



# **Brave New Monetary World: Exploring The Idea Of An International Cryptocurrency**

Developing a utopian model for a cryptocurrency for international trade

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*Abstract:*

*Since the launch of Bitcoin ten years ago, there has been a proliferation of digital currencies with market capitalizations of billions of dollars, growing academic literature and a mixed reception. These new currencies allow for important improvements in the payment system such as reduced costs and higher transaction speed. The current study develops a theoretical model that explores a distant idea: an international cryptocurrency which would benefit from those advantages. The study focuses on the economic feasibility of this monetary utopia and how exogenous factors would affect it, taking into account that this cryptocurrency would only be used exclusively for international purposes, i.e. it would not substitute traditional currencies completely.*

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# 1. Introduction

On June 10<sup>th</sup>, 2017, Bitcoin prices surpassed 3,000 USD for a short time for the first time since its launch in 2008. At the same time, prices of other cryptocurrencies such as Ethereum or Litecoin skyrocketed too, and the cryptocurrency market reached a new all-time market capitalization record of more than 100 billion USD (Olszewicz 2017). These up and downs in the cryptocurrency market have been received with mixed opinions. While supporters argue that the overall increasing trend is the result and proof of the cryptocurrencies inherent advantages, detractors state that their volatility shows that they are mainly used as speculative assets and they are subject to bubble behavior. Some idealistic supporters even make a case for a cryptocurrency substituting all traditional currencies in some future.

The concept of an international currency, despite giving the impression of being completely unfeasible (especially with the nationalistic revival during the last years), is not new. Authors and academics have studied the possibility of this idea in the past. For example, nineteenth century English economist John Stuart Mill (1875) stated that a country asserting its nationality by “having a peculiar currency of its own” was a proof of the remaining “barbarism” in civilized nations. Also, Walter Bagehot supported the idea when writing in *The Economist* during the first decades of existence of this magazine (Bordo & James 2006). More recently, the experience of the creation of the Euro serves as an experiment of the process that would be needed for an international currency to be born.

Taking all of this into account, I consider that the idea of an international cryptocurrency, despite being extremely difficult to take to practice if not impossible, constitutes a thought experiment worth studying. It is the result of putting together the old concept of an international currency and the latest developments in e-money payment systems. These new payment systems allow for new features which possess some important advantages, such as reduced costs and higher speed.

Accordingly, the current study explores the idea of an international Bitcoin-type cryptocurrency used exclusively for international trading purposes and therefore not substituting national currencies. Additionally, this type of currency could be a perfectly valid mid-step towards a unique international cryptocurrency replacing all traditional currencies.

The research question of this study is as follows: *Would an international cryptocurrency be theoretically viable from an economic point of view?* To explore this idea I reinterpret a model by Chiu & Wong (2015). The authors developed their model as a baseline version to study the possible advantages of e-money over traditional money. It includes buyers and sellers interacting in two different markets.

I consider this model unsatisfactory, and consequently I will discuss some of its problematic issues later. However, it is one of the first models addressing this topic. I include a few changes to make it more realistic. In my adaptation the first market is an international decentralized market where agents exchange a cryptocurrency for international goods. Meanwhile, in the second market, a centralized one, agents exchange the cryptocurrency for national currencies.

One of the most important changes I introduce in my reinterpretation is this new currency, named Intercoin (ITC). Intercoin is a cryptocurrency with a transaction and supply system similar to those of Bitcoin: decentralized and self-sustainable thanks to the use of blockchain technology. Nonetheless, the design of this cryptocurrency has one major difference to that of Bitcoin: it includes a constant supply growth rate across periods following Friedman's  $k$  percent rule (Friedman 1959). This feature will be crucial for the performance of this cryptocurrency: the benefits in stability and certainty that it provides according to Friedman facilitate reaching equilibrium easier while keeping controlled inflation levels. This may imply that international markets and the use of the cryptocurrency become more attractive for agents. Additional changes include, for example, the introduction of an interchange fee for buyers in one of the markets.

The study continues as follows: Section 2 consists on a literature review about Bitcoin, explaining how it works, its history, reception and future. Section 3 presents Mundell's paper *The case for an international currency*, where he advocates the idea of an international currency. He discusses the origin and evolution of this idea and presents a plan to implement it based on the Euro process. In Section 4 Chiu & Wong's baseline model is explained. It presents buyers and sellers who trade across periods consisting of two subperiods: one with a decentralized market and another with a centralized market. This model is adapted in Section 5 for our international cryptocurrency taking also into account Mundell's implementation plan and Friedman's  $k$  percent rule. Section 6 concludes.

## 2. Bitcoin: The first cryptocurrency

In this section, we are going to examine the history of Bitcoin, its perception and its future. However, to understand Bitcoin a discussion on what digital currencies and cryptocurrencies are and their main differences is necessary before.

### 2.1. Definition of digital currency and cryptocurrency

What are virtual currencies? Virtual or digital currencies are those which use exclusively digital format, with no coins, banknotes or other physical form. They have proliferated in the last decades, with different degrees of usability and development.

On their 2012 Report on *Virtual Currency Schemes*, the ECB classified these virtual currencies schemes into three groups depending on their interactions with official and convertible currencies: 1) *Closed virtual currency schemes*. Users pay a subscription fee with an official currency such as USD or EUR to be able to participate and earn units of the virtual currency depending on their performance. There are a lot of examples of this kind of currency in the videogame industry, e.g. World Of Warcraft credits. 2) *Virtual currency schemes with unidirectional flow*. Users are allowed to exchange units of official currencies for units of the virtual currency, but not the opposite. Videogames and online services provide a good example of this kind of currency, e.g. Facebook Credits, Eve Online ISK. 3) *Virtual currency schemes with bidirectional flow*. Users can buy and sell this type of currency in exchange of official currencies. Functionally, these currencies are similar to any other convertible currency and allow buying both digital and real goods and services. Therefore, there is nothing preventing them from substituting traditional currencies. Almost all cryptocurrencies belong to this category, including the most important ones such as Bitcoin and Ethereum.

Then, what are cryptocurrencies? They are a subtype of digital currencies characterized by the use of cryptography<sup>1</sup> to secure both transactions (including a variable level of privacy and antifraud measurements) and the supply of the currency (as they are mainly decentralized), Farrell (2015).

Another more technical definition could be the one provided by Ahamad *et alia*. (2013), which states that “cryptocurrencies are physical<sup>2</sup> precomputed files utilizing

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<sup>1</sup> Cryptography is defined as “The art of writing and solving codes” (Oxford English Dictionary).

<sup>2</sup> On this definition “physical file” refers to a type of digital file, in contrast with “logical file”.



public and private key pairs<sup>3</sup> generated around a specific encryption algorithm”. Simplifying it considerably, we could say that a user can sign that she is ordering a transaction with her private key, while anyone else can check this using her other key, the public one. All this process is supervised and protected using cryptography, run by other users who get rewarded with fees paid by users on each transaction and/or new currency units. This system varies considerably among different cryptocurrencies.

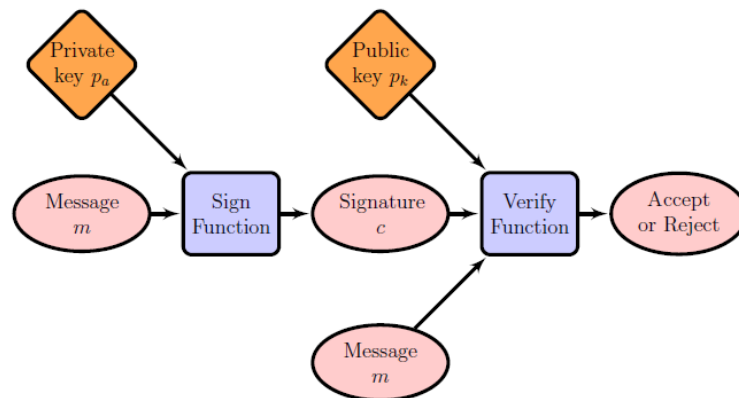


Figure 1. Public Key Encryption for Bitcoin. Source: Badev & Chen 2014.

## 2.2. Basics of Bitcoin

Undoubtedly, the first successful decentralized cryptocurrency is Bitcoin. Prior to that, there had been some very primitive attempts to create the first functional digital currencies. The first one was Wei Dai’s *b-money* in 1998. According to Bitcoin.org, the official Bitcoin website, it was an electronic cash system which first introduced the idea of using cryptography to control money creation and transactions, therefore making a traditional banking interface non-necessary. Shortly after, American computer scientist and cryptographer Nick Szabo designed the system for a decentralized digital currency with the name “bit gold”. Although it was never implemented, it is widely considered the precursor of Bitcoin (Peck 2012).

In 2008, pseudonymous developer Satoshi Nakamoto<sup>4</sup> published the now famous paper *Bitcoin: A Peer-to-Peer Electronic Cash System* on a cryptography mailing list. In this paper, he presented a digital and decentralized currency named

<sup>3</sup> On the context of Bitcoin keys are part of the Elliptic Curve Digital Signature Algorithm (a system which allows creating shorter keys with the same level of protection than longer keys from other systems). Private keys are secret random numbers, usually 128, 256 or 512 bit-numbers, while public keys are points of the curve given by 2 coordinates.

<sup>4</sup> Its identity is still unknown. Due to the pseudonym, I will use male gender when referring to him.

Bitcoin (abbreviated BTC). The system proposed, called Bitcoin Protocol, was to some extent self-sustainable and allowed partially for anonymity. Later, in January 2009, the network was launched and the first bitcoins created.

Satoshi justified the creation of Bitcoin based on the high transaction costs needed for electronic payment due to mediation of the central authority, which made small transactions inefficient. Additionally, according to him the traditional system makes complete non-reversible transactions impossible even when they include non-reversible services. This limitation increases the need for trust between seller and buyer. He states that, within his system this problem can be solved thanks to cryptographic proof.

From the theoretical view, the idea behind Bitcoin is in line to some extent with those expressed by some members of the Austrian school of economics. These economists argue that the actual system of fiat currencies controlled by public institutions have a negative effect on the economy. In particular, they consider that monetary interventions aggravate business cycles and inflation (ECB 2012). However, the proposals made by these economists differ considerably from the Bitcoin Protocol. We have to consider that most of them were made decades ago, when not even computers were fully developed.

As explained before, the system uses private and public key pairs to verify and secure transactions (known as “Public Key Encryption”). However, it also includes new features.

Probably, the most important one is the concept of *blockchain*<sup>5</sup>, which Satoshi used to manage the currency supply and to solve the problem of double-spending<sup>6</sup>. A blockchain is a distributed database (usually called “ledger” when used for digital currencies) which keeps a list of ordered records (commonly called blocks) on a verifiable and permanent way (Iansiti & Lakhani 2017). These blocks are chronologically added to the public ledger by users, who get very small transaction fees (at present they are voluntary) and new bitcoins in exchange. These users are usually called “miners” due to their similarity to gold miners, as I will further explain later. To add a specific block to the ledger it is necessary to compete with other miners to solve a computationally intensive mathematical problem (cryptographic function SHA-256, in the case of Bitcoin and some other cryptocurrencies), and the system is perfectly

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<sup>5</sup> For a most extensive and technical explanation of the concept of blockchain, see Pilkington (2015).

<sup>6</sup> Possibility of copying money, which allows a buyer to spend the same amount more than once.

designed to choose the winner (Badev & Chen 2014). It is important to notice that all miners also keep a synchronized copy of the public ledger, therefore increasing security.

With this system, Nakamoto not only solved the double-spending problem but also allowed the system to be decentralized while securing transactions and managing the supply of new units of the cryptocurrency. It is important to mention that Bitcoin being a decentralized currency only means that there is not central authority. Private companies may still provide wallet and payment services, but users are not forced to participate on them.

The supply of Bitcoin is not constant, i.e. the number of Bitcoins a miner receives as a reward when adding a block to the blockchain is not constant. More specifically, the supply follows a decreasing trend. First, a non-fixed number of transactions are put together into a block by a miner. The number of transactions needed is modified every 2016 blocks aiming for a more constant rate of block creation. Then, miners get a reward in form of newly issued Bitcoins for every block. However, the number of Bitcoins rewarded for each block decreases by 50% every 210,000 blocks (roughly 4 years), Grinberg (2011). These periods are usually called “reward eras”, and the transition between them “halving”. The total number of Bitcoins is expected to get extremely close to its 21 million limit around the year 2140 (an infinite number of reward eras would be needed to reach exactly 21 million<sup>7</sup>), Yermack 2013. Therefore, the supply is ultimately finite and can be shown as follows:

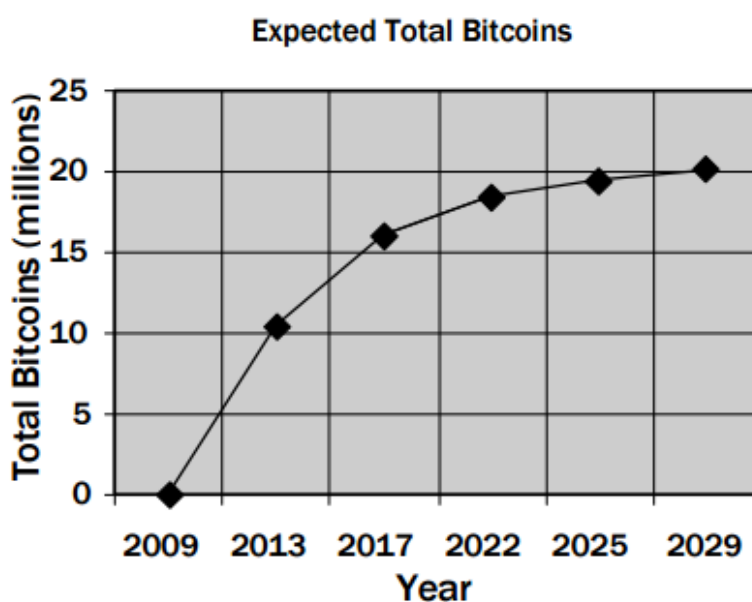


Figure 2. Expected Total Bitcoins 2009 - 2029. Source: Grinberg 2011.

<sup>7</sup> For further calculations, see Table 1 in Appendix A.

Following the mathematical expression:

$$\frac{\sum_{t=0}^{\infty} 210,000 \times \left(\frac{50 \times 10^8}{2^t}\right)}{10^8} = 21,000,000$$

For example, at this moment (July 2017) Bitcoin is on its third “reward era”, and miners get 12.5 BTC/Block as a reward (which is  $\frac{50}{2^2}$ , as 50 was the initial amount rewarded per block during the “first era”). The total number of Bitcoins in circulation is 16,432,663 (CoinDesk), which represents 78.25% of the maximum amount of 21 million.

As Nakamoto (2008) explained himself, this system aims to imitate the supply of gold. Similarly to gold miners, Bitcoin miners also spend resources to add new units to circulation. These costs are mainly computer and electricity bills (powerful computers are needed, as mathematical problems are very CPU intensive, requiring machines to take millions of guesses until reaching the correct answer).

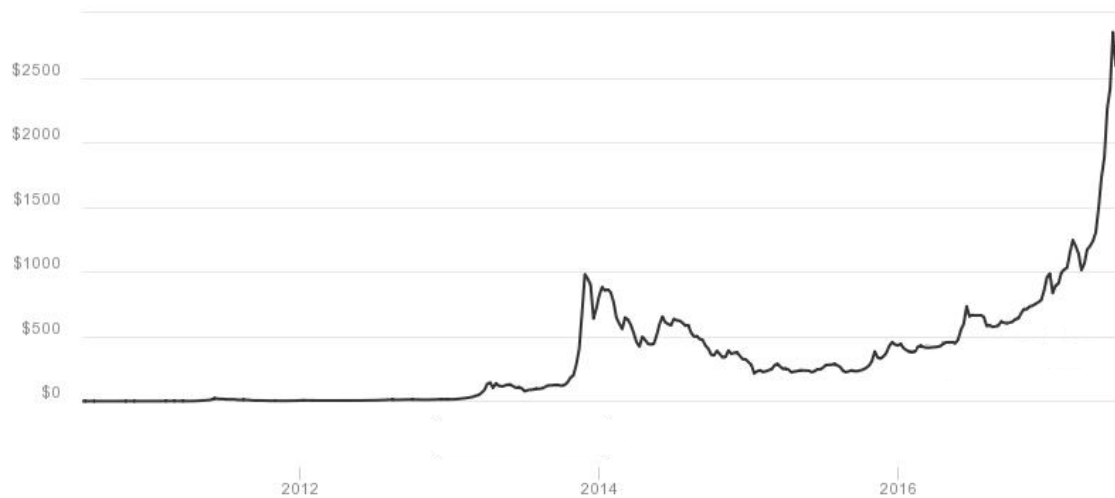
This mining system has formed its own industry, with a respectable number of companies worth millions of USD in world markets (Price 2016). These firms operate facilities informally called “Bitcoin mines” where hundreds of powerful-CPU computers mine the currency 24/7. During the last years these installations have opened worldwide. The case of Iceland stands out, as many companies have placed their facilities there due to cheap electricity, good internet connection and cold climate (which reduces computer cooling costs).

Due to the limited supply the value of a unit of Bitcoin is expected to grow if more people start adopting the currency. Because of this, multiple names for subunits have been proposed. One of the most-known is “*satoshi*”, named after Nakamoto himself. A satoshi is equivalent to  $10^{-8}$  BTC, which is the smallest division possible of a Bitcoin.

The supply system of Bitcoin and its transaction process are highly relevant for this work, as later I will investigate the viability of an international cryptocurrency with a similar design, but with a constant supply growth rate (following Friedman’s percent  $k$  rule).

### 2.3. Evolution of Bitcoin

Since its launch in 2009, Bitcoin has become undoubtedly the most successful cryptocurrency. The extent of its success is showed in Figure 2 with market numbers: 1 Bitcoin valued \$3,000 during its highest market peak (June 2017), with market capitalization reaching almost than 50 billion USD (source: CoinDesk). It can also be proved by mere comparison: on March 2017, one Bitcoin surpassed the value of a troy ounce of gold for the first price, with a price of \$1,268 (Molloy 2017).



*Figure 3.* Evolution of the prices of Coindesk Bitcoin Index (USD), July 2010 – June 2017. Source: Coindesk.com

Data from Bitcoin service companies can also help illustrating the growth of the market. For example, Blockchain.info, an important Bitcoin data service located on Luxembourg, estimates that their numbers of transactions per day and Blockchain Wallet users are still growing, with present peaks of 300,000 transactions and more than 13 million users. It is important to notice that the number of Blockchain Wallet users does not give us the total number of real active users of Bitcoin operating on Blockchain.info, as they may possess various Blockchain Wallet users. Also, many of these accounts are opened by people curious about Bitcoin and are abandoned quickly (Hajdarbegovic 2014). However, it shows a clear upward trend on both Bitcoin's trading and popularity.

Bitcoin's price history, as shown in Figure 3, can be divided in four periods. First, a five-year long period during which prices varied between \$0 and \$20. Second, a six-month period during which prices went up from \$19.87 in January 2014 to a peak of

\$979.45 in November 2014 (including an increase of more than 800% in less than two months). Third, a two-year period of descent and standstill with minimum prices between 215\$ and 230\$. And fourth, an ongoing increasing period with an abrupt and stronger price increase during spring 2017 (reaching a record above \$3,018 on June 2017).

These strong fluctuations prove a high volatility of the prices, and academics have warned or directly confirmed the existence of “bubble behavior” on the Bitcoin market (see for example Cheah & Fry 2015).

#### 2.4. The perception of Bitcoin

Since 2008 a growing academic literature about Bitcoin has been produced. New papers are published every year on both well-known and prestigious international journals and more specialized publications. One of the main aspects studied by academics has been the differences of Bitcoin compared with traditional fiat currencies. They have applied extra emphasis on the benefits and dangers of its quick growth and its sustainability on the long-term: as its market size increases, so do the negative effects of a hypothetical collapse. According to the ECB (2012), virtual currencies like Bitcoin do not pose a threat to financial and price stability at this stage, but on the future they may.

None other cryptocurrency has reached Bitcoin’s maturity until now and therefore the topic is unexplored territory with ideas open to debate and openly opposite positions coexisting. This debate includes the ability of Bitcoin to fulfill the three function of money: medium of exchange, unit of account and store of value.

According to its supporters, Bitcoin possesses several advantages. First of all, it allows transactions to be performed anytime, anywhere and by anyone. There is no need for the buyer and the seller to be in the same place on any transaction. This advantage is shared with actual e-banking. However, eliminating all physical currency leads to a substantial reduction of costs, especially when it comes to the production, transportation, distribution, storage and security of money. According to Plassaras (2013), the US spends and estimated amount of 60 billion USD on these activities and this amount would be reduced by 33-50% with a completely digital currency. Additionally, it would increase the users’ pace of learning on electronic payment systems. As the digitalization of the world continues this would produce a positive long-term effect.

Another aspect praised by supporters is that it greatly reduces transactions costs while increasing their speed (Dwyer 2015). As Bitcoin is designed to be used internationally through the Internet, the number of fees and steps is smaller. This cost reduction is notably when it comes to currency exchange.

Also, due to its limited supply it is expected that Bitcoin will become as scarce as other goods. Like in the case of gold this scarcity will increase its value, making it a valuable unit of account by itself and a proper store of value. Additionally, the way the supply system works implies that it is backed exclusively by its users, and not by any type of specific institution or government. That would make its stability more difficult to be jeopardized by partial and particular interests. This elimination of the monopoly of governments and central banks regarding money creation is greatly controversial. It has some support by important personalities along economic history (see for example Hayek's well-known book, *Denationalization Of Money*). However, the alternatives suggested differ greatly from the Bitcoin Protocol.

Finally, the increase in anonymity on both transaction and wallets has also been celebrated by many users (ECB 2012). Again, this point is polemical, but has been acquiring importance with the debate on Internet privacy and government mass-surveillance.

On the other hand, there are many critiques of Bitcoin. First, as I hinted before, there is a great uncertainty about the consequences of widespread adoption of a cryptocurrency like Bitcoin (Plassaras 2013). The lack of intrinsic value of the digital currency and the inexistence of an official authority backing it have raised concerns about the viability and desirability of the cryptocurrency on the long-term. This issue has many implications. It supports those concerned with the Bitcoin system working as a Ponzi scheme (ECB 2012). After all, the value of a Bitcoin is due exclusively to its demand by other users, with none physical good like gold backing it. Moreover, it also gives impetus to those stating that the Bitcoin market suffers from bubble behavior. Many economists labeled the period from September to December 2014 the "Bitcoin Bubble". As I show in *Figure 3*, Bitcoin possesses a very high volatility. This supports the bubble behavior claim and also makes its currency and store of value usages more risky and unattractive, while increasing its use as a speculative asset. Additionally, the lack of financial instruments to hedge the exchange risk of Bitcoin with other currencies also increases overall risk (Yermack 2013).

Another common critique is its lack of regulation (Plassaras 2013). Although there have been some advances on this matter, it is a fact that Bitcoin still lacks a fully developed legal framework. Its completely digital existence, the partial anonymity of its users and operations and its international vocation makes it even more complicated. According to the ECB (2015), until now official responses have been mainly warnings, statements and clarifications on the legal status, including outlines of future licensing, supervision plans, actions and bans<sup>8</sup>. One of these warnings has to do with the problems derived from its anonymity, as it facilitates its use for illegal activities such as trading in Darknet markets, e.g. Silk Road. (Yermack 2013). Also, some institutions (ECB 2015) have noticed that Bitcoin does not fulfill all conditions to be considered a currency. According to them, that is the case from a legal and economic perspective. They support this position stating that Bitcoin is more used speculatively than as a medium of exchange, and it is not used officially by any country.

Its security has been a controversial issue too. Cyber-security is an increasing concern even with traditional currencies. A digital currency would be even more vulnerable to cyber-attacks (Plassaras 2013).

Finally, its limited supply has been criticized as well. According to critics, it could make impossible for Bitcoin to keep up with its adoption rate and economic growth and adapt to different situations as a currency with a central authority can do. The lack of Bitcoins would increase its value, which would produce deflation on prices in Bitcoin. This deflation would incentivize users to postpone their buying, therefore driving prices down further and creating a deflationary spiral (ECB 2012). This constitutes an important danger to the real economy (Bank of England 2014). It is difficult to imagine a world where workers accept a reduction of their salary every year, even if this is just a nominal one. Besides, it would also affect transactions costs. Despite being usually cited as an advantage respect to traditional currencies, some critics predict the increase of transaction costs for Bitcoin on the future. The reasoning is that as the number of new Bitcoin issued as a reward for miners decreases (which at present constitute most of their profit) transactions costs may have to increase in the future to keep the activity attractive for miners (who are necessary for the transaction verification process). Hence, transaction costs could possibly reach higher values than those of traditional currencies (Bank of England 2014).

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<sup>8</sup> See the Annex of ECB (2015), for a more detailed description of the different national responses to virtual currencies by EU countries.



Additionally, in spite of not being a proper critic, the difficulty to incentivize buyers and sellers to adopt the currency constitutes an extra obstacle.

## 2.5. Future of Bitcoin

The future of Bitcoin can be summarized with a single word: uncertainty. Although it is possible that the problems stated by critics of the cryptocurrency will never materialize, it is also true that Bitcoin may need to adapt if it has the intention to become capable of competing with traditional currencies. Radical changes may be needed, or maybe even the launch of a very different and renovated version.

In fact, some important changes have already been proposed, especially on the programming aspects, and have become the main point of an ongoing debate. For example, various ideas have been suggested to improve the issue of network scalability, with the main focus on the number of transactions the network can process (Coppola 2016).

Included into the debate is Bitcoin Unlimited, a controversial project which allows users to choose their own block size limit. According to their creators, the removal of this control feature will allow users to reach their own consensus (similar to the price consensus in a free-market). They argue that this new adjustable variable will increase the adaptability of Bitcoin in the future.

In addition, other cryptocurrencies are also growing e.g. Ethereum, Ripple, Litecoin. Bitcoin's share of the market capitalization of all cryptocurrencies has fallen from 90% to 70% on the period between 2013 and 2017 (Valenzuela 2017). The possibility that one day another cryptocurrency will surpass Bitcoin seems higher.

### 3. ROBERT MUNDELL. The case for a world currency.

Robert Mundell is a Canadian economist famous for his works on monetary economics. He won the Nobel Prize in Economics in 1999 and he is a professor of Economics at Columbia University in the US and at the Chinese University in Hong Kong. His work on optimum currency areas became the theoretical base for the Euro (Mundell 1961).

In his paper *The case for a world currency*, published in 2012, Mundell states that the actual flexible exchange system has failed. To substitute it, he proposes to create a world currency. This currency would not substitute all local currencies, but would be used only for international trade purposes. He briefly explains a two-step procedure to implement it.

The implementation process of the international Bitcoin-type cryptocurrency which I will study later will be based on this plan. Consequently, an analysis of its viability seems appropriate. I will accomplish this after navigating through the main points of the paper.

#### 3.1. Summary

This idea of an international currency is not new. According to Bordo & James (2006), it has been present since the middle of the nineteenth century. Its main pillars would be reduced transaction costs, more credibility, more international consensus and possibly facilitating the road to deeper political integration (as in the case of the Euro).

Mundell argues that the actual absence of a real international currency is inexplicable, as well as the lack of political interest on it. He states that although in the last decades there has been a strong support for an increasing international trade and freedom of capital movements, no steps have been taken into creating an international currency. It would facilitate international movements enormously, reducing risks drastically (especially those associated to currency exchange).

He states that the main reason why it was not implemented was the same reason why the idea failed in all previous attempts: the opposition of the economic power of that time. As an example, he cites some of the most powerful currencies of many eras such as the British pound sterling and the American dollar, whose countries opposed to similar plans decades ago. During the post-war era the UK supported the idea after they

lost their dominant status (proposing the name *bancor* for the currency), while the US rejected it even after presenting its own plan (proposing *unitas* as name).

However, Mundell believes that at present there are higher possibilities of success. The main reason is that since the floating currency system was implemented at the end of the Breton Woods system during the 70s, there has not been any currency which could be called a universal currency. As proof of this, he maintains that the 70s was the only moment when there was a movement in the right direction: the creation of the Special Drawing Rights (SDR) by the IMF, which is a type of reserve asset whose value depends on the main currencies. Furthermore, the most dominating currency, the US dollar, has lost power recently with the introduction of the Euro at the beginning of the 2000s.

Mundell states that the floating system was implemented not because of its desirability, but because of the lack of alternatives. According to him, classical economists would have never supported it due to the inefficiency of each country or group of countries using exclusively their own currency.

Because of this, he heavily criticizes the actual flexible rate system. He refutes one by one its alleged advantages using in many cases empirical evidence from the last four decades. For example, he states that contrary to the predictions of the supporters of the flexible system, the need for international reserves has increased. On the same way, exchange rates have been less stable; there has been more inflation and speculative international capital movements, more balance of payments disequilibria and stronger shocks. Additionally, the possibility of using flexible interest rates as a monetary instrument has to be given up, therefore reducing its attractiveness. Mundell also criticizes the danger of high volatility of the main exchange rates, which is illustrated by the dollar cycle since the introduction of the system (data on dollar inflation and interest rates variations serves as proof).

He also adds that, under the floating system, real exchange rates change so quickly that they deviate more easily from their fundamental value due to incorrect expectations and temporal perceived need for intervention. This issue affects real interest rates, increases uncertainty and has a very high cost for the overall economy. Mundell believes it is one of the main reasons of some of the last crises, including the standstill of the Japanese economy since the 90s.

Therefore, to substitute this system, Mundell proposes to create an international currency in two steps. Previously he dismissed the idea of anchoring this new currency

directly or indirectly (though a currency like the dollar) to a known substance (probably gold). The hypothetical price of gold would need to be ridiculously high to be able to convert the trillions of dollars (or euros if it was chosen instead) into the metal. It would also put the dollar under a lot of pressure, as it would be ultimately impossible to keep the same proportion of gold and dollars to maintain a fixed conversion rate (same as at the end of the Bretton Woods System at the beginning of the 1970s).

Instead, his idea starts by stabilizing exchange rates. The first part would be creating a weighted basket with the most important currencies (Dollar, Euro and Yen) which could be called DEY, similar to the Special Drawing Rights. Their respective central banks would aim to minimize currency fluctuations. This mechanism would take time and would be similar to the one established during the years before the euro, stipulating ceilings and floors. However, it is important to notice that the ultimate target would not be all those areas adopting the same currency. The DEY would be a multi-currency G-3 monetary union with fixed exchange rates and unique monetary policy. All in all, it would include five conditions: a unique inflation target and measure system, fixed exchange rates, the creation of a DEY central bank and a mechanism for distributing seigniorage. It would include two-thirds of the world economy and generate a substantial profit.

The second step would start allowing more countries to join the union, thereby increasing the stabilizing effect. Other important currencies like the British pound could be included on the basket. Then, the international currency could be created (Mundell suggests the name INTOR). The basket and its individual currency components would be convertible to this new currency. It is important to highlight that the proportion of the components of the basket would not be completely fixed, and the DEY central bank would have the ability to modify them and use this as a new monetary instrument.

Mundell ends his paper arguing that although the possibility of creating a world currency may seem far from today, the recent crises may ultimately constitute an opportunity to start the process.

### 3.2. Discussion

On his paper, Mundell proposes a plan to implement an international currency consisting on two steps, before definitely introducing the new currency INTOR.

He clearly bases these steps on the experience of the Euro. The main difference between Mundell's plan and the Euro creation process is, as explained before, that in the first case the INTOR does not aim to substitute the other currencies. Regarding the Euro creation and introduction, first the European Monetary System (EMS) was arranged in 1979, including the European Exchange Rate Mechanism (ERM). According to the European Commission, its goal was to avoid large fluctuations between the target currencies. The next step consisted on the creation of the European Monetary Institute (EMI), which aimed to coordinate monetary policies of the target countries between 1994 and 1997. Finally, in 1999 the Euro was introduced and the European Central Bank (ECB) became the *de facto* substitute of the EMI. More specifically, in 1999 the Euro was just introduced as a common unit of account, substituting the European Currency Unit (a basket formed by the target currencies of the European Community, similar to the one proposed by Mundell). It was not introduced physically until the 1st of January of 2002.

However, I believe on his paper Mundell leaves unexplained the most complicated and unexplored part of his plan: the actual introduction of the international currency. He states that "*the value of the currency, the mechanism and agency by which it will be introduced, the system and criterion of controlling its quantity, its backing in terms of currency or commodity reserves and the location of the central authority*" should be decided. I think that these issues constitute terrible obstacles, probably even more difficult than those of the previous steps. It is true that the experience of the Euro could be useful when planning further steps (it is Mundell's main inspiration for this paper, after all). Nonetheless, it could not be faithfully applied for this case. As stated before, the INTOR would be exclusively used for international purposes and would not substitute the national currencies like the Euro did. Additionally, the complications of reaching a consensus on a monetary union like the Eurozone have remained clear during the last 15 years. There is nothing telling us that it would not be even more difficult with a wider trans-continental union like the one proposed in the paper, especially regarding non-democratic countries.

It is also important to notice that political costs would pay an important role, probably even more than economic ones. Mundell states that the absence of a clearly dominant international currency during the last decades should facilitate the plan. However, he may be underestimating the power of the most important currencies at present, which makes them more of an asset or influence instrument for their respective

countries. For example, there are multiple currencies anchored to both the dollar (especially in America and the Middle East) and to the Euro (in the Balkans and former French colonies in Africa), which constitute areas of influence of the United States and the European Union, respectively. Additionally, Mundell holds that the system he proposes, based on a basket of the main world currencies, would produce a notable increase in gains due to its efficiency. Nevertheless, it does not guarantee a fairer distribution of power on the new international financial institutions which would need to be created together with the INTOR. It may not give small countries a fairer share of power as Mundell hints. There is nothing preventing those institutions to grant excessive voting shares to the most powerful countries, aggravating international tensions. Furthermore, a powerful member would not even need a voting share beyond its weight to increase its influence on all other members: having the leading share could be enough. Paradoxically, in case some mechanism is created to avoid these issues that would make even more unattractive for those countries to accept the INTOR. All in all, I believe a system like the one Mundell proposes could give even more power to dominant countries, facilitating a more intense coordination among them and more influence power to the detriment of smaller countries. Mundell himself states that countries outside the core union could resent “trilateral dominance”.

Mundell also argues that the succession of crises during the last years may constitute an opportunity to take a big step like the INTOR. This may have seen like a realistic option during the years previous to 2012, when the paper was published, or at least as a possible one. Nevertheless, it has become less probably during the last years. The complications this kind of plan would face at present are best illustrated by the protectionist policies adopted by the US under Donald Trump’s presidency and the increasing support for anti-euro political parties.

Finally, it is also important to notice that despite being sometimes labelled as “the father of the Euro”, Mundell’s work on currency areas (Mundell 1961) possesses some arguments against a monetary union like the Euro area and the one he proposes on this paper. First, he states than labor and product markets should be flexible in a currency area. There are definitely several barriers, e.g. language, culture..., among areas like the US, Japan and the EU (including inside the EU itself). Second, he also argued that a central fiscal authority is necessary to counterbalance fiscal transfers produced by the monetary union. The argument behind this second idea is that although a monetary union increases the overall efficiency of the member areas, these profits are

distributed unequally. It has been commonly used in the EU to justify the existence of economic policies such as the European Regional Development Fund (ERDF), which aims to mitigate the negative effects of the union in parts of the EU at regional level.

In conclusion, a huge number of well-design mechanisms would have to be placed to allow Mundell's plan to be successful, including some controls for the most dominant countries. Therefore, the benefits of the INTOR would have to be substantial and certain in order to motivate countries to participate and cede part of their monetary policy. National interests would have to be put aside and the amount of political capital needed for the process would be unimaginable. Also, it is unknown to what extent fiscal and banking policies should be coordinated among members to make the INTOR viable on the long-term. This could increase political costs even more. Again, the case of the Euro can be carefully used as an incomplete guideline, specially its evolution during the last decade.

#### 4. JONATHAN CHIU & TSZ-NGA WONG. On the Essentiality of E-Money

In this paper, Chiu & Wong study the possibilities created by the latest innovations on payment systems, focusing on the rise of electronic money (e-money). More specifically, they explore the opportunities that these new systems offer (when compared with traditional payment systems) to increase the efficiency of a payment system.

First, they develop a baseline model based on Rocheteau and Wright (2005), which I will explain in detail. Then, they include a Money Mechanism, allowing for a non-lump-sum transfer scheme<sup>9</sup> which allows higher efficiency. After that, they study alternative models including e-money. The main e-money technologies they examine are “*limited participation*” and “*limited transferability*”. While the former one allows the e-money issuer to exclude agents from holding e-money, the latter one allows the e-money issuer to block e-money transfers among agents.

On the next section I will reinterpret Chiu & Wong’s baseline model for an international cryptocurrency, also including some changes to make it more realistic. Therefore, this paper is crucial for this study and a complete analysis of the baseline model appropriate for understanding.

Chiu & Wong’s baseline model<sup>10</sup> possesses notable assumptions. First, I will state them, also explaining the model intuitively and including an example to help the reader to get a more complete idea. Then, I will give a more technical explanation. Finally, I will conclude with a brief discussion of the paper

##### 4.1. Summary

As I have already explained, Chiu & Wong’s main objective in this paper is to investigate the advantages that e-money payment systems may offer over traditional payment systems. They argue that this issue can be useful both for academics and policy makers. They develop various theoretical models. I will focus on the first one.

The main conclusion of the paper is that e-money features can improve the efficiency of a monetary economy. According to the authors, the two technologies

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<sup>9</sup> A lump-sum payment is a one time-payment that usually substitutes a series of payments made over time (for example in pension schemes and annuities).

<sup>10</sup> For a complete list of all the symbols used henceforward and their meaning, see *List of Symbols* in Appendix B.

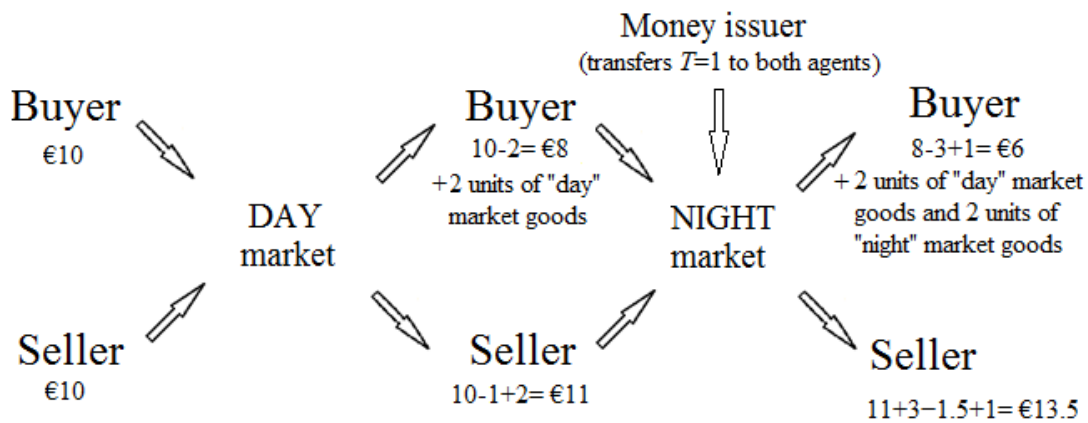


stated before (limited participation and limited transferability) allow for several new features<sup>11</sup>, which facilitate the achievement of a more efficient allocation of resources.

#### 4.1.1. Intuition

In this model, time is discrete and infinite, and every period comprises two subperiods (with a market on each of them). The authors call these subperiods “day” and “night”, respectively. There is only one medium of exchange: a fiat currency similar to traditional currencies such as the euro and the dollar. Agents live forever and can be buyers or sellers. This trading status is assumed to be permanent, i.e. a buyer cannot become a seller and vice versa.

Before explaining the model in detail, I will provide with a brief and simple example of the trading process during a whole period. The diagram of the model shown in *Figure 4* will facilitate the process.



*Figure 4.* Baseline model diagram for one period. Source: own work.

Let us suppose that the currency used in the model is the euro. At the beginning of a period  $t$ , both a buyer and a seller possess €10. Both agents meet in the “day” market, where they exchange 2 units of goods with a value of €2 (assuming price is €1/unit of “day” good). Therefore the buyer now possesses  $10 - 2 = €8$  and two units of “day” market goods. Meanwhile, the seller possesses  $10 + 2 - 1 = €11$  (assuming the cost of producing the goods is half of their market value, i.e. €0.5/unit, for a total of €1).

Now, both agents move forward to the night market, where they exchange 2 units of goods with a value of €3 (we assume price is €1.5/unit of “night” good). As

<sup>11</sup> For example, the authors mention non-linear pricing, membership fees, interchange fees, rewards and cross-subsidization.

trading status is permanent, they keep the same role: the buyer remains being a buyer and the same for the seller. In this market, they also receive a lump-sum transfer  $T$  by the money issuer, which I will explain later. For this example, we assume  $T = €1$ .

In this case, after trading, the balance of the buyer is  $8 - 3 + 1 = €6$  and he has two units of both “day” and “night” market goods. The balance for the seller is then  $11 + 3 - 1.5 + 1 = €13.5$  (again, we assume the cost of producing night market goods is half of its market value €0.75/unit, for a total of €1.5).

The design of this model includes various assumptions that I will describe now. It is also subject to multiple criticisms, which will be addressed later at the end of this section.

As stated before, there are two subperiods/markets in this model. During the “day” subperiod there is a decentralized market (DM henceforth). In this market there is not an official central authority matching buyers and sellers (which are subject to pairwise random matching, and therefore have to agree on price and quantity by themselves) and acting as an intermediate on transactions to reduce the risks on the market. Hence, there are frictions in this market and agents may not agree, so the transaction may not happen (in the previous example I have assumed that both agents match and a transaction is conducted). Additionally, transactions are anonymous, which has various implications. First, agents can only observe transactions when they participate on them. Second, control and enforcement of the regulation are more difficult. And third, credit is not possible (cash-in-advance constraint), as it is not possible to know the total balance of an agent in the market.

This constraint means that the medium of exchange (the traditional currency) is vital for trading. Also, it can lead to an inefficient allocation of resources, as buyers may not acquire enough money and be liquidity constraint.

On the other hand, during the “night” subperiod there is a centralized market (CM henceforth). On this market there are not frictions and agents trade at Walrasian prices<sup>12</sup>.

The goods traded on both markets are different, with those in the CM working as a numeraire, i.e. an item or commodity acting as unit of account. Therefore the CM goods work as a measure of value, facilitating the comparison of the value of other

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<sup>12</sup> Prices are set by means of a Walrasian auction, where each agent states its demand for the good for every possible price. Final prices are then set so that the total demand of the good is the same than its total supply.

goods and services. In this model,  $\Phi_t$  is the price of money in units of numeraire at time  $t$ .

Also,  $\beta \in (0,1)$  is the agent's discounting factor, and the stock of money possesses an exogenous growth rate  $\mu$  such as  $M_{t+1} = \mu M_t$  (where  $M_t$  is the monetary base at time  $t$ ). These new units of currency are introduced by means of a lump-sum transfer that every agent receives in the CM. The authors assume that the inflation rate is equal to the money supply growth rate.

The agents' main target is maximizing their value functions. These value functions depend on their money inflows (usually real balances of money carried from the previous subperiod plus transfers) and their money outflows (utility from consumption in that subperiod and the expected value derived from carrying the new balance of money to the next subperiod). Also, the buyer's and seller's bargaining powers are important, as they decide the distribution of the trade surplus (the extra value created by transactions) between both agents.

All in all, this system consisting on two markets is in equilibrium when the agents maximize their values and the quantity demanded maximizes the trade surplus (which will be explain later). Also, the design of the model implies another simple but important requirement: transfers made to the agents by the money issuer need to be adjusted to effectively introduce the desired number of new units of currency (keeping this way the desired currency supply growth rate). Additionally, as I already stated before, they assume that the inflation rate is equal to the money supply growth rate.

#### 4.1.2. *The baseline model*

Now, I will provide a more technical explanation of the model.

As I hinted before, the agents' utility depends on their actions in both the centralized and decentralized markets. The total utilities of buyers and sellers are given, respectively, by:

$$\tilde{U}_b(q, l) = U(q) + l, \quad (1)$$

$$\tilde{U}_s(q, l) = -C(q) + l, \quad (2)$$

where  $q$  are the goods traded on the DM and  $l$  are the goods traded on the CM market (the numeraire).  $U(q)$  is the buyer's utility function in the DM, with  $U'(q) > 0, U''(q) < 0, U(0) = 0$  and  $\lim_{q \rightarrow 0} U'(q) = \infty$ .  $C(q)$  is the seller's cost function in the same market, with  $C(0) = 0, C'(q) \geq 0, C''(q) \geq 0, C'(0) = 0$ . Therefore, the authors

suppose increasing marginal costs. Notice that for the CM the numeraire  $l$  does not take the form of a different utility function as the authors use it directly as a measure of value. These utility functions will be included on the valuation equations that summarize the agent's optimization problem.

Before moving on to these value equations, the authors include an agent's budget constraint for the CM:

$$\frac{\phi_t}{\phi_{t+1}}z + l = \tilde{z} + T. \quad (3)$$

The left-hand side (LHS henceforth) includes all possible outflows of money.  $\frac{\phi_t}{\phi_{t+1}} > 1$  is the inflation rate in terms of the numeraire (remember  $\phi_t$  is the price of money in units of numeraire). Meanwhile  $z \equiv \phi_t m$  is the real balance the agent carries to the next subperiod ( $m$  is the amount in the traditional currency). All amounts of currency in the value functions are expressed in units of the numeraire. Therefore  $\frac{\phi_t}{\phi_{t+1}}z$  is the balance of money the agent moves to the next subperiod DM.  $l$  represents the value of consumption in the CM. If the agent produces and sells CM goods instead of consuming them the value  $l$  will have a negative sign, which disappears when moving it to the other side (the right-hand side, RHS henceforth) of the equation. In this case it would be an inflow of money. The other components in the RHS are the real balance of money  $\tilde{z}$  the agent brought from the previous subperiod (DM) and the transfer  $T$  from the central bank.

Taking this into account, the authors move on to the value equations. Following their paper, the value equation in the CM is given by:

$$W_j(\tilde{z}) = \max_z \left\{ \tilde{z} + T - \frac{\phi_t}{\phi_{t+1}}z + \beta V_j(z) \right\}, \quad (4)$$

subject to (3) and where  $j = s, b$  depending on the agent's type. The agent maximizes his value when deciding the real balance of money  $z$  he will move to the next period. This amount indirectly includes in the equation the money the agent spends or earns trading during this subperiod. In the case of a buyer  $\tilde{z} + T > \frac{\phi_t}{\phi_{t+1}}z$  will hold, indicating that he has spent money on units of the numeraire, whereas for a seller  $\tilde{z} + T < \frac{\phi_t}{\phi_{t+1}}z$  will be true, showing the opposite. Increasing the amount of money moved to the next period rises the value obtained from the next subperiod  $V_j(z)$ , which is the value function of an agent with real balance  $z$  in the next DM market. Notice that  $V_j(z)$  needs

to be discounted, as its period has not started yet. Again,  $z$ , expressed in units of currency of this period, needs to be adjusted with the inflation factor  $\frac{\phi_t}{\phi_{t+1}}$  when carried to the next period.

On the other hand, the value equation for an agent in the DM differs depending on the type of agent. They are, for a buyer and a seller respectively, denoted as:

$$V_b(z_b) = \alpha[U[q(z_b)] + W_b[z_b - d(z_b)]] + (1 - \alpha)W_b(z_b), \quad (5)$$

$$V_s(z_s) = \alpha \int [-C[q(z_b)] + W_s[z_s + d(z_b)]] dF(z_b) + (1 - \alpha)W_s(z_s), \quad (6)$$

where  $F$  is the cumulative distribution of the buyer's real balances;  $d(z_b)$  is the amount of currency exchanged when the transaction is performed;  $\alpha$  is the probability there is a match between a buyer and a seller in the DM market, and thus multiplies the result if there is an effective transaction (e.g. utility from consumption and future value from the balance moved forward to the next subperiod in the case of the buyer); accordingly,  $(1 - \alpha)$  is the probability there is not a successful match (in that case the whole balance of money is just moved to the next subperiod). Notice that 1) sellers produce DM goods  $q$  on demand, and consequently do not keep stock; and 2) in these equations the subscripts  $b$  and  $s$  are included to  $z$  to indicate if it is the buyer's or seller's real balance (on other equations subscripts are omitted when referring to the main equation's agent). The cumulative distribution function  $F$  captures the distribution of buyer's real balances, as they can have heterogeneous money balances, i.e. they can hold different real balances, out of different trading history. In equilibrium every buyer chooses to hold the same real balances, no matter their trading history and therefore this integral can be dropped (it is a degenerate case<sup>13</sup>).

The authors denoted the surplus generated by the trade in the DM market as:

$$S_b(q, d; z_b, z_s) = U(q) + W_b(z_b + d(z_b)) - W_b(z_b), \quad (7)$$

$$S_s(q, d; z_b, z_s) = -C(q) + W_s(z_s + d(z_b)) - W_s(z_s), \quad (8)$$

where  $S_b$  and  $S_s$  are the fraction of the surplus that the buyer and the seller generate, respectively. In both cases the surplus is just the result of calculating the difference in value when the trade is carried out and when it is not: it is the extra value created by the

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<sup>13</sup> A degenerate case is a limiting case in which an object belonging to one class is qualitatively different from the rest and therefore it belongs to a different class, commonly simpler. For example, a point is a degenerate circle whose radius tends to zero, whereas a circle is a degenerate ellipse whose eccentricity tends to zero.

transaction. Also, in this case the authors add the subscripts  $b$  and  $s$  to the real balance  $z$ , as they need to distinguish between the buyer's and the seller's.

Accordingly, the bargaining problem can be summarized as:

$$\max_{q,d}\{S_b(q,d; z_b, z_s) + S_s(q,d; z_b, z_s)\}, \quad (9)$$

i.e. variables  $q$  (amount of DM goods) and  $d(z_b)$  (amount of money paid for them) need to be chosen to maximize the surplus created by the transaction. This is subject to the bargaining rule:

$$S_b(q,d; z_b, z_s) = \theta[S_b(q,d; z_b, z_s) + S_s(q,d; z_b, z_s)], \quad (10)$$

where  $\theta \in (0,1]$  represents the buyer's bargaining power. It could be defined as the percentage of the total surplus that the buyer receives and therefore the closer it is to 1, the more bargaining power the buyer has.

**Definition 1.** A degenerate monetary equilibrium is achieved with an allocation  $(q, z_b, z_s)$ , a policy  $\{M_t, \mu, T\}$  and inflation  $\{\Phi_t\}_{t=0}^{\infty}$ , such that:

- a. The agent's optimization problem is solved, i.e.  $z_b$  and  $z_s$  solve (4).
- b. The agents' real balances of money at the beginning of the period are equal to the monetary base  $\Phi_t M_t = z_b + z_s$
- c. The bargaining problem is solved, i.e.  $q = q(z_b)$  solves (9).
- d. The money issuer's budget constraint it met, i.e. the transfers made to the agents at the end of the period are equal to the amount of new currency supplied: given  $\Phi_t, \{M_t, \mu, T\}$  satisfies  $T = (\mu - 1)\Phi_t M_t$ .
- e. The inflation rate is equal to the currency supply growth rate:  $\Phi_t > 0, \frac{\Phi_t}{\Phi_{t+1}} = \mu$ .

Finally, the authors also discussed how exogenous variables affect the existence of a monetary equilibrium: money supply growth rate cannot be too high or too low, trades on the DM too infrequent and/or the buyer's bargaining power too low. These issues can be checked intuitively.

On the first case, if the money supply growth rate is too low ( $\mu < \beta$ ) then the agents' money demand will be infinite (the real balance moved to the DM,  $z$ ). Remember that they assume  $\mu = \frac{\Phi_t}{\Phi_{t+1}}$ , and therefore inflation would be too low and agents would make profit when carrying an amount from one period to the other (the rate of return would be  $\beta \frac{\Phi_{t+1}}{\Phi_t} - 1 = \frac{\beta}{\mu} - 1$ ). On the other hand, if  $\mu > \beta$ , then sellers will not move money to the DM ( $z_s = 0$ ). Similarly, buyers will not bring any quantity

not intended to be used for a DM transaction. If the money supply growth rate is too high ( $\bar{\mu}$ ) agents will not trade in the DM. Chiu & Wong summarize it as:

$$z_b = 0 \leftrightarrow \mu \geq \bar{\mu} \equiv \beta \left(1 + \frac{\alpha\theta}{1-\theta}\right) \quad (11)$$

Consequently the authors propose that a monetary equilibrium exists if  $\mu \in [\beta, \bar{\mu}]$ . If  $\mu > \beta$  consumption in the DM is lower than its efficient level  $q < q^*$ . When  $\mu \rightarrow \beta$ , then  $q \rightarrow q^*$ . Therefore, to implement the first-best allocation (which is the allocation with the highest trade surplus in equilibrium) it is necessary to deflate the economy at the discount rate.

The other two cases are straightforward. If the buyer's bargaining power  $\theta$  is too low, they will not have an incentive to get into the DM, as they cannot benefit from the surplus produced by trading there. On the other hand, if trades on the DM are too infrequent, i.e.  $\alpha$  tends to 0, then the market will be unattractive for both buyers and sellers. Costs of finding a trade partner would be too high.

## 4.2. Discussion

Chiu & Wong's model tries to simulate a complicated monetary system. Hence, numerous assumptions are made, some of them arguably unrealistic. They may be justified for the sake of simplicity, but I consider part of them could have been easily eluded.

First, the authors assume that the agent's trading status (i.e. buyer or seller) is permanent. They justify this decision stating that "(it) is more realistic given the frequency of trade captured by the model". In my opinion the frequency of the trade is irrelevant. As long as the model presents an infinite number of periods the agents' lack of ability to switch their trading status makes it utterly unfeasible. Buyers would eventually run out of money and sellers would accumulate all of it. The only case when it could properly work would be if the amount of currency traded was extremely small. The buyer could then finance his trade with the transfer that all agents receive every period from the money issuer. This is not only improbable, but highly unrealistic. Despite of this, as the authors stress, this issue does not have a notorious effect on the results.

A second point I believe worth discussing is the assumption that the money supply growth rate  $\mu$  is equal to inflation. As we have seen, it ultimately implies that it is necessary to deflate the economy at the discounting rate to achieve the first-best

allocation. I consider that this assumption, though necessary to simplify the problem, is quite unrealistic. It is indeed true that both variables are usually positively correlated (for each money supply growth rate  $\mu$  there is an estimated level of inflation). Due to this, it does not affect our results: a buyer would not have an incentive to hold and use money if  $\mu$  is too high (there is positive correlation between  $\mu$  and the cost of carrying balances). However, it could also happen that in real world a positive money supply growth rate  $\hat{\mu} > 1$  but not too high could be compatible with deflation, e.g. the supply of the currency, though positive, cannot cover its increasing demand.

Hence, I believe that the model is appropriate when comparing the efficiency of different payment systems and how external factors affect it, but we have to be careful when trying to measure efficiency directly. Additionally, as I will further discuss in the next section, permanent deflation seems completely unrealistic.

Finally, Chiu & Wong do not provide any justification for their model structure design, i.e. the DM and the CM markets. Consequently, I believe it is important to take into account how different designs may affect the conclusions. For this reason the results supporting the superiority of e-money over conventional money have to be interpreted carefully. Different designs may result on different results.

In conclusion, Chiu & Wong try to model a complicate monetary and market system, with multiple assumptions and variables. While these assumptions make the model easier and more understandable, they also endanger the generalization of the results, which need to be analyzed carefully.



## 5. A model of an international cryptocurrency

In this section I adapt Chiu & Wong’s model for an international cryptocurrency used exclusively for international trade purposes. Apart from including some changes respect to the original model to make it more realistic, the interpretation of the model is notably different. The new international cryptocurrency is called Intercoin (ITC). It has a supply and transaction system similar to the Bitcoin Protocol explained in Section 2. Also, its implementation plan is based on Mundell’s paper, presented in Section 3.

As in the previous section first I will explain intuitively the model, including an example. Then I will continue with a more detailed and technical explanation, before finishing with the discussion of the results.

### 5.1. The cryptocurrency and the markets

In this model time is discrete and infinite  $t = 0,1 \dots$ . Similar to the previous model, every period is divided into two subperiods (each one including a market) which are called “day” and “night”, respectively. Also, the economy is populated with two types of agents: buyers and sellers. However, in this case an agent’s type is not permanent, and agents always switch type at the end of each period. This is consistent with one of the critiques made in the previous section: permanent trading status is unfeasible in the long run, as sellers would accumulate all money and trading would no longer be possible. *Figure 5* shows an example on how trading status changes for two agents during three periods:

	Period 1		Period 2		Period 3	
Market	“Day” market	“Night” market	“Day” market	“Night market”	“Day” market	“Night market”
Agent A	Buyer	Buyer	Seller	Seller	Buyer	Buyer
Agent B	Seller	Seller	Buyer	Buyer	Seller	Seller

*Figure 5.* Variation of trading status for three periods. Source: own work

The intuition of the model is shown in *Figure 6*, and it is very similar to the one presented in the previous section. The main differences are that now buyers have to pay an interchange fee in the “day” market (which finances part of the transfer in the “night” market), agents are capable of carrying balances of the “night” good between periods

and the currency used is a cryptocurrency called Intercoin (ITC). Also, not all agents receive a transfer in the “night” market (which I will explain later).

For this example, we have supposed 1) an interchange fee of 10% of the transaction value on the “day” market, 2) a transfer on the “night market” of 2 ITC for both the buyer and the seller, and 3) a balance of “night” market goods from the previous period of 2 units for both agents too.

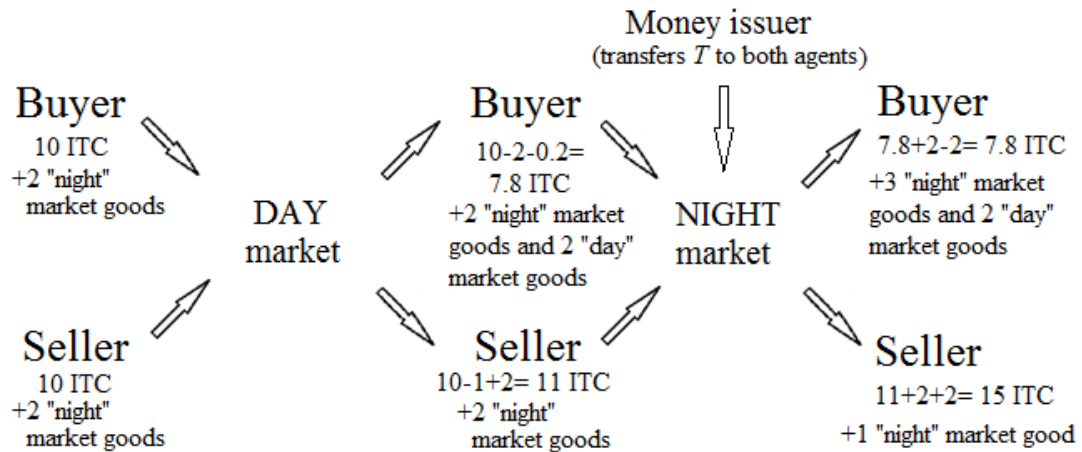


Figure 6. Intercoin model diagram. Source: own work.

The process is as follows. At the beginning of the period before the first transaction, the buyer possesses 10 units of Intercoin and 2 units of "night" goods he carries from the previous period. The seller has the same balances, and he produces 2 units of "day" goods for the transaction (with a market value of 1 ITC/ unit for a total 2 ITC, and a cost of 0.5 ITC/unit for a total 1 ITC). When the transaction in the "day" market is carried agents exchange those goods and 2 ITC. The buyer pays an additional 0.2 ITC (10% of the transaction amount) as interchange fee.

Then the agents enter the "night" market. As stated before, both of them receive a transfer (2 ITC). In this case, the buyer acquires 1 unit of "night" market goods (with a value of 2 ITC/unit). Therefore the buyer's transfer offsets the cost of the transaction (2 ITC), so he ends up with the 7.8 ITC he already had, 2 units of "day" market goods and 3 units of "night" market goods (remember he already had 2 units from the previous period). On the other hand, the seller now has 15 ITC (the 11 he already had, 2 from the transfer and 2 from the trade) and 1 unit of "night market goods" (he sold one of the 2 units he had from the previous period). With this, a whole period is over. Remember that at the start of the next period agents switch trading status, with the buyer becoming seller and vice versa.

Now, I will explain the details. During the “day” subperiod, there is a decentralized market (DM henceforth). Again, this implies frictions in the market. There is not an official central authority monitoring the market and facilitating the pairing of buyers and sellers. Also, the cash-in-advance constraint remains. Nonetheless, there are notable differences with respect to the previous model.

The first difference with the previous model is that in our case agents trade exclusively international goods and services in the DM. We assume that, when goods and services are equivalent, agents prefer national ones and therefore only participate in the DM when they cannot find goods on their own national markets or the prices are notably different. They do not need further motivation. The second important difference is, as I already explained, that in the DM agents trade using a cryptocurrency named Intercoin. This currency is similar to Bitcoin, with the difference that its supply growth rate is constant and positive ( $\mu > 1$ ), instead of decreasing. However, new units of cryptocurrency are still introduced with the same system of “miners”.

On the other hand, there is a centralized market (CM henceforth) during the “night” subperiod. It is a currency exchange market where Intercoin is swapped for the main conventional currencies: euro, US dollar, yen and possibly yuan and British pound. They have a fixed exchange with the Intercoin (and therefore also between each other) and work as numeraire. In my model I will simplify these currency exchange rates combining them into a single one: the national currencies/Intercoin exchange rate, denoted as  $\varphi$ . Also, any other country using a different currency and wishing to participate could adopt a fixed or pegged float exchange regime with respect to those currencies.

Intercoin is a Bitcoin-type decentralized cryptocurrency which uses blockchain technology to verify transactions. Miners are rewarded with a transfer they received before the CM opens, which consists on new units of cryptocurrency and the amount collected by interchange fees. For the sake of simplicity, I assume that agents become miners with probability  $\rho_t$ , and when they do they always mine a single block. The number of transactions needed to complete a block varies in order to keep the Intercoin mining pace constant within one period (for example in the case of Bitcoin it gets adjusted every 2016 blocks). Meanwhile, the amount of Intercoin received per completed block needs to increase after each period (the absolute amount of new units of Intercoin being introduced increases). Interchange fees are proportional to

transactions in the DM and paid exclusively by buyers in that market. Contrary to the case of Bitcoin, these fees are mandatory.

Additionally, the money supply growth rate  $\mu$  in this model is fixed exogenously. For the sake of simplicity I assume that  $\mu$  is equal to the inflation rate (which in this case is measured using a consumer price index).

Before we continue, there are four issues I consider important to mention.

First, according to some economists the idea of a constant monetary supply growth rate has numerous advantages. Austrian economist Milton Friedman was one of his supporters, formulating Friedman's  $k$ -percent rule (Friedman 1959). He argued that the use of money supply as a monetary instrument by central banks or other authorities exacerbates business cycles. There is an excess of money supply leading to inflation during some phases and a lack of money supply during liquidity crises. He supported a constant supply growth rate which would be calculated taking into account various macroeconomic and financial factors. It would target a desired level of inflation and facilitate long-term stability. All agents would be able to anticipate monetary policy and make their decisions well-informed and with certainty. This point will be extremely relevant for the future discussion.

Second, one could argue that this fixed-exchange union of currencies would work as a unique international currency. Nevertheless, it is important to notice that its political costs would be clearly inferior. Countries would not have to abandon their symbolic currencies, reducing nationalist and emotional costs. Also, they would be more tempted to join the project, as an international currency completely substituting national currencies would be seen more irreversible. Despite all of this, entrances and exits from members would have to be regulated in support of stability. All in all, it would soften the implementation process.

Also related with the fixed-exchange rate between Intercoin and the national currencies, it is important to mention that the national currencies also need to have their own money supply growth rate (otherwise it would be impossible to maintain the same exchange rate between Intercoin and the national currencies across periods). This supply growth rate is not explicitly included in the model, but I have considered that these new units of currency are introduced between periods increasing the balances of national currencies carried by agents from one period to the other (denoted as  $\tilde{l}_{t-1}$  in the model). The aim of this supply growth rate is merely to maintain the fixed exchange rate.

Third, as hinted before, the national currencies have no use in the DM. However, they let agents to buy extra Intercoin units in the CM. This trading is more realistic in our model, as agents can switch their type, allowing them both to buy and sell across different periods. It also implies that, in order to maintain the fixed exchange rate between the national currencies and the Intercoin, national central authorities need a coordinated monetary policy similar to the monetary policy adopted during pre-Euro years.

Fourth, in this model we want to study how diverse factors would affect an international market with an international cryptocurrency. For the sake of simplicity, national markets where goods and services would be exchange for conventional currencies are not explicitly presented into this model. Including this third market would make the model far more complicate and could be a possible extension for future work.

## 5.2. The model

As I explained before, this model is an adaptation of Chiu & Wong's and for this reason it follows a similar structure. *Figure 6* has shown the diagram of the whole process. In this case we include 1) the interchange fee  $\Delta$ , 2) the mining process to introduce new units of the cryptocurrency, and 3) the exchange trade with national currencies/Intercoin. Also, adding the possibility of switching trading status makes it more realistic.

In the CM, the agent's budget constraint is:

$$\frac{\phi_t}{\phi_{t+1}} N_t + l_t = \tilde{N}_t + \tilde{l}_{t-1} + \gamma_t T_t(\Delta_t, \rho_t). \quad (12)$$

The main differences with respect to (3) are that this time we are using  $N$  to refer to the Intercoin balances (instead of  $z$ ) and the transfer made by the e-money issuer depends on the interchange fee paid by the buyers  $\Delta$  and the amount of new currency issued per mined block  $\rho_t$ . I will explain variable  $\gamma_t$  later.

Also,  $\phi_t$  denotes the level of prices in the international market at time  $t$  (in this case using a consumer price index, CPI). All amounts in the equation need to be in the same unit. The fixed exchange rate between the national currencies and the Intercoin ( $\phi$ ) can be used for that, e.g.  $N_t = \phi n$  (with  $n$  being the Intercoin balance expressed in Intercoin).

Also, another important difference is that now  $l_t$  is always in the LHS and represents the balance of national currencies that the agent holds after trading in the CM (buying or just keeping currencies from the previous CM). Meanwhile  $\tilde{l}_{t-1}$  is always in the RHS and represents the balance of national currencies that the agent brings from the previous period.

The LHS of the equation includes the outflows, consisting on the real balance of e-money  $\frac{\varphi_t}{\varphi_{t+1}}N_t$  the agent carries to the next DM market and the amount of national currencies he holds at the end of this subperiod  $l_t$ .

The RHS of the equation shows the inflows, including the real balance of e-money  $\tilde{N}_t$  the agent brings from the previous DM, the balance of national currencies  $\tilde{l}_{t-1}$  and the transfer rewarded to miners. This transfer depends on both the interchange fee that buyers paid in the previous DM ( $\Delta$ ) and the amount of new currency issued per mined block  $\rho_t$ . With constant  $\Delta$  we have  $T_t'(\rho_t) > 0$ ,  $T_t''(\rho_t) = 0$ ,  $T_t'(\rho_t) < T_{t+1}'(\rho_{t+1})$ , which mean that the amount of the transfer is proportional to the reward per mined block (remember the assumption that miners can only mine one block). As the number of new units of Intercoin being introduced grows every period the Intercoin received per mined block needs to increase with time too. The new variable  $\gamma$  represents the probability an agents mines a block, i.e. probability the agent is a miner. It depends on both the number of agents in the market and the amount of blocks per period.

The CM problem for buyers and sellers can be denoted as:

$$W_j(\tilde{N}_t) = \tilde{N}_t + \gamma_t T_t(\Delta, \rho_t) + \max_{N_t} \left\{ -\frac{\varphi_t}{\varphi_{t+1}}(N_t) + \beta[V_c(N_t)] \right\}, \quad (13)$$

where  $j = s, b$  depending on if the agent is a buyer or seller and  $c$  represents the opposite agent's type (remember agent's trading status changes for the next period). This equation is subject to (12).

This equation is derived from (4). However, now it includes e-money balances and takes into account that an agent switches trading type after this subperiod. The agent brings Intercoin from the previous DM  $\tilde{N}_t$ , and receives the transfer  $T_t(\Delta, \rho_t)$  in case he is a miner. He decides the balances of Intercoin  $N_t$  he will move forward, taking into account the future value he will get in the next DM subperiod. Notice that if  $\tilde{N}_t + T_t(\Delta, \gamma_t) > \frac{\varphi_t}{\varphi_{t+1}}N_t$  the agent has sold Intercoin to obtain national currencies and  $l_t - \tilde{l}_{t-1} > 0$  holds in (12). On the contrary, if  $\tilde{N}_t + T_t(\Delta, \gamma_t) < \frac{\varphi_t}{\varphi_{t+1}}N_t$  he has bought e-money in exchange of national currencies and  $l_t - \tilde{l}_{t-1} < 0$ . If both sides are equal

the agent has not traded in the CM. Also, remember that the value the agent will obtain from the next DM needs to be discounted.

On the other hand, taking all of this into account, the DM problem for buyers and sellers can be presented, respectively, as:

$$V_b(N_t) = \alpha[U[q(N_t)] + W_b[N_t - d_t(N_t) - \Delta(d_t)]] + (1 - \alpha)W_b(N_t), \quad (14)$$

$$V_s(N_t) = \alpha \int [-C[q(N_{b,t})] + W_s[N_t + d_t(N_{b,t})]] dF(N_b) + (1 - \alpha)W_s(N_t), \quad (15)$$

where all terms have the same meaning than in (5) and (6), with  $N$  substituting  $z$  to indicate the use of a cryptocurrency.  $\Delta(d_t)$  is the interchange fee that the buyer pays for the transaction with  $\Delta(d_t) \geq 0, \Delta(0) = 0, \Delta'(d_t) > 0, \Delta''(d_t) = 0$ . This means that the fee cannot be negative and it is proportional to the amount in Intercoin paid on the transaction (being zero in case of no transaction). Again,  $\alpha$  is the probability that the buyer and seller match (remember that there are frictions in the DM) and multiplies the results in case the transaction is carried successfully, with  $(1 - \alpha)$  for the opposite case.

The surplus generated by the trade in the DM market would be then:

$$S_b(q, d; N_b, N_s) = U(q) + W_b(N_b + d_t - \Delta(d_t)) - W_b(N_b), \quad (16)$$

$$S_s(q, d; N_b, N_s) = -C(q) + W_s(N_s + d_t) - W_s(N_s), \quad (17)$$

where all terms have the same meaning than in (14) and (15). The main difference with respect to (7) and (8) is that we add the interchange  $\Delta(d_t)$  fee to the buyers costs.

We have the following bargaining problem:

$$\max_{q,d} \{S_b(q, d; N_b, N_s) + S_s(q, d; N_b, N_s)\}, s. t. \quad (18)$$

$$S_b(q, d; N_b, N_s) = \theta[S_b(q, d; N_b, N_s) + S_s(q, d; N_b, N_s)]$$

where  $\theta \in (0,1]$  is a exogenous variable representing the buyer's bargaining power with the same meaning than in (9) and (10).

**Definition 2.** A degenerate monetary equilibrium is achieved with an allocation  $(q, N_b, N_s)$ , a policy  $\{M_t, \mu, T(\Delta, \rho_t), \Delta(d)\}$  and inflation  $\{\Phi_t\}_{t=0}^{\infty}$ , such that:

- The agent's optimization problem is solved, i.e.  $N_b$  and  $N_s$  solve (13).
- The real balances of e-money brought by the agents at the beginning of the period are equal to the monetary base  $\varphi M_t = \sum_{j=1}^k N_j$  where  $k$  is the total number of agents (both buyers and sellers) and  $\varphi$  is the basket of currencies/Intercoin exchange rate.
- The bargaining problem is solved, i.e.  $q = q(N_b)$  solves (18).

- d. The money issuer's budget constraint it met, i.e. the transfers made to the agents at the end of the period are equal to the amount of new Intercoin supplied plus the interchange fees: given  $\Phi_t, \{M_t, \mu, T(\Delta, \rho_t), \Delta(d)\}$  satisfies:

$$\sum_{j=1}^k \gamma_t T_{t,j}(\Delta, \rho_t) = (\mu - 1)\Phi_t M_t + \sum_{j=1}^k \alpha_j \Delta(d_{t,j}),$$

- e. The inflation rate is equal to the cryptocurrency supply growth rate:  $\Phi_t > 0$ ,  

$$\frac{\Phi_t}{\Phi_{t+1}} = \mu.$$

### 5.3. Discussion

Now that the equilibrium is defined, we move forward to study how exogenous variables affect the monetary system and its equilibrium. The exogenous variables we keep from Chiu & Wong's model are 1) the matching probability between a buyer and a seller in the DM,  $\alpha$ , 2) the buyer's bargaining power  $\theta$ , 3) the agents' discounting rate,  $\beta$ , and 4) the money supply growth rate,  $\mu$ . Our model's new extra exogenous variables are the interchange fee  $\Delta$  and the number new units of currency issued per block  $\rho_t$ .

In the case of the agents' discounting rate  $\beta < 1$  we have assumed that the Intercoin supply growth rate  $\mu > 1$ . Therefore  $\mu > \beta$  is true. As  $\mu$  is equal to the inflation rate the costs of carrying Intercoin balances across periods increase and the quantity traded in the international market  $q$  (DM goods) decreases. As in Chiu & Wong's baseline model, permanent deflation would be needed to achieve the first best allocation.

**Conjecture 1.** *In our model, a Bitcoin-type international cryptocurrency cannot implement the first-best allocation as  $\mu > \beta \Leftrightarrow q < q^*$ .*

However, as I already stated in the previous section the model and its assumptions have important limitations. First,  $\mu = \frac{\Phi_t}{\Phi_{t+1}}$  does not have to be true in the real world (though  $\mu$  and  $\frac{\Phi_t}{\Phi_{t+1}}$  are usually considered positively correlated), and therefore there may be cases when it is possible to implement the first-best allocation with  $\mu > 1$  and  $\frac{\Phi_t}{\Phi_{t+1}} < 1$ . And second, deflation has many disadvantages not reflected in the model. Some of these disadvantages could be consumption delay, unemployment increase or the social costs related to nominal decreasing salaries. Proof of this is the fact that central authorities such as the ECB aim to keep inflation close to 2%.



Regarding the matching probability in the DM,  $\alpha$  needs to be big enough to make the DM attractive for the agents and make equilibrium possible. If  $\alpha \rightarrow 0$ , then the costs (e.g. opportunity costs) for trading in the market would be too high and agents would not participate. However, a small  $\alpha$  is improbable in our model. In a cryptocurrency DM like the one proposed it is expected that private individuals and companies would take the place of the absent central authority. It is similar to the case of Bitcoin I hinted in Section 2, where multiple companies offer their Bitcoin wallet and payment services internationally on the internet (Voorhees 2015). The difference between this system is that while agents are obliged to deal with a central official authority in a centralized market (coercive centralization), in the case of a decentralized market that is not mandatory (market-based centralization), i.e. agents can freely choose to use a centralized service or meet bilaterally with others. Also, they can opt out and trade directly over the blockchain or use a local wallet.

Also, there are indirect benefits derived from the decentralization of the payment system (in terms of stability and neutrality<sup>14</sup>) due to its unique features and the implementation of Friedman's  $k$  percent rule, which reduce uncertainty and the costs related to it. These benefits make more attractive for agents to use this payment system and join the market, thereby increasing the number of participants and  $\alpha$ . This rise in the number of DM transactions could increase, at the same time, the combined total trade surplus of the  $k$  participants  $\sum_{j=1}^k S_{t,j}$ .

The increased value of  $\alpha$ , when taken into account in (11), means that it is possible to achieve equilibria with higher money supply growth rate  $\mu$ .

**Conjecture 2.** *A Bitcoin-type international cryptocurrency facilitates equilibria when  $\mu = \frac{\phi_t}{\phi_{t+1}} > 1 > \beta$ , i.e. there is inflation.*

I consider this last Proposition to be the main advantage of this type of currency when compared to traditional fiat currencies. As we said before, permanent deflation to implement the first-best allocation seems utterly unrealistic. Hence, facilitating equilibria while keeping the level of inflation controlled seems like a relevant advantage.

Regarding the buyer's bargaining power  $\theta$ , its interpretations remain the same than that from Chiu & Wong's model: equilibrium is not possible if  $\theta \rightarrow 0$ . In our case,

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<sup>14</sup> Remember that one of the advantages of decentralized payment systems are more resistant to third-party influences.

buyers would participate in the national markets instead if they do not receive a share of the trade surplus big enough.

The design of the transfer rewarded to miners, which includes the interchange fees  $\Delta$  and depends on the number new units of currency issued per block  $\rho_t$ , has also important implications. As stated before, the number of new units of Intercoin issued per mined block  $\rho_t$  needs to increase every period. The reason is that I have supposed that the pace of block creation is constant while the absolute amount of new units issued increases every period.

Also, notice that interchange fees have a direct negative effect in DM trade. Because of this, it is relevant to mention that with this system these fees can remain lower than those in traditional payment systems. In our model, interchange fees constitute a tiny percentage of the miners' transfers and are not used primary as a finance source for the money issuer but to incentivize miners when verifying and securing big transactions (as fees are proportional). This, together with the continuous decrease in the price of CPU power increases the competition in the "mining market". Miners continuously increase their computational power to be the first to verify big transactions.

Additionally, contrary to the case of Bitcoin there is no need for users to compete paying higher fees to get a transaction verified faster (Torpey 2017), as we suppose no block size limit (which reduces competition for block space among users). Consequently, overall transaction speed is always elevated.

***Conjecture 3.** In our model, the security of a payment using a Bitcoin-type international cryptocurrency increases with the size of the transaction.*

Getting  $\alpha, \theta, \Delta$  and  $\mu$  conditions together:

***Conjecture 4.** A Bitcoin-type international cryptocurrency is only viable if the probability a buyer and a seller are matched in the DM  $\alpha$  and the buyer's bargaining power  $\theta$  are not too low, interchange fees  $\Delta$  are not too high and the money supply growth rate  $1 < \mu < \bar{\mu}$ .*

In conclusion, the use of an international cryptocurrency facilitates reaching equilibrium thanks to higher number of participants and reduction of costs. It also increases transaction security and reduces exchange rate risk. Additionally, it may increase overall trade surplus.

Deflation is necessary to achieve the model's first-best allocation. However, as there has to be inflation for the system to be self-sustainable and have small interchange

fees, this allocation cannot be accomplished. In spite of this, it cannot be considered a serious disadvantage taking into account the problems derived from deflation not reflected in the model. Additionally, the level of inflation needed for equilibrium is controllable, meeting central banks' recommendations.

It is important to mention that, despite all changes introduced in the reinterpretation of the model to make it more realistic (such as interchange fees and non-permanent trading status) its design still has limitations, which could be further addressed in future studies.

## 6. Conclusion

The research question of this study is “*Would an international cryptocurrency be theoretically viable from an economic point of view?*” As the results in the previous section suggests, reaching monetary equilibrium would be possible. The currency would even facilitate equilibrium thanks to the additional stability that following Friedman’s  $k$  percent rule would provide and the design of the cryptocurrency. Additionally, an optimal and stable level of inflation would be achievable. All in all, it would result in increasing participation in the international market where this cryptocurrency would be used. The main reason would be the increasing attractiveness of this market due to the decrease in uncertainty.

It is important to bear in mind that the objective of this study has been exclusively to make a thought experiment, studying what could be the basic theoretical consequences of an international cryptocurrency and introducing the reader to the idea. It aims at taking a look to the economic advantages this kind of currency could offer at a global scale, using a theoretical approach. As discussed in Section 3, an international currency is clearly not achievable at present or in the near future. Its costs, especially the political ones, would be too high. Most of the powerful nations would oppose as it would imply a loss of influence and power.

Future research could improve and extend the current study in different ways. Researches could focus on the effects of the addition of new features, as well as the change of existing ones. They could analyze how these features would change the results of the theoretical model or directly speculate how they would affect a hypothetical real-world implementation.

For example, in the case of the model it could be extended to test if including the national markets is feasible and/or advantageous. It could be interesting to check if increasing the complexity of the model pays off with additional results and higher robustness for the conclusions presented in this study. Also, the payment system could be modified in many different ways, for example implementing a non-constant supply growth rate for the cryptocurrency.

I consider that self-sustainability of the system and the efficiency of the range of possible equilibria should be the main concerns. They are key issues to achieve impartiality and optimal economic results, respectively.

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# Appendix

## Appendix A

**Table 1. Bitcoin supply (2008-2140).**

This table shows the Bitcoin supply “expected” for the first 34 “Reward eras”. Each era lasts approximately 4 years and rewards 50% less BTC/Block than the previous one (starting with 50BTC/Block). Therefore, the supply possesses a clear decreasing rate. We can observe that more than 99% of all BTC will have been mined by 2032. Source: own work.

Reward Era	Year Aprox.	BTC/Block	New BTC	Total BTC	Total BTC (%)
1	2008	50,000000000	10500000,000	10500000,000	0,500000000
2	2012	25,000000000	5250000,000	15750000,000	0,750000000
3	2016	12,500000000	2625000,000	18375000,000	0,875000000
4	2020	6,250000000	1312500,000	19687500,000	0,937500000
5	2024	3,125000000	656250,000	20343750,000	0,968750000
6	2028	1,562500000	328125,000	20671875,000	0,984375000
7	2032	0,781250000	164062,500	20835937,500	0,992187500
8	2036	0,390625000	82031,250	20917968,750	0,996093750
9	2040	0,195312500	41015,625	20958984,375	0,998046875
10	2044	0,097656250	20507,813	20979492,188	0,999023438
11	2048	0,048828125	10253,906	20989746,094	0,999511719
12	2052	0,024414062	5126,953	20994873,047	0,999755859
13	2056	0,012207031	2563,477	20997436,523	0,999877930
14	2060	0,006103515	1281,738	20998718,262	0,999938965
15	2064	0,003051757	640,869	20999359,131	0,999969482
16	2068	0,001525878	320,435	20999679,565	0,999984741
17	2072	0,000762939	160,217	20999839,783	0,999992371
18	2076	0,000381469	80,109	20999919,891	0,999996185
19	2080	0,000190734	40,054	20999959,946	0,999998093
20	2084	0,000095367	20,027	20999979,973	0,999999046
21	2088	0,000047683	10,014	20999989,986	0,999999523
22	2092	0,000023841	5,007	20999994,993	0,999999762
23	2096	0,000011920	2,503	20999997,497	0,999999881
24	2100	0,000005960	1,252	20999998,748	0,999999940
25	2104	0,000002980	0,626	20999999,374	0,999999970
26	2108	0,000001490	0,313	20999999,687	0,999999985
27	2112	0,000000745	0,156	20999999,844	0,999999993
28	2116	0,000000372	0,078	20999999,922	0,999999996
29	2120	0,000000186	0,039	20999999,961	0,999999998
30	2124	0,000000093	0,020	20999999,980	0,999999999
31	2128	0,000000046	0,010	20999999,990	1,000000000
32	2132	0,000000023	0,005	20999999,995	1,000000000
33	2136	0,000000011	0,002	20999999,998	1,000000000
34	2140	0,000000005	0,001	20999999,999	1,000000000



## Appendix B

### List of Symbols used

Symbol	Explanation
Section 3	
$\beta$	Agents' discounting factor
$\mu$	Money supply growth rate
$\tilde{U}_b$	Buyer's total utility function
$\tilde{U}_s$	Seller's total utility function
$U$	Buyer's utility function in the DM
$-C$	Seller's cost function in the DM
$q$	DM goods
$z$	Real balance of money carried from CM to DM
$m$	Balance of money carried from CM to DM
$l$	Value of numeraire; CM goods
$\phi_t$	Price of money in terms of the (numeraire) CM goods
$\frac{\phi_t}{\phi_{t+1}}$	Inflation factor
$\tilde{z}$	Real balance of money carried from DM to CM
$T$	Transfer
$W_j$	Value function in the CM
$V_j$	Value function in the DM
$\alpha$	Probability a buyer (seller) is matched with a seller (buyer) in the DM
$d$	Balance transmitted from buyer to seller in the DM when there is trade
$F$	Cumulative Distribution Function of the buyer's real balances
$S_b$	Buyer's surplus
$S_s$	Seller's surplus
$\theta$	Buyer's bargaining power
$M_t$	Monetary base
$\bar{\mu}$	Maximum money supply growth rate to get an equilibrium
$q^*$	DM traded for the first-best allocation
Section 4 (only new variables and changes with respect to the previous section)	
$N_t$	Real balance of Intercoin carried from CM to DM
$l_t$	National currencies, after CM
$\tilde{l}_{t-1}$	National currencies, before CM

$\tilde{N}_t$	Real balance of Intercoin carried from DM to CM
$\varphi$	National currencies/Intercoin exchange rate
$n$	Balance of Intercoin carried from CM to DM
$T_t$	Transfer
$\Delta$	Interchange fee in the DM
$\gamma_t$	Probability the agent mines a block
$\rho_t$	Reward in Intercoin for each mined block.
$\emptyset_t$	Level of prices at time $t$
$k$	Total number of agents