

"Blockchain is to Bitcoin, what the internet is to email. A big electronic system, on top of which you can build applications. Currency is just one".

Sally Davies, FT Technology Reporter.

1 Introduction

The emergence of distributed ledger technology has coincided with fundamental changes in the organisation of economic activity, and in particular how economic agents interact within markets. The traditional model of exchange has a firm producing goods and/or services upstream and selling them to consumers downstream. However, with the proliferation of online marketplaces and e-commerce, we have observed the rise of alternative forms of organising economic activity, including platform markets and more recently peer-to-peer exchange.

One example where the application of blockchain technology has significant potential to disrupt and create new markets is the energy sector. As Gugler et al (2017) note, prior to the introduction of liberalization and regulatory reforms in the European Electricity sector, vertical integration of upstream and downstream operations of an electricity utility was the predominant organizational form in order to benefit from scope economies.

More recently, the emergence of distributed energy resources (DERS) in the form of solar and wind generation and energy storage, is changing the nature of energy markets. Unidirectional flows of energy from transmission to end customers now coincide with a distributed system where reverse and peer-to-peer flows occur over a network where the size distribution of sellers is changing. In this context, a key challenge is how to manage, integrate, and monetize an increasingly distributed mix of energy supply and storage.

Increasingly, machine learning and artificial intelligence are being integrated with the trading systems, facilitating the execution of agent-based transactions within a more distributed network. At a recent financial technology conference at Michigan Law School, it was estimated that computers are now generating around 50-70 per cent of trading in equity markets, 60 per cent of futures and more than 50 per cent of treasuries. The JP Morgan analyst Marko Kolanovic estimates that a mere 10 per cent of US equity market trading is actually now conducted by discretionary human traders; the rest is driven by various rules-based automatic investment systems, such as computerised high-speed trading programs.[1]

Decentralised systems, based upon blockchain technology combined with autonomous agents, have the capacity to manage the flow of information emanating from the so called Internet of Things (IoT) which operate and monitor systems that control electricity consumption. Platform markets such as Uber operate a model of exchange whereby the supply side is decentralised (by allowing any driver the opportunity to drive) with the platform providing a matching role. However, although the potential to buy services directly from individual providers gives the impression of a distributed peer-to-peer (P2P)

[1] Originally reported by Gillian Tett, the FT writer.

network, as Tasca and Ulieru (2017) emphasise, "*Uber runs on a 'smart' phone via a quite 'dumb' application which links into a centralized platform*". In this regard blockchain as a technology has the capability to facilitate an alternative form of decentralised exchange, threatening the monopoly position of platform intermediaries in sectors such as transportation, e-commerce and financial services.

As McLeay et al (2014) point out, trust protocols such as banking systems and credit rating agencies that provide the basis for exchange between parties, face the emergence of new measures of trustworthiness. These measures, representing the codification of reputation and trustworthiness, provide a critical prerequisite for distributed interactions between buyers and sellers by allowing potential customers to rank supplier performance. In this respect a network of buyers and sellers has the potential to self regulate, circumventing the need for a centralised platform.

In its original form, blockchain technology facilitates monetary exchange, as in the case of Bitcoin. However, as noted by Perez (2003), the digital ledger, the so-called blockchain, is expanding beyond the creation of efficiencies in financial intermediation to a technology that can facilitate different forms of exchange through smart contracts. Potential applications extend to a large number of areas, including the management of consumption data originating from the micro devices, the trading of surplus renewable energy, and programmable transactions in the form of smart contracts. As noted by Deloitte (2016), blockchains also promote vertical disintegration by changing the costs of supply chain management, streamlining processes spread across multiple parties and databases on a single shared ledger.

As emphasised in a report by the UK Government Chief Scientific adviser,[2] new technologies come with a new vernacular, which in some cases can create problems for policy makers and those charged with making decisions around adoption. In the above quote by Sally Davies[3] blockchain is being used generically to denote the related family of technologies and solutions. In contrast the use of blockchain as the indefinite article refers to the distributed ledger technology, where blocks of transaction made in bitcoin (or another cryptocurrency) are recorded chronologically.

In this paper we examine the evolution and design of marketplaces for digital economies. To do this we first need to understand the economic and technological antecedents of blockchain, and ultimately the emergence of decentralised marketplaces. In examining how the forces of scale and scope economies and the relative costs of transacting within firms and markets have facilitated the emergence of decentralised and agent-based marketplaces, we make use of a number of core economic principles, such as the economics of transaction costs, matching, the principal-agent problem, bounded rationality, information asymmetry and trust relations. We also consider the technological antecedents of blockchain technology, and in particular the fundamental distinction between a distributed database and ledger.

In Section 2 we consider blockchain technology in the broader context of the obstacles to competition in online marketplaces. In Section 3 we introduce a simple economic model which we use to understand the dynamics of firm boundaries, and the organisation of economic activity more generally. Section 4 provides a brief examination of the ownership and control dichotomy in a decentralised digital economy. In Section 5 we examine a

[2]See *Distributed Ledger Technology: beyond blockchain.*

[3]This distinction is eloquently made in Deloitte (2016a), *Bitcoin, Blockchain & distributed ledgers: Caught between promise and reality.*

number of mechanisms which facilitate the operation of decentralised markets including the distributed ledger and trust and reputation systems. In Section 6 we examine a number of what we refer to as "emerging markets" which exploit the availability of cheap storage and computer processing to deliver information and data. Against this backdrop, in Section 7 we take a brief look at the FETCH platform, which provides a set of tools for the dynamic creation of intelligent marketplaces for a future agent-based economy. Section 8 concludes.

2 Online Markets and The Internet

Although the Internet has brought significant benefits by improving the efficiency of markets through the increase and speed of information flows, we have simultaneously observed the emergence of a new type of monopoly provider based upon the provision of internet-based services. In examining *The Market Failures of Big Tech*, Martin Sandbu[4] highlights a number of obstacles to competition inherent in internet-based businesses, summarised below.

First and foremost, as the number of customers using platform applications and services increase, network externalities accrue creating economies of scale. The efficiency of the platform increases, as do entry costs for competitors. Second, independent of the scale effects that derive from network externalities, internet companies such as Amazon enjoy cost advantages due to the scale of operation. In addition, companies which assume a pure intermediation role by matching buyers and sellers, will accrue significant savings in unit cost following an increase in scale.

Third, the fact that internet companies collect huge amounts of information on their customers, allows them to offer an increasing array of products and services. The resulting economies of scope, with average total costs falling with the increase in variety, provide further advantages over competitors.[5] As Scott Leland notes[6]

> *More than anyone, the Alphabet* CEO *Larry Page understands that if you first "organize the world's information," then second track and analyze most all of most everyone's interaction with that information, one can then understand global supply and demand better than any mortal ....*

Below we first examine the evolution of firms, markets, and platforms in terms of a changing dynamic between the returns to scale and scope, and the potential change in the costs of transactions, and ultimately market structure. In Section 5 we contrast the design of the Internet and blockchain protocols, and for the latter highlight the role of open source software, a distributed ledger, and a token mechanism, in providing alternate business models and the potential for a different market structure.

[4]See Financial Times, February 2017.

[5]An additional characteristic is that some Internet business activities have been designed to be addictive.

[6]See `http://www.precursorblog.com/?q=content/what-everyone-missing-alphabet-google-restructuring`.

3 Firms, Markets and Platforms

> *"A firm has a role to play in the economic system if transactions can be organised within the firm at less cost than if the same transaction were carried out through the market. The limit to the size of the firm is reached when organising additional transactions within the firm exceed the costs of carrying out the same transactions through the market".*
>
> Ronald Coase, The Theory of the Firm (1937).

The arrival and subsequent growth of the Internet has threatened to make one of the principal tenets of neoclassical economics, perfect information, where consumers and producers are assumed to have full information on prices, quality and production methods, a reality. Relative to off-line markets, search costs on the Internet might be expected to be lower and online consumers to be more easily informed about prices. However, as Don Tapscott,[7] an author on the impact of digital technology on business and society, notes that "*With today's internet of information you can't store, move, transact value without a powerful intermediary. And that's what blockchains solve.*" Although information technology has also lead to a fall in transaction costs for both buyers and sellers, blockchain technology provides the potential to reduce the returns to scale and scope through the cost reduction potential of decentralised consensus mechanisms, allowing smaller entities to transact in the market.

In this section we utilise a simple economic model to understand how the tension between centralised and distributed marketplaces gives rise to alternative forms of economic organization. We begin in Section 3.1 by focusing on the pivotal role of transaction costs in shaping the structure of markets and ultimately the boundary of a firm. In Section 3.2 we briefly examine the economic model underlying platform markets. In Section 3.3 we examine the evolution of decentralised markets, an alternative form of organising economic activity which represents a fundamental break from the classic Coasian firm-market dichotomy. Finally in Section 3.4 we examine a number of key factors which drive the economics behind peer production, including the impact of new suppliers on incumbents, and the choice of pricing models.

At the outset it is important to be clear as to what we understand by the terms decentralised (DC) and distributed (D). In the blockchain literature these terms are often used interchangeably. Although these terms are also context specific, in this paper we take the position that D does not imply DC, as, for example, in the case of a distributed but *not* decentralised database. However, DC does imply D in that a decentralised database must be distributed.[8]

3.1 Firms and Markets

Throughout much of the 20th century the combination of the fall in both transaction and communication costs, together with attendant economies of scale and scope, has resulted in an increase in the division of labour within and beyond national boundaries, with a significant effect on the size distribution of firms. Prior to the emergence of the firm as a means to organise economic activity, goods and services were traded directly

[7] See *Blockchain Revolution: How the Technology Behind Bitcoin Is Changing Money, Business, and the World.*

[8] In this respect the two terms are not completely interchangeable.

without middlemen; trade took place directly between individuals, with production on a relatively small scale. With changes in the scale of production, facilitated by new technology and changes in geographic distribution of the population, the relative costs of organising economic activity through firms fell.

Here we introduce a simple economic model which relates the organisation of economic activity and the structure of marketplaces according to the costs of transactions. Neoclassical economic theory at the time of Coase was based on an implicit assumption of zero transaction costs. In an essay on *The Nature of the Firm* (1937), Coase highlighted the role of the costs of transacting in markets, as the principal factor mediating economic activity through the firm, as opposed to a multitude of independent traders who contract in markets. In brief Coase viewed the market and the firm as "alternative methods of coordinating production" (1937, p. 388).

A key component of transaction costs arise from the costs of coordinating buyers, sellers, suppliers and labour. For example, in considering the size of firms, one of the most widely cited stories on changes in firm boundaries is the case of Fisher Body (FB) and General Motors (GM). In the first instance FB produced bodies for GM, with both firms operating as separate firms, linked by contractual arrangements. During the 1920s GM's demand increased substantially, and FB refused to accommodate the increase in supply. Subsequently GM bought out FB, creating an example of a vertical integrated firm, effectively internalising trade. Arrow (1969) noted that "the existence of vertical integration may suggest that the costs of operating competitive markets are not zero, as is usually assumed in our theoretical analysis" (1969, p. 48).

In this context one perspective on the existence of a firm, and the one expounded by Coase, is that it serves as a device for creating long-term contracts between labour, suppliers and debt providers, when short-term contracts are too costly or time consuming. However, Coase also pointed to the limits in the returns to scale and scope, and as such the benefits of vertical integration, given that internal markets within firms create transaction costs of their own.

Following in the footsteps of Coase, Williamson (2009) in his Nobel Prize lecture, highlights the key motivating question driving his work on transaction economics: "What efficiency factors determine when a firm produces a good or service to its own needs rather than outsource?" Williamson,[9] together with a number of researchers including Baumol (1959), sought to clarify the specific nature of transactions costs, introducing the behavioral elements of principal-agent conflicts as additional determinants of the boundary between the market the firm.

Other notable contributions in this area include Gibbons (2005) who develops an integrated framework for examining the contracting theories of Coase and Williamson and vertical integration. Based upon the notion that the theoretical underpinnings of transaction cost economics represent a partial equilibrium view of the world, Bresnahan and Levin (2012) extend the analysis beyond contracting theories to include the role of economies of scale and scope, alongside network effects.

[9] See Williamson (1975, 2002).

3.2 Market Places as Platforms

A predominant feature of online commerce is the presence of two-sided markets or platforms, where platform operators derive revenue from the role of an intermediary. Martens (2016) notes that platform markets represent a new “generation of online business models where firms organise markets rather than behave like a vertically integrated firm”. Platform markets exploit information technology to provide a coordination mechanism, facilitating interactions between buyers and sellers. By using various market design mechanism platforms allow buyers to locate and trade with trustworthy sellers. Einav et al (2016) provide an excellent review of the academic research in this area, and also examine the design of Internet markets along with the economics of peer production. As Martens (2016) notes, the emergence of online platforms has coincided with the dramatic decline in information costs, changing the balance between the benefits of internal (firm-based) and external markets, enabling a volume of exchange that was not feasible in online markets. In this sense information technology shifts the boundary between the firm and the market.

Rochet and Tirole (2004) define two-sided markets as “markets in which one or several platforms enable interactions between end-users (i.e. buyers and sellers, advertisers), and try to get the two sides *on board* by appropriately charging each side”. In order to capture network externalities, platform owners face the so-called "chicken and egg" problem, where the value to each side is dependent on the use of the other side. To overcome this problem platforms face the choice of a pricing structure which reflects the relative price sensitivities of the groups at both sides of the platform. One example, Ramsey Pricing, sets individual prices above marginal cost in accordance with each service’s price elasticity of demand. Services with more inelastic (elastic) demand face prices with a higher (lower) mark-up above marginal cost, effectively cross-subsidising the other side.[10]

Business models vary according to the relative strength of each side. In reviewing the form of competition in two-sided markets, Rochet and Tirole (2003) provide a number of examples of pricing strategies. In the case of video game platforms operated by Sony, developers are charged to access the platform in the form of fixed fees for development kits, and also per-unit royalties on games, with the gamers side of the platform treated as a loss leader. Other operators derive revenue from charging for the service (Uber), or subjecting the consumer to advertisements (Facebook or Google).

Pollitt and Richter (2016) consider the choice of pricing structure for platform markets in the context of the demand and supply of data. The principal question is whether on one side of the platform the supplier of data (i.e. smart-meter) should pay to access the platform, or be compensated given a high level of demand on the other side. The authors utilise a stated preference methodology to examine the demand for electricity service contracts in a smart grid context. In the presence of network externalities and where the marginal value of a connection for current and future customers exceeds the marginal cost of connecting an additional customer to the platform, the service provider can compensate consumers and still generate positive profits. A main finding is that in order to participate in automated demand response programs, customers are likely to require significant compensation from the retailer to share their usage data.

[10] See `http://regulationbodyofknowledge.org/tariff-design/economics-of-tariff-design/ramsey-pricing/`.

3.3 Decentralised Markets

A natural progression of this form of market evolution is the removal of the platform or in other words peer-to-peer transactions without an intermediary. We refer to this type of exchange as decentralised in the sense that both supply and demand is geographically dispersed, with trade occurring outside of any centralised physical or online marketplace.[11] A notable example is OPENBAZAAR, a peer-to-peer commerce network using bitcoin which in essence is a decentralized version of eBay. In the absence of intermediation there are no fees and no restrictions on what goods can be listed and sold. Peer-to-peer transactions can also be enabled in distributed energy markets, with as an example, small-scale transactions between individual producers of solar panels and consumers. Power Ledger has built a decentralised energy trading market that allows prospers to export energy to their peers in a trustless environment.

In this context blockchain technology can be viewed as the enabling technology by providing a *platform* for disintermediation. As we discuss further in Section 5, the mechanisms underpinning market design in peer-to-peer decentralised market places are centred upon a distributed ledger in conjunction with a consensus mechanism, providing a means for authenticating the trustworthiness of buyers and sellers, and thereby facilitate exchange in a permissionless network. This then provides the preconditions for an increase in competition and less friction in transactions.

It is now well recognised that there exists a market for data that is created by individual behaviour. Blockchain technology provides the mechanisms to create a market for individual consumers to sell data for monetary rewards, avoiding the high transaction cost of fiat currency, given the existence of micropayments. Examples include, traffic congestion data, electricity consumption on smart meters, and health. In many instances this type of data is extracted from user appliances (which in some instances can occur without the knowledge of the consumers) and aggregated through central points.

As emphasised by Coase, peer-to-peer marketplaces come at a cost, in that dependent on the design of the marketplace, it is possible that the total cost of decentralisation exceeds that of a comparable centralised marketplace. We expand on this point in Section 5, where we examine the technology of the distributed ledger, along with a number of scalability issues which have plagued the adoption of Bitcoin, and in particular the problem of both settlement times and transaction costs.

3.4 Peer Production

In this section we briefly outline a number of features of what has been referred to as the economics of peer production. Benkler (2002) argues that peer production represents a "third mode of production in the digitally networked environment", and best understood as a category of economic organization that represents a fundamental break from the traditional Coasian firm-marketplace dichotomy.

Einav et al (2016) develop a stylized model of peer production with two types of producers. Type $\mathcal{A}$ sellers are characterised by relatively large firms who operate in a market with up-front investment and employ labour on a full-time basis. Type $\mathcal{B}$ sellers are characterised by being smaller and as a result more able to respond to price signals.

[11] It is noteworthy that Einav et al (2016) use a different vernacular referring to eBay, Uber, and Airbnb as peer-to-peer markets. However, the key characteristic is the focus on markets that are centralised in that peer-to-peer trade is mediated by a central authority.

Both types of sellers face a cost of advertising, f, in order to become visible to sellers. An entering seller can choose to operate off-platform and pay the direct advertising cost f, or join the platform and pay a combination of fixed of fixed and variable fees. The model assumes that buyers can purchase readily on or off the platform, such that sellers can expect the same market price π independent of whether they join the platform.

One interesting output of their model is a stylised representation of the rise of peer-to-peer markets and specifically the impact on prices and market structure. A number of interesting questions can be addressed with this type of model. One particularly important consideration for both incumbents and new entrants is the impact of the structure of platform fees. For example, in the simple case where the platform charges a fixed fee to all sellers, the platform will attract all (none) of the sellers dependent on whether the fee exceeds (is less than) the direct advertising cost f. We believe that future research might use this type of model as a basis for addressing similar questions for decentralised peer-to-peer markets, isolating the role of alternative consensus mechanisms and pricing using a (potentially) volatile cryptocurrency.

4 Ownership and Control in a Digital Economy

In this section we consider the fundamental dichotomy between ownership and control in the context of decentralised markets, and examine how blockchain technology provides the potential to change the form of the traditional principal-agent relationship. In addition, we examine the case for combining the digital technology of the distributed ledger and smart contracts with a native token, or currency. We also examine the nature and form of cryptocurrencies, and it what sense these currencies can be considered the digital equivalent of money.

4.1 Ownership and Control

A fundamental prerequisite underlying the decision to enter a market to consume, invest, or trade, is the presence of safe institutions and attendant good governance. This applies equally to sovereign and digital economies, although there are a number of notable differences. Fiat currencies are traditionally issued by sovereign governments, who alongside central banks determine rules governing the supply of the currency. In these economies banks hold the centralised digital record of transactions and are trusted to ensure its validity. In a digital economy the distributed ledger contains the record of all transactions.

One of the central tenets in the theory of corporate governance is the potential conflict that emanates from the separation of ownership (shareholder/principal) and control (manager/agent). The agency relationship is generally defined as a contract between principal and agent whereby the agent acts on the principal's behalf (See Jensen and Meckling (1976)). However, as Brennan (1995) and Kaal (2017) have underlined, the existence of both bounded rationality and information asymmetries means that it is not possible for principals to contract for every possible action or inaction of the agent.

The technology of the distributed ledger, and in particular the presence of a consensus mechanism and information that is consistent across the entire network, goes someway to circumvent the conflicts which arise through the separation of ownership and control. As noted by the Boston Consulting Group (2016), there is no need for a Bitcoin "account", with a separation between the account holder and the location of funds. The lack of separation between individual ownership and control of a personal account is apparent since Bitcoins are held in a personal wallet.

In the case of digital currencies, authenticity is provided by the digital ledger, which is maintained by a network of computers. Governance is distributed throughout the network as opposed to being allocated to special institutions. In the Bitcoin network, governance is distributed in the sense of being controlled by special users known as 'miners'. Miners collect blocks of transactions and using cryptographic techniques compete to determine whether the payer is the owner of the currency in question. As a reward for successfully verifying the authenticity of a block of transactions, miners receive an allocation of tokens and any transaction fees offered.

As security of the network increases, there are network effects as the demand for the token increases, which then attracts more miners to provide additional verification. Miners receive rewards in the form of new tokens, and dependent upon monetary rules, this can create monetary inflation. As the currency appreciates in value, prices and transaction fees within the token economy can be adjusted by pegging transaction fees to a fiat currency.

4.2 Cryptocurrencies

The term cryptocurrency derives from the fact that the tokens are encrypted using cryptography techniques that secure and verify transactions, whilst preserving the anonymity of users holdings of digital currency. However, the very notion of a crypto*currency* is, in many cases a misnomer, given that the role of money is fulfilled to a limited extent. As an example, Paul Krugman (2011) has noted that, based upon recent market conditions, the short-run inflation of the dollar/pound value of cryptocurrency, can make these currencies a good store of value for investors. However, in the case of Bitcoin we have seen the emergence of a scenario that blockchain decentralised marketplaces were designed to overcome, namely high prices, driven in part by the design of underlying protocol, to the detriment of use value.

Here and throughout this paper, we stress the importance of clarity in terms of the meaning of terms that are often used interchangeably. In this context, there is often confusion as to the vernacular surrounding the terms digital token, currency, and cryptocurrency. In the most broad sense, tokens are simply units of currency enabling transactions within a particular environment, and may be exchanged for legal tender or other cryptocurrencies such as Bitcoin or Ethereum. However, in contrast to fiat currencies where the value of the currency is generally fixed, cryptocurrency fixes the total quantity. This is analogous to the gold standard, where the money supply is fixed rather than subject to increase via a central monetary authority. Bitcoin, for example, has a clear monetary policy: the supply of coins is fixed at 21 million. The rate of creation decreases by half every four years.

In addition, digital currencies are distinct in a number of other notable ways. First, whereas bank deposits represent a liability for the bank and an asset for the account holder, digital currencies do not represent a claim on anybody. Second,[12] although digital currencies may be viewed as a commodity, their intangible nature make them more akin to digital commodities.

As a point of reference, McLeay et al (2104) points to the following role of money in

[12]See McLeay et al (2014).

society: a store of value with which to transfer purchasing power (the ability to buy goods and services) from today to some future date; a medium of exchange with which to make payments; and a unit of account with which to measure the value (i.e. price) of any particular item that is for sale.

To the extent that digital currencies serve as money, the allocation of tokens to users that contribute computing resources towards the verification of transactions on the network is similar to seigniorage, in the sense that tokens have a net value given the cost of its creation.[13]

Kalla (2017) emphasises that it is important to recognise that cryptocurrencies are distinct, making reference to the following classification:

- Cryptocurrencies built using Bitcoin's open-sourced protocol are generally referred to as *Altcoins*. As an example, the Litecoin token changed a number of parameters including the mining algorithm and the total supply of coins.
- Cryptocurrencies designed for a different purpose using a different blockchain. Examples include Ethereum and NXT, a proof-of-stake coin.
- Cryptocurrencies designed for a specific application, and required to use that application. In this sense the generic term cryptocurrency is not appropriate here, with digital (or *use*) token being a more appropriate moniker.

5 Mechanism Design for Agent-Based Decentralised Economies

> .. *Because computers are now cheap and ubiquitous, we can design "smart markets" that combine the inputs of users in complex ways. Kidney exchange is an example of a smart market. By running through every possible combination of donors and patients, it can arrange the highest possible number of transplants.*
>
> Al Roth (2007), Nobel Laureate.

In Section 3 we examined the role of transaction costs, alongside scale and scope economies, in determining the organisation of economic activity, and specifically defining the boundary between the firm and the market. In this section we examine a number of tools that are used to enable the operation of decentralised markets, and specifically how these tools impact transaction costs. In this context it is instructive to view the Internet protcols, aligned with web browsers and search engines, as a mechanism which provides efficient and low costs matching between buyers and sellers. The design of market mechanisms for online markets presents further opportunities to reduce the costs of entry and transaction costs, and therefore increase competition. However, there are very real challenges if the 'automation of user-market interaction' is to deliver the potential of truly automated transactions over a wide range of sectors.[14]

In agent-based marketplaces the agent is a piece of software which in general terms works on behalf of a user by implementing a series of instructions. Here we make the distinction between simple agents and those which we will refer to as *intelligent*. Simple agents are

[13] A key difference is that a payment is made to miners in return for the verification of transactions, whereas seigniorage accrues to the government.

[14] See Vulkan and Priest (2013).

autonomous *conditional* on a set of instructions which exist in the form of a contract. We can think of such a contract as complete in the sense that for the task at hand, the instructions encompass the set of possible outcomes. For example, eBay's bidding agent autonomously bids on behalf of a user, conditional on an upper limit and pre-specified increments. In contrast a number of protocols such as that being developed by FETCH (see Section 7), have combined machine learning with the distributed ledger, providing *intelligent* agents that have the capabilities to learn from their environment and do far more than execute simple instructions.

Although these tools physically exist in the form of computational features such as Internet and blockchain protocols, distributed storage and databases, the rationale for the underlying design rests firmly with a number of principles provided by a sub-field of microeconomics, mechanism design, used by analysts and policymakers to design institutions and markets where agents are incentivised to behave in a particular way.

We highlight the role of mechanisms that can be deployed to solve a number of key problems in the design of markets which operate within permissionless networks. These mechanisms are used in the determination of identity, matching buyers and sellers, the authentication of transactions without a trusted intermediary, and the design of digital tokens. For example, in the area of auction design and regulation of monopoly providers, mechanisms can be put in place so that agents are incentivised to reveal true values in a world of asymmetric information. In addition, in the case of online marketplaces, a key design mechanism concerns how to build enough trust so that strangers can trade remotely.

Blockchain technology has the potential to reduce transaction costs, execution risk, and information asymmetry, and in doing so increase the speed of transaction. The central feature of mechanism design based upon blockchain technology is the use of decentralised consensus which provides the authenticity of transactions within a trustless network. That said, it is important to highlight significant variation in the form of blockchain technology, manifest as different protocols which impact the way in which exchange is mediated. For example, the limitations of the proof-of-work protocol that supports the use of Bitcoin as a means of payment for goods and services, have been well documented. Most recently Goldman Sachs in a note to clients[15] underlined the potential of digital currencies that leverage blockchain technology, including "ease of execution, lower transaction costs, reduction of corruption ... and safety of ownership." At the same time, the authors noted that "Bitcoin does not provide any of these key advantages," pointing to the relatively long settlement times.

Below we examine the anatomy of the so-called "decentralised stack", which represents the totality of computing functions which constitute blockchain technology. This comprises storage, processing and communication protocols, combined with a distributed ledger, a payment system, a trust and a token mechanism, machine learning and one or more decentralised applications. We also contrast the design and associated incentive mechanisms that underpin the decentralised stack of blockchain protocols and the stack of the Internet protocols.

In Section 5.1 we look at the precursor to the distributed ledger, the distributed database. Section 5.2 considers the role of payment systems within the decentralised stack, and in particular how micro transactions require a different protocol than used in standard blockchains. Section 5.3 examines the mechanisms by which trade is facilitated through

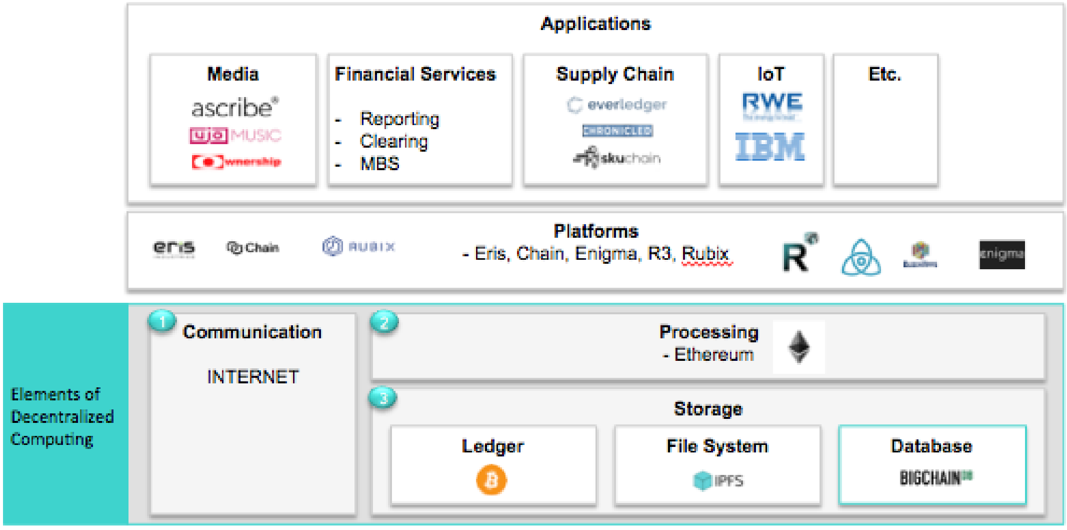
[15] *(Un) steady as She Goes. Outlook* Report, January (2018).

trust and reputation, and in Section 5.4 we examine the role of machine learning as a tool to add value to a history of transactions recorded on the distributed ledger. Section 5.5 looks at decentralised applications, and Section 5.6 examines the role of digital tokens.

The Anatomy of The Decentralised Stack

In Figure 1, reproduced from Pon (2015), we present a schematic representation of the layers of computing technology that comprise what some have referred to as the "decentralised stack". The base layer comprises the computing functions of communication, processing and storage on which applications can be built. In a number of protocols, decentralised storage has three components: a ledger which keeps track of all transactions on the network, a file system, and a decentralised database. In this instance we have represented decentralised processing using the Ethereum protocol.[16]

Figure 1: A Decentralised Stack: Computing, Platforms and Applications



Below we first list and then consider a number these components.

- **Decentralised Storage** the base layer of the network comprised of:

  a distributed ledger which provides **consensus** on transactions;

  a file system;

  a distributed database which stores information other than pure;

  transaction data.

- **Trust and Reputation** to provide assurance to users of the network.
- **Payment Systems** which facilitate exchange of value between buyers and sellers.
- **Smart contracts** to automate and streamline business processes.
- **Machine Learning** to drive better decisions and detect network anomalies.
- **Decentralised Applications** such as software which provides access to goods or services.

[16]In Section 7 we will present the FETCH protocol and consider the advantages.

- **Digital Tokens** providing digital representation of value.

5.1 The Distributed Database and The Distributed Ledger

In Section 3 we considered the evolution of decentralised marketplaces from the perspective of how changes in technology and the costs of transactions, determine the organisation of economic exchange and the structure of marketplaces. In a similar fashion it is instructive to consider how the distributed ledger itself has evolved from a distributed database.

The Distributed Database

> *Why can't companies wanting to share business logic and data just install a distributed database? What is the essential difference between a distributed database and a distributed ledger?*
>
> G. Brown (2016).

The distributed database emerged, in part, with the development of the internet, and the attendant need to process large quantities of structured and unstructured data which could scale across networks. Databases are distributed when the storage devices are spread across multiple physical locations or nodes. However, as emphasised in Section 3, the physical distribution of a database (either in parts or in its entirety) over locations within a network, does not say anything about the form of control. For example, given that a database management system (DDBMS) can integrate and manage distributed data, we observe that although a distributed database is a necessary condition for the decentralised control mechanism, distributed databases can coexist with a centralised control mechanism.

Brown (2016) makes a distinction between a distributed database and a distributed ledger. In the case of the former, the network is comprised of a group of computers which is invariably under the control of a single organisation where "each node in the system trusts the data that it receives from its peers, and nodes are trusted to look after the data they have received from their peers." As a result, in a world where trust and governance can be reliably delegated to a central operator, the gains from blockchain technology do not derive from the decentralised consensus mechanism.

Gideon (2015) in considering the extent to which blockchain can be considered both an economic and a computer science innovation provides an excellent comparison of the technology of the distributed database aligned with multiversion concurrency control (MVCC) and the distributed ledger. To do this Gideon utilises the following example, based upon a

> *... list of bank accounts, in which each row contains an account number along with the balance of that account. Let's say your account starts the day with a balance of £900. Today an automatic mortgage payment of £750 is scheduled and you also need to withdraw £400 from an* ATM*. Unfortunately you do not have an overdraft facility so one of these operations is set up to fail.*
>
> *The processes for mortgage payments and* ATM *withdrawals run on separate systems, both of which access this single account database. Let's say that each process works by reading your account's balance, checking it is sufficient for the operation,*

initiating that operation, verifying the operation completes, calculating the new balance and then finally writing it into the database.

As long as the mortgage payment and ATM *withdrawal don't overlap, this logic will work fine. The first operation will execute successfully, and the second will abort because your account has insufficient funds. Depending on the order, you'll get an angry phone call from the bank or a rude message on the* ATM *screen.*

Given that MVCC technology facilitates parallel transaction within a short time interval, whilst preserving the integrity of the database, Gideon (2015) further notes that

If two transactions attempt to delete the same row version, then only one of these transactions will ultimately be accepted. Multiversion concurrency control acts as a unified mechanism to detect and prevent these conflicts within a database.

This example demonstrates that blockchain technology solves the same problem using an alternative mechanism for synchronising distributed databases. The question that naturally follows is how is the distributed ledger technology different from a distributed database? We consider this question below.

The Distributed Ledger

Cheap computing in the form of processing power and storage is a fundamental precondition for a digital economy. The distributed ledger technology exploits the availability of cheap storage, distributing copies of the complete record of transactions across the network, thereby creating the conditions for a decentralised consensus mechanism.

As demonstrated above, both blockchain and MVCC enable concurrent transactions to access a single database without conflict or a degradation in process time. However, as Raval (2015) points out, blockchains have a number of additional important features which are not available in today's distributed databases. The most important of these in the context of permissionless networks, is that the mechanism of the distributed ledger solves a key problem with distributed databases in that it is not possible to facilitate transactions between parties within a network that do not know each other. In the case of blockchain technology, the consensus mechanism is itself distributed throughout the network, operated by multiple computers or "nodes". This technology has the potential to be less costly than traditional databases because the distributed system regulates itself and automates much of the overhead generally required for verification of various transactions. The reduction in risk inherent in blockchain systems provides the potential for financial institutions to settle transactions faster and with less scrutiny.

The technology of the distributed ledger may be considered an application in its own right, and can be deployed without digital tokens. As an example, IBM has developed a blockchain platform which among other uses is designed to reduce the cost of making global payments for businesses and consumers.[17] Moreover, companies that currently own and operate centralised platforms, such as MasterCard, are looking into the use of blockchain as a means to increase the speed and reduce the cost of transactions for existing business models.[18]

[17] See `https://www.ibm.com/blockchain/`.

[18] See `https://developer.mastercard.com/product/mastercard-blockchain`.

5.2 Scalability and Payment Systems

When individuals send payments in the form of cryptocurrency in the absence of a central banking authority, a primary challenge is the design of a (payment) system where transactions can be verified and automatically updated without transactions being altered. Stocker (2018) refers to the distributed ledger mechanism which underpins Bitcoin and Ethereum, as a *discrete* blockchain given the way in which blocks of transactions that are collected en masse, authenticated by a 'miner' and committed to an existing chain of transactions.

There are, however, a number of known problems with particular instances of the distributed ledger technology. One immediate problem with this type of payment system is scalability in the presence of micro, time-dependent transactions. In the case of public blockchain networks which rely on proof-of-work for mining (i.e. Bitcoin and Ethereum) the payment throughput handling capacity is limited given the way in which transactions are written to the ledger. This creates a constraint on the viability of micro-transactions without paying large fees. As a reference point, Bitcoin can handle around four transactions per second, Ethereum 15 to 25, Ripple around 1,000, and Visa around 10,000.

The issue is particularly important in the context of markets that are emerging based on the demand and supply of data from the so-called IoT. Most current IoT applications connect devices with a common owner, so they only need to exchange information or instructions. When devices have different owners, then in the absence of a shared intermediary, transactions involving small monetary value may not be economically worthwhile. This is particularly true on a large scale as the transaction delay becomes consequent and thus not suitable for most applications. IOTA, formed in 2015, with a primary focus on enabling automated IoT applications, was designed to transfer crypto-tokens at zero transaction fee.

5.2.1 Micro Payment Systems

In a world where machines are continuously transacting physical and digital values in a peer-to-peer (P2P) network, the use of blockchain protocols which rely on *discrete* payment methods (i.e. proof-of-work) are not an economically viable method to process micro-transactions. In this instance the scalability requirement may be realised by using a permissioned blockchain network, in conjunction with consensus algorithms such as Proof-of-Authority or Proof-of-Stake. So-called *payment channels* provide high frequency scalable micro payments with zero transaction fees. This type of payment system does not require block confirmations on the main chain and as a result can be used for device-to-device transaction or in any scenario where instant payments are needed. In contrast, a smart contract discrete payment method such as Bitcoin / public Ethereum blockchains, is not yet scalable and requires payment of transaction fees to public chain networks which makes micro-payments impractical.

5.3 Trust and Reputation

> *Matching two strangers with each other and facilitating a transaction to completion is very similar to a blockchain facilitating peer-to-peer interaction between two (or more) parties that do not know each other.*
>
> William Mougayar.

A prerequisite for exchange in online markets between anonymous agents is the existence of trust and reputation mechanisms. However, trust is not a problem that applies only to transactions between a buyer and seller. It is central to the authenticity of data, the terms of an agreement, and the notion of identity. In some markets, such as used cars and furniture, trust is created by inspection or by external regulations. Although in-store transactions allows a buyer to physically inspect the product before buying, this is not possible with electronic commerce where in some cases the identity of the seller may not be able to be verified.

As Nosko and Tadelis (2015) underline, trust and reputation mechanisms mitigate the inefficiencies in markets with asymmetric information. In his seminal article *The Market for Lemons*, Akerlof (1970) highlighted the role of information shared between buyers and sellers in determining the efficient operation of markets. For example, if we do not know the true quality of the car as well as the selling owner, we are exposed to the possibility of exploitation. In return, the lack of full information is reflected in the price individuals are willing to pay. As information asymmetry increases, the trade that does occur will be selective, mostly for poor quality cars, or 'lemons', where the cost of judgement error is low.

The economics literature has formalised this problem in identifying two sources of uncertainty that hinder markets from operating efficiently. First, *adverse selection* occurs when uncertainty is linked to hidden information that determines the quality of the good or a service. For example, products for sale in online marketplaces such as Ebay may be misrepresented. Second, moral hazard relates to the unknown actions of the seller that determine the quality of the good or service. For example, the shipment of a product without the necessary protection to ensure that it arrives undamaged.

In some markets trust has long since been a problem. Consider the example of the energy sector. Speaking to Utility Week in August 2017, JoJo Hubbard, the chief operating officer of the blockchain company Electron, cited figures published by the consumer website `uSwitch.com`, that 1.3 million energy customers have been overcharged by a total of £102 million, the equivalent of approximately £79 each.

Although the success of online marketplaces such as eBay, Uber and AirBnB, can be attributed to the efficiency in matching buyers and sellers, and being able to facilitate trade between strangers, a number of studies have pointed to problems with the design of trust and reputation mechanisms. Nosko and Tadelis (2015) highlight two issues. First, a poor quality transaction may cause a buyer to update not only his prior beliefs on a particular seller, but on all sellers, thereby generating a reputational externality on the platform as a whole. Second, using eBay records the authors demonstrate that recorded estimates of reputation measures are upward biased, originating from buyers not providing feedback in response to a poor transaction.

5.3.1 Trust and Reputation in Decentralised Markets

In a study written prior to the emergence of distributed ledger technology, Josang et al (2006) review the state of the art in trust and reputation systems for online services. At the time of publication it was felt that it was not possible to prevent reputation systems from being manipulated. This conclusion is consistent with the general observation that although the protocols underlying distributed communications architecture are well established, the ability to manage trust without a centralised authority is only now possible. Through a combination of a consensus mechanism, verification of identity and measures of trust, blockchain provides the basis for a reputation system which can determine the trustworthiness of users.

One obvious question when considering decentralised peer-to-markets is what are the additional issues facing the design of trust and reputation mechanisms? One immediate observation is that the design of trust and reputation mechanism in these markets needs to be multilayered. For example, in the case of eBay, the problem of asymmetric information begins and ends with the buyers and sellers, with the platform assuming the role of the trusted central authority. In decentralised markets, the role of authenticating and monitoring transactions lies within the network. Although we have pointed to the benefits of organising economic activity in this way, there is an additional cost in monitoring the trustworthiness of network nodes.

Just as the mechanism of the distributed ledger can be modified to account for different types of transaction, trust mechanisms can also be designed according to the granularity of the transaction. In this context one can consider a tradeoff between the level of assurance that a particular trust mechanism can be provide and the speed of the transaction. We consider this issue further in Section 7 where we examine the features of the FETCH platform.

5.4 Machine Learning

The realisation that a record of transactions across multiple users and over time can be used to add significant value in future consumption is well known. Machine learning techniques such as neural networks, support vector machines, and decision trees[19] are now widely recognised as set of powerful tools that can be employed to both understand and predict many dimensions of consumer behaviour. Early successes were obtained using supermarket scanner data (see, for example, Hendel and Nevo (2006)) allowing analysts to generate individual level demand elasticities, facilitating better targeting of price promotions. Data from search engines has been used by Choi and Varian (2009) to predict activity in a number of markets including automobile, retail and trade. More recently O'Neill and Weeks (2018) construct decision trees using recursive binary splitting to predict demand response to the introduction of time-varying electricity prices.

As pointed out by McConaghy (2017), the characteristics of the blockchain in terms of a decentralised ledger and immutability, has direct implications for any analysis that is conducted. The decentralised structure of the blockchain coupled with the fact that no single agent controls the data, facilitates data sharing where there exists some benefit. For example, the existence of shared control facilitated by the distributed ledger makes it easier to integrate data from different markets. Moreover, distributed ledgers with shared control result in more data, shared control of training data, and (generally) better models. The existence of immutability implies that data and models are more trustworthy.

In considering the full set of tools that are deployed in marketplaces for autonomous economies, it is important to note that although each tool has a set of properties, the total value added within the system critically depends on how the tools are deployed. Consider the following two examples. First, the use of either supervised or unsupervised machine learning methods for prediction depend critically on the availability of large amounts of data. Second, the fact that computer processing in the form of machine learning tools sit on top of the distributed ledger means that data, representing, for example, user choices

[19] See Hastie et al (2009).

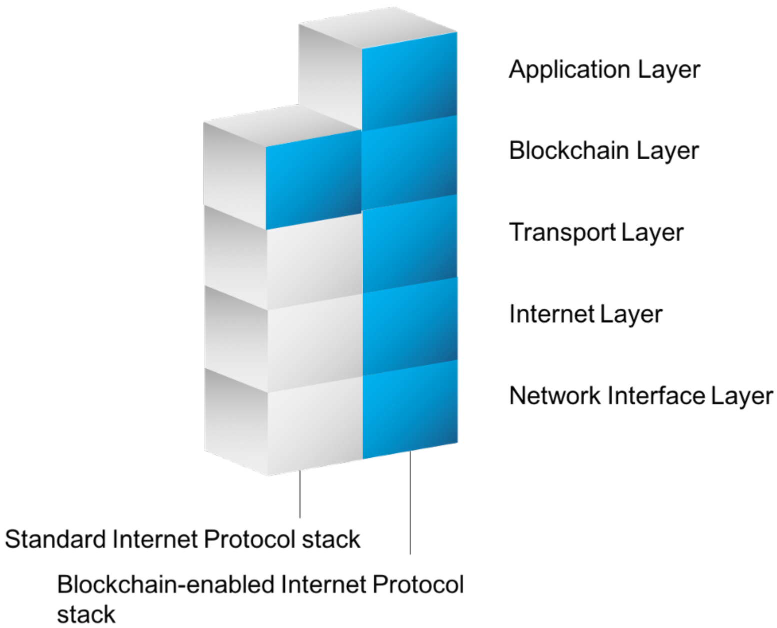
across multiple markets, may be seamlessly integrated and processed.

5.5 Decentralized Applications

In this paper we have considered how the combination of distributed data, a decentralised consensus mechanism, and a digital token, facilitates the operation of decentralised markets. An initial application of this protocol was the transfer of digital currency without a central intermediary. To truly understand the incentive mechanisms of the blockchain protocol, it is instructive to contrast this with the principal Internet protocols, IP/TCP, HTTP, and SMTP, respectively the method for transmitting data between computers on the internet, the method to display web pages in a browser, and the method for sending email.

Using IP/TCP as a reference point, and as Gajek (2018) points out, we can think of the blockchain protocol as providing another layer on top of the network layer on which decentralized applications, or DAPPS, can be built. This is apparent in Figure 2, reproduced from Gajek. In comparing the blockchain and Internet protocols, Union Square Ventures (2016), characterise the latter as comprised of 'thin' protocols and 'fat' applications; with the reverse relationship holding for blockchain technology - namely 'fat' protocols and 'thin' applications. Here fat (thin) alludes to the existence of high (low) returns to investment.

Figure 2: Extending the Internet Protocol Stack



As the authors emphasise, under the blockchain protocol the distributed nature of user data coupled with open source software reduces barriers to entry and provides incentives. However, although there is general agreement that open source software, alongside a decentralised consensus mechanism, represents two key components of blockchain technology, there remains the question as to how to incentivise and monetize both the development of protocols and an open source decentralised application in permissionless networks.[20]

5.6 Digital Tokens

In the context of new and emerging decentralised markets, the additional component that provides incentives for protocol development, which in turn incentivises competition at the applications layer, is a digital token. Raval (2015) has referred to the digital token as acting like an additional protocol layer for value transfer. The end game here is the potential of the combined technologies of open source applications, the distributed ledger, and a decentralised consensus mechanism coupled with a protocol token, to impact the organisation of economic activity, and in particular the nature of rent extraction across economic platforms.

In Figure 1 we observe the role and type of token varies across the levels of the decentralised stack. Soman (2017) enumerates the different types of tokens in monetizing rewards for contributors. Unlike developers of the previous generation of Internet protocols, developers of blockchain protocols such as Bitcoin and Ethereum are rewarded as demand for platform services increases, with the native currency (here either Bitcoin or Ether) appreciating in value, acting as an incentive for the development of new protocols. Developers of a new application may be rewarded with usage tokens (or appcoins), purchased using cryptocurrency (or fiat) to access digital services on a particular blockchain platform.

In further considering the role of tokens in decentralised markets we pose the following questions.

1) What characteristics of e-commerce based on blockchain technology influence the decision to introduce platform-specific digital tokens?

2) What factors determine the specific design of digital currencies?

Mougyar[21] notes that a major advantage of digital tokens is that "companies can be their own payment processors without the cumbersome or costly aspects of traditional financial settlement options." As we have highlighted in this paper, a characteristic of number of emerging markets is the granularity of transactions. Micropayments, combined with off-chain payment channels, can be used to obtain access to a wide range of services and commodities including APIs, media content, bandwidth, computing power, storage, and electricity. Protocols based on blockchain technology have the potential to enable small payments which given the size of the transaction, could not be processed by a traditional financial system. As an example, the Raiden Network[22] is an off-chain scaling solution for any ERC20 compatible token, enables near-instant, low-fee and scalable payments.

The question of the design of digital currencies is taken up by Halaburda (2016), who emphasises three main attributes: whether tokens can be i) bought and/or earnt; ii) transferred between users; and iii) redeemed for fiat currency. Dependent on the particular business models, control over these design attributes will determine the demand for platform services and also determine the extent of network effects. Although this

[20]Raval (2015) provides a detailed review of how the components of blockchain technology, combine to provide a set of critical prerequisites for profitable decentralised software applications.

[21]See `BrainyQuote.com`.

[22]`https://raiden.network/`.

particular review focusses upon the variation in the design and use of tokens in centralised platforms, it is nonetheless informative. For example, Facebook's (FB) Credits and Amazon coins are testimony to the role of digital tokens in existing marketplaces. As an example, FB Credits could be bought or earnt, with users unable to redeem tokens for fiat currency.[23] Amazon coins are provided to users who purchase the Kindle, but expenditure of these coins is restricted to Kindle-specific apps, creating incentives for developers to produce additional applications.

Given the decision by a large number of companies to provide products and services which require digital tokens as a means of payment, the comments of Goldman Sachs on the problems that derive from the plethora of alternative cryptocurrencies are pertinent.[24][25] Since the success of a particular platform can be measured by the demand for its own tokens, the value accruing as a result of network externalities is constrained by the large number of available tokens across fragmented markets. The question of interoperability between different blockchain protocols naturally then follows. A related question is why do we observe a proliferation of use tokens for purchasing alternative services and products, when outside digital economies we use a single currency for *all* purchases. The fact that currently there is no dominant internet or email provider, with emails exchanged between individuals using different email providers, suggests that a world with multiple blockchain networks will need to interoperate. In future work we plan to consider these design issues in more detail.

In Section 5.3 we examined the design of trust and reputation mechanisms, noting the differences in these mechanism across centralised and decentralised platforms. Although Halaburda (2016) provides a useful framework for assessing the functionality of digital tokens, there are once again very real differences across these two types of platforms. Critically, above we have focussed on the design of *use* tokens as a means of payment for platform services. In the case of decentralised platforms, currency is also used as an incentive which underpins the consensus mechanism. In this regard, payment systems for decentralised platforms need to consider the design features of alternative types of tokens, and the potential interaction between them.

At this juncture, and at the risk of stating the obvious, we emphasise that in designing mechanisms which can deliver the appropriate incentives for the functioning of decentralised markets, it is imperative to understand the technology, and in particular the critical role of the blockchain layer on top of the network protocol. In this regard, although we currently observe a large number of papers dedicated to the design of mechanisms at various points of the decentralised stack, such as those designed to provide trust and reveal reputation, there is in general a dearth of studies that consider the design and interaction of the consensus and token mechanism at the base layer.

[23]FB Credits were phased out in 2013

[24]See `https://www.ft.com/content/7bef9506-f669-11e7-88f7-5465a6ce1a00`.

[25]In January 2018 the Financial Times reported that there were 39 digital currencies with market capitalisations of more than $1bn.

6 Emerging Markets

> *The Fourth Industrial Revolution will usher in an era of radical automation, with billions of connected smart machines interacting with humans and with each other and generating a growing share of global GDP. As the Internet of Things converges with artificial intelligence, a growing population of smart, connected devices will eventually operate autonomously, creating new business models and new value in the process.*
>
> Commonwealth Bank of Australia.

In this section we review the characteristics of a number of emerging decentralised marketplaces, alongside the challenges for traditional market mechanisms, in particular the viability of traditional payment systems based upon a fiat currency.

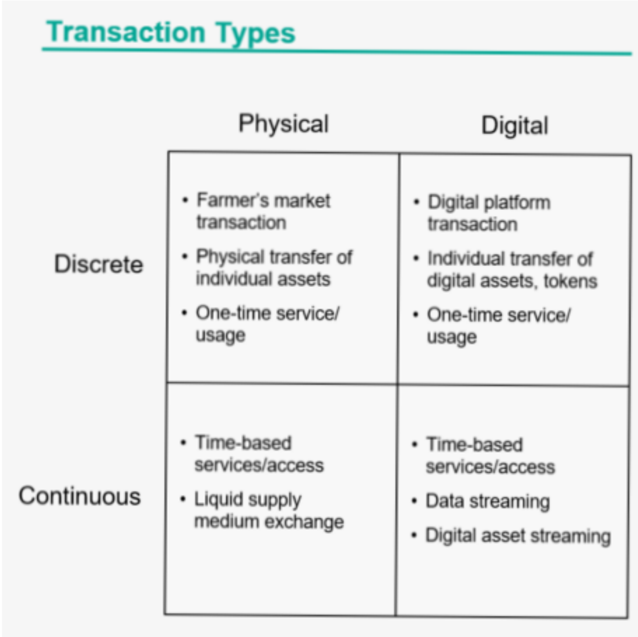
6.1 Granularisation of Digital Business

There are a number of notable characteristics of decentralised markets, including the emergence of many more sellers, an increase in the number of transactions, and a change in the size distribution of the value of transactions. Commensurate with these developments is a change in the scale of operations and what we refer to as an increase in the *granularity* of consumption. Used in this context granularity refers to the trend for consuming products in smaller chunks. As an example, consider the demand and supply of print medium. One of the consequences of the Internet was the creation of new markets for online media, disrupting the traditional booksellers and newsprint markets. Over time we have observed further changes with the emergence of new markets that present content differentiated by size. These markets are able to satisfy variation in consumer preferences: from a consumer who wishes to subscribe to all available content of a particular supplier over a fixed-term, to a consumer who wishes to consume on a pay-per-article basis.

Increasing granularity creates a world with high transaction volumes, and a commensurate emergence of micro-level transactions. Related, markets have become more time dependent in the sense that in some instances the demand for the product is not separable from the time of purchase. These markets require changes in the design of certain market mechanisms, including governance, the representation and management of trust, process optimization, and payment systems. For example, it is likely that trust mechanisms will need to evolve, reflecting the realisation that the required level of assurance of authenticity of a given transaction is falling with the value of the transaction. In addition with time-dependent demand, payment and settlement will need to be faster and intimately tied to the provision of services. In Section 7 we examine the protocol underlying the FETCH platform, which incorporates an innovative solution to this problem of transaction authentication in markets with micro-payments.

Figure 3, reproduced from Stocker (2018), provides a useful taxonomy, distinguishing between physical versus digital exchange and the discreteness of the transaction. In considering the design of a technology to facilitate the trade of goods and services in a digital economy, instances where the transaction is both continuous and time-dependent will require the development of new payment systems based upon a decentralised blockchain protocols.

Figure 3: Transaction Types and the Blockchain



6.2 Managing Identity

A fundamental prerequisite for exchange to take place within decentralised markets with no central authority is the existence of a verifiable identity. By owning and controlling our identity and associated data, we may choose to be anonymous or reveal certain truths, without having to transfer the data that proves it to a third party.[26] Kim Cameron, Chief Architect of Identity for Microsoft, observed that "The Internet was created without an identity layer" or in other words that the Internet's addressing system is based on identifying physical endpoints (machines) on a network and as such has no way to uniquely identify people.

As an example, Sovrin, an open source distributed ledger, that has been created in conjunction with the Sovrin Token, to provide secure peer-to-peer interaction by both protecting and revealing identity.[27][28]

6.3 Digital Content

In today's markets internet content is experiencing an increase in the demand for granularity in terms of the ability to consume small amounts of media content. Although it is possible to record media consumption by the page or the minute, this demand has been confronted with a supply constraint, largely driven by the problem of inappropriate payment systems.

[26] This capability is based on the use of so-called "zero-knowledge proofs".

[27] See `https://www.evernym.com/`.

[28] See `https://www.evernym.com/https://medium.com/@jamie247/why-we-are-backing-evernym-the-sovrin-foundation-1822d2804991`.

6.4 Decentralised Energy Markets

The emerging landscape of the energy sector is an expanding network of smaller suppliers and microgrids creating the potential for P2P transactions with supply surplus being traded on a more micro scale. With a distributed ledger provided by blockchain, a number of the problems that plague centralised energy networks can be addressed. These problems include a single point of failure, low speed of transactions, high transaction costs, billing discrepancies, and a general lack of transparency.

As a example, Power Ledger, an Australia-based startup, is developing a blockchain-based platform that can turn an apartment building into a microgrid based on a shared system of solar panels and battery storage. In such a system producers are able to trade energy peer-to-peer with consumers. In the U.K Electron has developed a meter registration platform which allows users to identify which asset in a system you want to trade and optimise, what their characteristics are and where they are. One possible use of the Electron platform is to facilitate the ambition of the Gas and Electricity regulator, Ofgem, to move to reliable next day switching of energy supplier without relying on a monopoly service provider (intermediary) that would need to be regulated.

The question as to how blockchain technology can be used to replace centralised platforms with monopoly authorities, is particularly pertinent when considering the design and management of a new repository for smart meter data, holding customer-level data on identity, location, and consumption. Currently the licence to manage the data and communications network is held by an intermediary. Given the use of mechanisms to reveal identity, and both validate and provide trust in data, blockchain technology provides a decentralised alternative with the potential to enable individual households to realise value in their own consumption data.

6.5 Machine-to-Machine Markets

> *Blockchain embeds a wallet into machines. As a consequence machines are getting their own profit and loss statement and the ability to do transactions with other (machine) entities in an automated way.*
>
> Dr Carson Stocker (2017).

Driven by the continued fall in the cost of computer chips, it is estimated that by 2020 between 20 and 50 billion connected devices, from mobile phones to consumer durable, will be in use, representing an incremental spend[29] on the Internet of Things (IOT) of €250 billion.[30]As the IOT converges with artificial intelligence, smart connected devices will facilitate exchange between micro devices, mediated by autonomous economic agents (AEAs).

The nature of these markers where billions of internet driven devices exchange currency and data, will require the development of new data-driven business models and market infrastructure. In Section 5.2 we highlighted the importance of designing payment systems that are able to scale in the face of a large number of micro, time dependent transactions. Consider the case where two parties agree on the value of data in a particular data stream. The buyer of the data sends a nano-payment (in the form of tokens)

[29] `https://www.weforum.org/about/the-fourth-industrial-revolution-by-klans-schwa.`

[30] Boston Consulting Group (2017).

to compensate the seller, who is able to sell the data at no credit risk.[31]

The Internet of Things Alliance (IOTA) has developed a blockchain architecture based on a Directed Acyclic Graph structure (DAG), providing the potential for a high throughput of micro transactions with almost zero fees.[32] However, there remain significant problems to overcome before this type of exchange can be made profitable.

7 Fetch.AI

To date we have examined how the various layers of blockchain technology, aligned with the tools of mechanism design, can be combined to create a set of tools which incentivises disintermediation exchange between economic agents. In this section we examine a specific instance of a blockchain protocol in the form of FETCH.

Built using an extended version of distributed ledger technology, FETCH incorporates artificial intelligence and machine learning technology, combined with advanced measures of a trust protocol, to create a platform where autonomous software agents, working on behalf of their stakeholder (i.e. human owners, organisations etc.) perform tasks such as delivering data or providing services. Agents are rewarded with a digital currency for their efforts - the FETCH token. As we explain below, a critical feature of the FETCH protocol is the way in which the distributed ledger mechanism, machine learning and trust, are combined to create an *intelligence driven agent system.*

7.1 Combinatoric Innovation

A consistent theme throughout this paper has been the role of technology in shaping the relative costs of transacting within firms versus within markets. Blockchain technology, provides the potential to reduce transaction costs, provide the service or good in a more timely manner, and in doing so allows new markets to emerge. Existing business models in physical markets typically depend on multiple layers of decision making, adding to both the cost, complexity and time to deliver a service. The FETCH protocol is predicated upon the realisation that, relative to existing digital infrastructures, there are a number of essential enablers missing.

In Section 5, *Mechanism Design for Agent-Based Decentralised Economies*, we examined the key components of blockchain technology. The uniqueness of the FETCH protocol and a particular source of value, is the way in which the specific components of blockchain technology are integrated within a unifying framework. In reducing both the costs of transaction and contract costs, and decreasing delivery time, FETCH has the potential to serve new and emerging markets, based on granularity and where a key attribute of a service is the immediacy of the delivery time.

7.1.1 Key Features of the Fetch Decentralised Stack

In Figure 1 we presented a schematic view of a decentralised stack, with ETHEREUM included as the blockchain protocol. The details of how the FETCH decentralised stack differs is covered in a technical summary paper.[33] In particular this document provides

[31] This example is taken from http://www.ibtimes.co.uk/blockchain-automating-machine-transactions-fourth-industrial-revolution-1608216

[32] https://www.infoq.com/news/2017/05/iota-cryptocurrency-m2m-economy.

[33] See Simpson et al (2018).

a detailed review of the three layers of the FETCH architecture: *Autonomous Economic Agents*, the *Open Economic Framework*, and the *Open Economic Ledger*.

Below we highlight three central features in the design of the FETCH decentralised stack: payment systems, machine learning and intelligence, and a stochastic consensus mechanism.

Machine Learning and Intelligence

The FETCH ledger is designed to support economic agents that reside within its network with information and guidance. A key element of this support is the manner in which the ledger exploits the information provided by the history of transactions undertaken by the agents, beyond that contained in the value and the identities of the transacting parties. A history of transactions can be used to understand preferences, thereby differentiate agents, measure reputation, target delivery of options and so on. For example, if we knew the past history of transactions in a supermarket at the level of individuals, one could design an optimal coupon strategy that *doesn't* provide discounts to consumers who (from their past transactions) would continue to purchase the good irrespective of a price increase.

It is important to emphasise that the use of a time series of individual transactions and related information is not in and of itself novel. The novelty exists in the way in which the data is used to create a prediction model. Moreover, distributed ledger systems that have been designed to date, have not *integrated* the use of these histories as part of the consensus mechanism. Current designs have provided a mechanism to authenticate transactions, with other processes built on top. A significant disadvantage of assembling a system in separate layers is that users have to deploy their own method and resource to create intelligent models which can predict actions, trades, correlations etc.

FETCH in contrast, is providing this feature inherently, e.g to predict which two agents amongst thousands are more likely to trade based on such attributes as trust, transaction histories, and owner preferences. It is in this sense that FETCH is an *intelligence driven system*, providing a toolkit for agents with a *built-in* prediction model. As an example, imagine an agent $\mathcal{A}$ interacting with other agents to trade. In connecting to a marketplace, Agent $\mathcal{A}$ is *actively provided* services, such as optimal trading strategies provided by machine learning using transaction data recorded on the ledger. Although agent $\mathcal{A}$ still has to make a decision, such a system is able to present relevant services much faster and much more accurately.

In a non-intelligence driven system we would observe a number of agents advertising and an agent, say $\mathcal{A}$, *searching* for the service. Once the relevant service is discovered a decision is to be made by $\mathcal{A}$ based on a more or less hard coded criteria (a smart contract). Once $\mathcal{A}$ decides to accept service/data from one of the agents the transaction is recorded in the database.

Market intelligence

Market intelligence is a particularly interesting aspect of FETCH's activity. Over time, it learns increasingly more about what kind of markets interact with others, under what conditions and which ones overlap with others. This data has previously been held in proprietary silos by large on-line markets such as Amazon and eBay, but for the first time will be available publicly. This hugely valuable information becomes accessible to participants in the marketplace as well as enabling smart market structure and an additional layer of information for agents to leverage in order to maximise opportunistic value use and increase utilisation of data and services.

Payment Systems

In this paper we have highlighted the limitations of existing market infrastructure both in terms of providing a basis for blockchain as a new technology, and also considering variants of blockchain. A critical issue in the use value of a number of blockchain protocols, and the applications which sit on top, is scaling and payment systems. In Section 5.2 we alluded to one solution based on the use of payment channels. Systems such as Lightning or Raiden provide scalability to blockchain solutions by taking large numbers of small payments off-chain. In an off-chain system the transactions are aggregated and then placed on the main blockchain. Although this system provides authentication as to which transactions happened such that any change would result in a non-consensus, the information as to which parties were involved in the transaction, and for what purpose is lost. This information is critical for intelligence driven agent systems like FETCH since in order to provide agents with information (i.e the tools to find the right parties to trade with), this type of information is required.

Stochastic Consensus Mechanism

Similarly to Bitcoin, Ethereum and many other ledgers, the FETCH system is designed for rapid validation of transactions, and includes a set of deterministic rules for reaching a consensus. However, the FETCH ledger differs from other blockchain protocols in that the machine learning system, integrated with the design of the distributed ledger, operates as a secondary layer that enables transactions to be assigned a probability of being incorporated into the consensus chain. This probability reaches 1 when the consensus is agreed according to the deterministic algorithm.

The advantage of adding a probabilistic approach to the consensus mechanism is that this enables transactors to tradeoff a small probability of being defrauded via a double spend with an increase in transaction time. This is particularly valuable for IOT contexts with goods (such as energy) and/or low value transactions. These probabilities can be combined with other information such as the identity of the goods provider and historical records to allow agents to assess their trust in counter-parties and thereby transact rapidly and efficiently with each other.

8 Conclusion

In this paper we have sought to understand both the evolution and requirements of marketplaces that are emerging in digital economies. As a point of departure we considered the Theory of the Firm and in particular the role of transaction costs economics, alongside scale and scope economies, in determining the dynamics of the boundary between the firm and the market.

The evolution of how economic activity is organised is a running theme throughout this paper. In this context we highlighted the pivotal role of the Internet in changing the costs of both disseminating and retrieving information, and moreover its role in facilitating a large matching mechanism for buyers and sellers. The emergence of both centralised and decentralised peer-to-peer marketplaces is testimony to both understanding the incentive properties of these markets, and designing the appropriate tools.

In considering the design mechanism for markets where trade is peer-to-peer without a central authority, we focussed on the pivotal role of the decentralised consensus mechanism and the distributed ledger, placing the evolution of this technology relative to existing distributed databases. We also examined the design of decentralised applications and their protocols, smart contracts, the use of digital tokens, machine learning and the importance of trust and reputation systems.

As with the evolution of any technology, there are many variants of blockchain technology, based upon different protocols. To a greater or lesser extent these protocols will succeed or fail in their stated aim of providing the market infrastructure which supports a particular decentralised marketplace. Similarly, and as already stated with respect to existing centralised platform markets, platforms that succeed will need to add value beyond the simple matching of buyers and sellers, and the ability to execute smart contracts.

In writing on the phenomenon of computer mediated transactions, Hal Varian, the Chief Economist of Google, has underscored the role of 'combinatorial innovation', where *the component parts of these technologies can be combined and recombined by innovators to create new devices and applications*. It is instructive to view the way in which the FETCH platform has integrated the layers of the decentralised stack in this light. Although the protocol underlying the FETCH platform incorporates a number of singular innovations such as a means to handle transaction authentication in markets with micro-payments, the *combination* of agent-based technology with a transaction-level database integrated with machine learning tools, provides the potential to add value through real-time learning.

Going forward we see the need for further research in a number of areas. First, there exist considerable benefits in taking the simple model of peer-to-peer production developed by Einav et al (2016) and adapting this for decentralised platforms. How and to what extent do decentralised markets reduce entry costs, facilitate entry of smaller suppliers and affect market structure? In addition, research is required into the dynamic properties of markets where new and old technologies will, at least in the short-run, co-exist. For example, in the face of new entrants to these type of markets, how will incumbents respond? In the U.K electricity sector the emergence of distributed energy resources has coincided with a move away from traditional unidirectional flows of energy from generation, distribution, and retail. This shift has prompted incumbents to create a number of new innovations, including the emergence of virtual power plants enabling the aggregation of household-level savings in electricity consumption and the related innovations in so-called *passive* demand response.

In addition there is a large extant literature on mechanism design for agent-based marketplaces. As we have stated, the design of market mechanisms for online decentralised markets presents further opportunities to reduce the costs of entry and transaction costs, and therefore increase competition. Much of the existing work on platform competition in two-sided markets, the economics of peer production and market design, has been carried out for centralised platforms. Key questions such as how does price setting in two-sided platforms interact with the i) alternative consensus protocols and ii) volatility in cryptocurrency, indicate that there remains much work to be done in applying the principles of mechanism design to decentralised marketplaces.

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