Beyond money: cryptocurrencies, machine-mediated transactions and high-frequency hyperbarter

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As blockchain technology is adopted into modern economies, the underlying institutional protocols will evolve. In this paper we set out the reasoning behind how this will likely take us to an economy beyond both money and money prices. Money facilitates human-to-human exchange in the presence of cognitive limitations. However in the near future personal artificially intelligent machine agents will be able to conduct exchanges with a matrix of liquid digital assets (such as cryptocurrencies). We call this process high frequency hyperbarter. The existence of markets without money present complex public policy challenges around privacy and taxation.

1. INTRODUCTION

Modern economic models and analysis of cryptocurrencies as new technologies of financial evolution tend to frame the problem as a study of the evolution of money (Yermack 2014, Böhme et al 2015, Fernandez-Villaverde 2018, Kirby 2018, Kumar and Smith 2017). We argue in this paper that this basic assumption, which has been correct for thousands of years, is now likely to be wrong for an unexpected reason, namely that money has always intermediated trade and exchange between humans. Our argument is that cryptocurrencies and blockchain technologies (Böhme et al 2015, Narayanan et al 2016) are coevolving with a suite of computational technologies that will facilitate agent-to-agent trading. The implication, which we elaborate in this paper using a combination of behavioural economics and institutional economic theory (Berg et al 2017, Berg et al 2019), is that we don't actually need a money in this exchange context because it can be mediated with an n-dimensional matrix transfer of digital assets. What our conceptual and theoretical argument shows is that modern economic analysis of money has largely ignored the implication that money and money-institutions (such as market prices) have evolved in the context of human-to-human trade, which is computationally far more limited than the possibilities of machine-to-machine trade that can function more like a high-dimensional, high-frequency barter exchange. This is the sense in which cryptocurrencies and digital assets, combined with AI-type trading agents, take us 'beyond money'.

2. THE SOCIAL HISTORY AND ECONOMIC THEORY OF MONEY

Throughout history, economies have evolved money as an institutional technology to facilitate trade and exchange (Jones 1976). New technologies lead to new forms of money, and new forms of money shape economic institutions. In economic theory, money evolves from commodities, emerging from a barter economy as a particular commodity that everyone will accept in exchange, in part because they know that others will accept in in exchange (Menger 1892, Radford 1945, Clower 1995, Dalziel 2000, Szabo 2002). Money is a special type of economic good that emerges by convention to become a *medium of exchange*, a *unit of account* and a *store of value*. Masciandaro (2018) argues that cryptocurrencies are an evolution of money to also be a *store of information*. Money is what money does such that it is demanded for transactions and supplied for that purpose, and what is money is therefore what evolves as money. In other words, money is not a thing, but a set of properties that some things can have in consequence of technology and institutions. This is why money evolves as economies evolve. Money is an emergent institution in an economy (Menger 1892), so the history of money maps the institutional and technological evolution of economies.

Money also gives us money denominated prices (i.e. unit of account). As Clower (1967: 5) explained long ago: in a monetary economy 'money buys goods and goods buy money, but goods do not buy goods'. Money emerges because it solves the double-coincidence of wants problem in a barter economy, which is a *transactions cost efficiency*. But money also solves a *computational cost efficiency* by denominating prices in a standardized base unit (a money price) rather than a commodity price (an exchange ratio). Posted prices, standard pricing models, and market

institutions all facilitate further simplifications on the cognitive load of economic transactions (Heiner 1983). Prices, denominated in money, are an interface that has evolved for human-human transaction, unsupported by machine intelligence. This eases the cognitive load on trading and exchange, making comparison, bargaining and record-keeping easier, and certainly within the realm of normal human ability. Indeed, money has evolved not only with human technology and society, but also with human neurobiology. Bartering is more costly from a transaction cost perspective and because the permutation space is much larger, barter is also cognitively costlier.

An important but widely overlooked observation is that much of our transactional world has evolved, in its economic institutions, to adapt to the processing speed, memory and bandwidth of pairs or networks of human brains. A money price is such an institution, which is legible to (boundedly rational) humans. The implication is that those transaction cost and cognitive cost efficiencies that favour money prices over barter exchange ratios manifest when economic agents are human, but not necessarily when those agents are machines (i.e. software), including when those machines are acting as agents for the humans. Machines have different data legibility standards to humans, being able to process and transform much larger and more complex data sets. The combination of crypto-currencies or tokenized digital assets, combined with AI enhanced trading agents, could usher in a world beyond money in which 'goods might indeed buy goods' (we call this *high frequency barter* of matrixes of liquid digital assets) without needing either money or money prices. A blockchain-based economy can therefore develop an economy *beyond money*. But it goes beyond money because of better technology of record-keeping and exchange. This is still a market economy, and an extension of Hayek's (1945) insights into the nature of market prices, not a repudiation of it.

An economic definition of money does not refer a thing, but rather to the properties things can have when they function as a unit of account, a story of value, and a medium of exchange. What counts as money can be variously defined in law (i.e. legal tender), in practice (a bearer bond), or in custom (cigarettes in a prison camp, Radford, 1945). And the 'moneyness' of the thing can derive from scarcity (cowry shells, gold), trust (commodity money, fiat money), and utility (payments networks such as credit cards). Money evolves as new technologies and protocols better solve money-ness properties. For instance fiat money for exchange outcompetes barter exchange by better solving the double coincidence of wants problem (by lowering transactions costs). Money is fundamentally an institutional technology to facilitate the accounting of cooperation between people who seek to create value together (Smith 1776). Money, in other words, is a dynamic ledger, and like all technologies evolves and develops through time.

Government (fiat) money, often with monopoly protection by statute as legal tender, and legislatively required for payment of taxes, has been the prime form of money since the rise of the nation state through the 19th and 20th centuries (Alchian 1979, Ingham 2004, Dequech 2013). However, the predominance of State-based money is an artifact of both legislation and technological constraints, and as Hayek (1976) explained, the absence of market competition in money supply has produced low quality (inflationary, insecure, slow, featureless) money (Bagus 2009). Fiat money under government monopoly has experienced relatively low levels of technological innovation.

Money is a technology for exchange (Lagos and Wright 2005). Attempts to build better technologies of money have for the past half-century or so been focused on platforms for digital money. The first generation was mostly private payments platforms and derivative markets that sat on top of the existing monetary and banking system. For consumers, these were credit cards, and for business these were new financial instruments. Credit cards use a native fait currency (say the US dollar) as a unit of account, but operate a payments platform in which the credit card company guarantees transactions made on its network, which is connected into the banking system, as a credit money. New financial instruments, such as options or swap contracts, created new liquid assets with money-like properties in that they could intermediate transactions.

The next generation, starting in the 1990s, sought to build new types of money with new protocols on digital infrastructure (Cohen 2001). Early attempts, with varying degrees of market success, were DigiCash (developed by David Chuam), Bitgold (by Nick Szabo), b-money (by Wei Dai), PayPal (by Peter Thiel et al.). These all, ultimately, involved centralized ledger solutions to facilitate clearing and avoid double-spending (i.e. sending a money transfer to one digital address, and then sending it again quickly to another before the first recipient subsequently spends the unit, thus engaging in a double-spend). But it was bitcoin (Satoshi Nakamoto), the world's first

cryptocurrency that finally technically succeeded in solving the double-spending problem that had bedeviled all previous attempts to create decentralised digital money. Nakamoto's solution used blockchain technology to recombine aspects of earlier ideas while eliminating the hazard of a double-spend using consensus protocols.

The discovery in 2008 of a new technology of money using distributed ledgers secured with consensus protocols (i.e. a cryptocurrency) has given monetary economists a fresh view on the evolution of money (Luther and Olson 2013, White 2015, Bohme et al 2015, Weber 2016, Fernandez-Villaverde 2018, Fernandez-Villaverde and Sanches 2018, Kumar and Smith 2017). A key debate in this account that has concerned Central banks world-wide is the extent to which cryptocurrencies (such as bitcoin) compete with government issued fiat currencies (Kirby 2018), such that they are potential privately issued substitutes (as Hayek 1976 envisaged), and if so on what margins? Are we re-entering a monetary world more like the 16th-18th centuries, with widely circulating private issued coinage and notes from merchant banks, a.k.a. *free banking* (Selgin and White 1987, Selgin 1988, Yeager 1987)? Furthermore, what prospects for government issued digital currencies (on a central ledger) versus a government cryptocurrency? What does the recent invention of blockchain technology and cryptocurrencies auger for the future of money and banking (White 2015, 2018)?

3. DO WE STILL NEED MONEY?

Early theorists of money (such as Menger, Mises and Hayek) focused scholarly attention (and central bank worry) on the future of money through the analytic lens of competitive supply. From this perspective, the key question is whether bitcoin (say) will replace the USD (say) as a global reserve currency or unit of account by being on some margins or overall, a better money (Kirby 2018, Masciandaro 2018). Will this new technology of money replace the old technology of money? However, we think the question should be: with these new developments in the technology of record-keeping and exchange (e.g. cryptocurrencies and blockchains, see Davidson et al 2018, Berg et al 2018) will we still need money at all?

This argument is already familiar in modern monetary economics, where Kocherlakota (1998) and Kocherlakota and Narayana (2002a, 2002b) argue that money (and observed money balances of traders) functions as a substitute for perfect record-keeping devices (or what they call *memory*) and Luther and Olson (2015) then point out that bitcoin, as a new digital money, actually works by being a near perfect record-keeping device. In other words, cryptocurrency is a near perfect money because it creates near perfect memory. As Fernández-Villaverde (2018: 517) explains 'tokens serve as records of our net balances with society regarding what we have produced and what we have bought. … Or more simple: money is the memory of society: an informationally efficient record-keeping mechanism to allow for decentralized trading.'

The technological contribution of cryptocurrencies and blockchains is not that bitcoin and other cryptocurrencies are a better money, but that they are a better record-keeping mechanism that works across peer-to-peer networks. Critics of cryptocurrency argue that unlike fiat currencies backed by Treasury vaults of gold, or expected future tax revenue, cryptocurrencies have zero intrinsic value because they aren't actually backed by anything. Defenders of cryptocurrency sometimes argue that they are backed by scarcity (built into the protocol), or by math. However, a better argument is that the intrinsic value of cryptocurrencies comes from being both money and a P2P payments network (Huberman, Leshno and Moallemi 2017, Tucker 2018), and a permanent public record of those payments (Luther and Olson 2015). The distributed payments network side of cryptocurrencies is the revolutionary and disruptive aspect, and by focusing on this we can see the future of money. It is not crypto-money that competes with fiat money, but rather crypto (or decentralized) payments and prices that compete with centralized network payments and prices.

The functions of money are unit of account, medium of exchange, and store of value. These functions can all be furnished with a basket of liquid digital assets when coupled with a computational (AI) agent. So, in a cryptocurrency world you don't actually need money (nor money prices) because payments (and prices as exchange ratios) can work directly from a matrix of digital assets that cryptocurrencies and tokens represent. In principle, such machine-mediated hyper-barter trading would necessitate each human using a trading agent (or AI bot) that would interact with

other bots as an agent of the human principal. For this to work, however, it would require full access to all owned assets and the rights to trade them, based on achieving outcomes consistent with learned preferences and subject to continual feedback from the human principal about its trading and exchange performance. This technological capability is far from developed at the time of writing, but it is a foreseeable consequence of machine-learning AI coupled with blockchain technologies such as self-sovereign identity, digital wallets, and smart contracts. However, there are significant technological, regulatory and psychological (or user interface and user experience) hurdles to overcome before this type of hyperbarter exchange could occur.

Money and money prices are an enabling technology of exchange that works by decomposing a transaction into its basic elements enabling each part to be efficiently achieved. Money prices also produce highly efficient coordinating signals across an entire economy, producing coordination without a central coordinator, as Hayek (1945) explained. But money prices are also a cognitive efficiency for human decision-making. Standard economics models that show the allocative efficiency of a competitive market assume a general equilibrium model in n markets, with an n+1 numeraire good (money), and with money prices determined by continuous auction. However, many real world prices are short run fixed by sellers (they are *posted prices*) rather than determined by market mechanism. Posted prices are an example of cognitive efficiency in reducing the cost of comparisons (e.g. items on a menu), and easily slot into decision heuristics. So an economy with both money and money prices has lower transactional costs (higher transactional efficiency), and therefore more transactions, which creates more value. Modern monetary economics (known as search-theoretic models of monetary exchange, Lagos and Wright 2005) in turn emphasize the information costs of these trading frictions and the way that money and money prices economises on search costs. But some of these search and transactions costs are simple consequences of the fact that the agents transacting and searching are humans running cognitive neurobiological wetware, not digital software and on internet enabled hardware.

But transactions need involve neither money nor money prices, but can be a swap (or barter exchange) across two or more sets of goods (X1 and X2). The reason this doesn't tend to happen in practice is because of the transactional and cognitive efficiencies that money and money prices bring. In portfolio theory of money, money is one element in any set of assets Xi, with the special characteristic of being the most liquid. Indeed, the portfolio model of financial assets supposes that all economic assets exist on a spectrum of liquidity, with cash and demand deposits as the most liquid assets (i.e. the high-powered money base) and other money-like assets (M1, M2, M3, etc) constituting the money supply. The money supply is the liquid end of the stock of all financial assets, which is in turn the liquid end of the stock of all real assets, such as inventories, equities, capital assets, land, intellectual property, and so on.

Money is an element in the set of all assets. Therefore what counts as money can be drawn from the set of all assets, when money-like features can obtain. This is what the creation of cryptocurrencies and tokenization of digital assets (to make them liquid assets) can achieve. Any liquid digital asset can become money. In this view, money is not the end point on a spectrum of liquidity, but rather is drawn from a matrix of digital asset types with different properties (including liquidity) but also additional properties that fiat money lacks (e.g. programmability).

To use digital assets as money, they need to acquire money-like properties, which the blockchain economy accomplishes through tokenization, or by linking entries in blockchain ledgers with ownership or control of real and financial assets (Swan 2015, Davidson et al 2018, Berg et al 2018). In a blockchain economy, all economic assets map to tokenised representations of those assets on distributed ledgers, and furthermore the identity of people and assets are also on blockchains, enabling decentralized verification of permissions and agency with respect to a matrix of assets. This also assumes that value can move across different blockchains through cross-chain protocols (e.g. state-channels, Polkadot, Cosmos, Interledger, etc).

The matrix of assets that each agent owns or controls now refers to anything that can be tokenized, including, not only real and financial assets, but also personal data. For instance, data can function as money (within a digital asset matrix) in a cryptoeconomy when that data stream is able to be permissioned with private key control, so creating an exchangeable property right. In essence, once an asset can enter into a digital ledger controlled by an individual, that asset can function as money.

However, cryptoeconomic exchange over an asset matrix (rather than money) (i.e. what we might call hyperbarter, or high-frequency barter) is computationally harder, and therefore better suited for machine-to-machine interaction rather than money mediated exchanges, which are institutionally adapted for to human-to-human interaction. However, hyperbarter is only possible with machine-mediated transactions, as illustrated in Figure 1 below, because the computation requirements of matrix-to-matrix exchange are well beyond normal human functioning.

Economic exchange

human 1 > market prices < human 2

Cryptoeconomic hyperbarter exchange

human 1 > machine agent 1 > digital asset matrix X1 >|< digital asset matrix X2 < machine agent 2 < human 2

Fig. 1. Abstract schematic of hyperbarter versus money exchange.

In an economy beyond money, i.e. a cryptoeconomic enabled economy with fully tokenized assets, and with hyperbarter exchange, some kind of machine agency will be needed for each economic agent, including both human economic agents, and also autonomous machines (such as autonomous vehicles, or IoT devices that need market enabled capabilities). These may be artificial intelligence enhanced digital trading apps (operating on a smartphone, for instance) that would compose at least the following capabilities:

— Register of digital assets, and metadata
— User preferences
— Identity protocols
— Broadcast, search & match, and bidding engines (including ability to contact, scan and evaluate other asset matrices, and auction and bargaining protocols)
— Contracting, payment, and settlement capabilities
— Learning protocols, regulatory compliance protocols, tax protocols

In practice, an agent wanting to purchase or sell something would broadcast a message with these bids and asks, or conditional offers. This may be bilateral (P2P, rather than on a market), as when one agent observes an asset in another agent holds and wishes to make an offer. The two agent machines would interact, and if an agreement can be reached, an exchange would take place, with assets being exchanged, and each asset matrix (the ledger) updating. Or the exchange could begin as a multilateral broadcast of offers and asks, and be facilitated by multiple arbitrage trades culminating in a bilateral swap.

In a cryptoeconomy, all real and financial assets, as well as new assets such as data, map to tokens in ledgers. Such an economy could in principle operate without money or money prices, but instead exchange would occur through high frequency barter. However, to do so human agents will need the services of algorithmic trading agents in order to exchange (as in Figure 1 above). This will require a new class of technology: an AI supported app-based universal barter interface through which agents will interact with the world.

This is not such an exotic idea in general, and we think a reasonable prediction about the pathway of money and transactiosn evolution. Indeed, there are many areas of life where humans once interacted directly with nature (including other people) but routinely now interact only through machine interfaces or with machine-mediated support. Most operators of heavy, fast-moving or dangerous machinery, or in hazardous environments will happily use for instance hydraulic actuators and electromechanical control interfaces. And this is already true in trading environments that well exceed human response or processing capabilities (e.g. high frequency trading, or continuous auction markets, such as advertising placement on social media platforms). Humans flying through airspace interact with other humans in airspace entirely through machine-mediated interactions and transactions, and would be extremely foolhardy to do otherwise. We believe that blockchain enabled market environments coupled with AI enabled trading bots are

evolving human-human market interactions along a similar trajectory. In a cryptoeconomy, with machines acting as our agents to transact and negotiate with other machine agents, we can operate a very different transaction environment in a world beyond money.

4. LIMITS AND PREDICTIONS

Given that money and money prices had evolved and adapted to other institutions over 1000s of years, there are at least several major institutional adaptations required to transition to an economy beyond money.

One problem is privacy and disclosure. A hyperbarter model requires mutual asset disclosure sets to facilitate exchange. This creates privacy problems that did not exist in a money economy. However, technologies such as zero knowledge proofs may overcome this.

Another problem is taxation, which has adapted to a legible world of money-valued taxes, whether as a fraction of income or expenditure. In a barter economy in which asset holdings are opaque to anyone unless permissioned, taxation is equivalent to some kind of asset seizure, which again requires a reckoning. An immediate implication is that public finance and the provision of public goods would be much more user pays.

This connects with the prospects for national digital currencies. Our model predicts that we are unlikely to see a demand for a national digital currency except for the purpose of paying tax. Tax paying citizens would then need to acquire units of that currency, which for instance could be issued to particular agents the government wanted to service (government could issue tokens to, for instance, soldiers, and citizens would then seek those in order to pay tax by offering goods or services to those soldiers, e.g. lodging or food, etc). However, a tax system could completely bypass money and go directly to a reckoning, where a certain percentage of all assets are confiscated per time period. Or taxation could be at the platform level, as a fee for using particular blockchains and the economic infrastructure they support (*a la* Ostrom 2010)

This same technology of bargaining and exchange beyond money could however also extent to political operations and the creation of emergent community governance mechanisms and voting procedures, or what is called crypto-secession (MacDonald 2019) and liquid democracy (Blum and Zuber 2016, Allen et al 2018, Allen et al 2019).

As blockchain technology enters the economy, it will likely at first have only small impacts around a few areas, as we have been observing with new payments modes adopted to solve particular problems (such as remittances, or creating privacy in transactions). Next, as the technology is more widely adopted and embeds further into use cases in, for instance, self-sovereign identity, finance and insurance, asset registries and certification records, decentralized P2P exchanges, supply chains, data markets, and so on, we will see adoption through various industry sectors. We will observe the building out of new economic infrastructure that will digitize and tokenise digital records and registries of data, people and assets to blockchains (onchain) or connect them to blockchains (offchain). And as this happens in the protocol layer, the economy will transition beyond money and money prices.

5. CONCLUSION

This paper has sought to elaborate on a key prediction of the evolution of money along the trajectory introduced by the recent invention of cryptocurrencies and blockchain (Narayan et al 2016). The specific argument we have sought to clarify here is that, surprisingly, money is not actually inherent to market capitalist economies (it was long ago shown that money prices are also necessary for allocation a socialist economy, for instance, Mises 1920), but rather that money and money prices are essential in an economy with human-human interfaces for exchange because money and money prices furnish cognitive efficiencies in human calculation for exchange, and the resultant emergent price information coordinates distributed economic activity. A blockchain economy generalizes this phenomenon to all assets by taking humans out of the loop, in the sense that humans can interact via software agents and these agents to a significant degree do not experience the cognitive and computational limitations that constrains human-to-human exchange (and for which money and money prices are an efficient technology). With machine mediated exchange (high-frequency hyperbarter), there is less or even no need for money or money prices because, in effect, everything that is tokenized is now money, and prices are the set of all possible exchange ratios across all digital

asset permutations in the core. There are money equivalent prices that can subsequently be calculated, but these are not actually necessary to facilitate trade and exchange between agents. This argument does of course assume that the software bots are high-quality agents for the principals, which is a continuing technological challenge (Rust 2018). But as these new digital technologies significantly improve record-keeping of assets and transactions and machine-facilitated exchange, we enter an economy beyond money.

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