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A model to think about crypto-assets and Central Bank Digital Currency*

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Abstract

This paper introduces digital assets, crypto assets in general, and Central Bank Digital Currency in particular, into an otherwise standard New-Keynesian closed economy model with Financial Frictions. We use this setting to study the impact of a change in preferences towards the use of digital assets and to address whether the emergence of this type of instruments affect the transmission of monetary policy shocks. In this context we study the introduction of Central Bank Digital Currencies. The model is stylized but it could be a baseline for the design of models for quantitative analysis.

Keywords: New Keynesian; Crypto assets; Central Bank Digital Currency.

JEL classification: E00; E4; E5.

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1 Introduction

The means of payments in the society evolve together with technology. Whether the government(s) decides to follow technology close or not is a second order matter, the private sector will. A sample of this phenomena is that accordingly to the BIS the use of cash in transactions has been falling in major developed economies for the last fifteen years. For instance, the Sveriges Riksbank shows that only 13% of surveyed individuals paid their latest purchases with cash in 2018, in contrast to the 39% of 2010. Moreover, during the COVID-19 crisis this tendency exacerbated due to the many economic lock-downs and other public health measures implemented by different governments. The impact of these habits may have changed permanently implying larger use of online transactions. Hand in hand with the evolution of transaction habits, the private sector have offered solutions to consumers, for instance PayPal and more recently Revolut, Bizum and other private entrepreneurs provide payment solutions for a "cashless economy". The last episode of private solutions for transactions purposes comes with the emergence of crypto assets.

In this paper, I study the emergence of Central Bank Digital Currencies (CBDC). The issuance of a digital currency by the governments is a possibility currently under scrutiny in several countries and economic areas such as the Eurozone, Sweden, the United States (USA), and People Republic of China (PRC) to name a few. To understand why countries are considering this option we will first discuss briefly about crypto-currencies and blockchain technology as well as the solutions developed and provided by the private sector, i.e. the Bitcoin and the alt-coins. The emergence of the CBDC is inevitable given that as far as private solutions became more important in the payment market, the role of cash (the unique type of money issued by Central Banks so far) will tend to vanish, implying that governments will loose the possibility of affecting transaction markets.

After presenting an overview on digital currencies, we turn to the main objective of the paper. We introduce a baseline model that can be used to think about crypto-currencies and Central Bank Digital Currency (CBDC) in formal terms. The model developed in this paper is designed to introduce an asset that I define as crypto-currency in an otherwise standard New-Keynesian economy with a financial accelerator and conventional monetary policy. To introduce a role for currency, we assume that there are costs to purchase consumption goods in the form of transaction costs and having different assets that provide liquidity, the costs can be reduced. Yet, the model is highly stylized and the objective would be to capture one role of crypto-currencies and CBDC, i.e. the transaction purpose. We will use the model to understand the implications of crypto price changes, to understand the effect of changes in the preferences for the use of digital assets, and the role of crypto assets and CBDC in the transmission of monetary policy shocks. It is important to highlight in relation to this that one aspect that I abstract from, to a large extent, is the role of crypto as a speculative instrument. This is an important role given that currently most of the use of crypto is for speculative motives as it is not widely accepted for transactions so far. Implicitly one would expect that overtime, when more people access this technology, the speculative motive will fall and leave space for its transaction role.

The crypto-market is relatively new and the interest of macro-economists in that market has started to grow only recently. However, the literature on crypto-currencies have grown very fast in the last few years. The next section presents a brief discussion about the key references.

2 A brief review of the literature

By now, a few papers have already started to highlight several important features towards the introduction of CBDC. The existing literature is focusing on many aspects at the same time. This is reasonable because it is somewhat clear that, given the proliferation of private solutions for the transaction markets, governments may need to issue CBDC soon and our knowledge about how to analyze the impact of CBDC and how to implement their use is in early stages. The current questions that the literature focuses on include how to supply the CBDC directly to households, which should be the design of the technological structure, how to allow for offline payments, what are the implications of CBDC regarding privacy issues, and many more. International institutions like the Bank of International Settlements (BIS) have been working actively in many of these dimensions.

On the other hand, there has not been many formal approaches to model CBDC or crypto assets in the context of a general equilibrium model, that is, from a theoretical macroeconomic perspective. There are, however, some notable exceptions. For instance, Davoodalhosseini (2021) and Kumhof and Noone (2018).

Davoodalhosseini (2021) uses a search model of money, a model in the tradition of the New Monetarist models where there are two markets, a centralized market where money is not needed, and a decentralized market where transactions are carried using money. With such a model, Davoodalhosseini (2021) studies the optimal monetary policy when the government issues only cash, CBDC or both. The author finds that if it is not too costly to use CBDC, there are potentially large welfare gains than from using cash.

Related to this strand of the literature but with a focus on private crypto assets, Choi and Rocheteau (2021) study the price dynamics when money is created using time-consuming mining technologies and show that money that initially starts being used for speculative purposes can be used for transaction purposes when it becomes abundant. The authors study conditions for existence and unicity of equilibrium in a model similar to Davoodalhosseini (2021).

Chiu and Wong (2015), instead, implements a mechanism-design approach to identify the features that different payment systems should have in order to improve the constrained optimal allocation of resources. They show that e-money can improve social welfare.

A different approach is followed by Fernandez-Villaverde (2021) and Schilling et al. (2020). In these papers, the authors are concerned about the banking implications of CBDC and to study this topic the authors extend models usually used to study bank runs. Schilling et al. (2020) study the role of deposit producer by means of CBDC. They show what they refer to as "CBDC trilemma": the central bank can achieve at most two out of the three goals of (1) efficiency, (2) elimination of runs, and (3) price stability. In turn, Fernandez-Villaverde (2021) studies whether an economy with CBDC can be less prone to bank runs than an economy where the central bank does not have such an instrument. The digital currency allows the Central bank to do financial intermediation. This combined with its role of last resort makes the system more stable.

Fernández-Villaverde and Sanches (2019) also uses a setup of New Monetarist economics to study the importance of crypto assets. In particular they extend the basic setup to allow for private money supply. They show that this money supply will not improve on price stability

All the previous approaches are highly theoretical. From a more quantitative perspective, Barrdear and Kumhof (2021) study the impact of introducing CBDC and show that it can have real output effects through a fall in the real interest rates in a macro-model with frictions. Kumhof and Noone (2018) studies the implications of CBDC issuance that is a substitute for commercial banks deposits. The authors focus on how CBDC affects the balance sheets of different actors (central banks, commercial banks, non-banks financial institutions, households and firms). The model itself is similar to the one in Barrdear and Kumhof (2021). Additionally, the authors want to study the role CBDC may play in the case of confidence loss in the banking system.

3 Blockchain, crypto-currencies and CBDC

Fernández-Villaverde (2018) studies the emergence of blockchain technology, bitcoin and competence between currencies from the point of view of a monetary theorist. Appropriately, this article suggests that crypto assets are a bubble without fundamental value and this is to a large extent what makes them similar to money. The value of monetary instruments is given by the probability that people will accept them in the future. That is, it is based on expectations without a fundamental value. Yet, according to this, they represent the next stage in the evolution of monetary instruments. A second conclusion of the paper is that, it is unlikely that crypto-assets issued privately, will attain a socially optimal outcome. It can, however, put discipline into the behavior of the monetary authorities.

In this way the volatility of the price of crypto assets can be rationalized by the lack of fundamental value and the existence of a relatively thin market for these assets. This is true for Bitcoin and many of its forks, but the concept of alt-coins is very different. In this section we want to characterize the differences between the Bitcoin, a pure ledger technology, and the alternative coins. We discuss these differences, as well as the limit issuance of bitcoin and other crypto assets and the development of one of the first CBDC that is currently under study.

3.1 Crypto as currency: bitcoin

Bitcoin is the cryptocurrency with the largest market-cap and the first one developed under a blockchain technology. The blockchain is a ledger that is both immutable and shared and is used to annotate transactions. The bitcoin is the currency used to reward the "workers" that mine, i.e. provides the service of record-keeping, on that ledger. Hence, what is called "the process of mining" is only the process of writing a new transaction on the ledger. However, writing a new transaction on the ledger is not trivial, in fact this process is time and energy consuming that implies finding what the literature refers to as "a nonce" (number used once, that is used to annotate the transaction the first time). This number that is very difficult to find, it is indeed very easy to recognize (that is, for other workers it is very easy to check once the number was already found).

Leaving the technical details aside, the most important, distinctive, feature of Bitcoin is that there is no project behind the asset. That is, people accepts bitcoin in exchange for their computational power and time because they expect it will be accepted in transactions by other agents in the future. In this way, Bitcoin is a decentralized digital currency whose transactions are recorded in a ledger using blockchain technologies. It works in the same way as money, and is a decentralized currency given that it is not supplied in a centralized way by any government. Bitcoin price depends on the expectation that it will keep its value in the future, in the same way as money.

Bitcoin is, however, not the only digital asset as that after the appearance of this asset many different crypto assets emerged, with features that are somewhat different from Bitcoin. A particular type of asset is the one that are currently referred to as "alt-coins".

3.2 Crypto as stocks: a few examples

Many crypto assets emerged as medium of exchange and unit of account within a specific ecosystem. Those are the crypto assets whose value is backed-out by the expected success of a project. In a way, these crypto assets resemble a stock.

The projects behind some assets are actually very tangible. For instance, the ecosystem around the Theta and the T-fuel token. The Theta network is designed to decentralize the supply of video streaming in order to solve the last-mile problem. The Theta network exploits computation capability, bandwidth and storage of agents, all around the world, that allow to share the unused bandwidth and storage of their own personal computers to store and reproduce fractions of the videos, making the "servers" closer to the users. In this way, if a user wants to watch a video, connecting to many personal computers nearby and collecting the whole video from them is "cheaper" than connecting to a server (will allow for faster and higher quality access). Firms supporting the development of this network includes, by 2021, Samsung and Google, among many others. In order to reward the users that make available their band-with and their storage space, the ecosystem uses T-fuel and Theta tokens. As is clear, the larger the number of users of this technology, the more valuable should the coins be. That is the value of the project may explain the value of the coins that are used in that ecosystem.

Other crypto assets are built with a more financial orientation, for instance those associated to decentralized financial projects (defi projects). Those include Cardano and Etherum, which are not necessarily limited to defi. Other are oriented to gaming projects, for instance Axie Infinity, Eijin Coin, Decentraland, etc. whose native tokens are used for gaming purposes.

These projects substantially differ from the idea of Bitcoin but use similar technologies as they are built and rely on the block-chain technology. The main difference from Bitcoin is that there are projects associated to the currency (that is the importance of the currency is linked to the success of the project). The more people using the project, the higher the value of the currency as there will be more demand for it. In this way, it is similar to a firms' equity. Notice that, if a firm decides to go public, that is to start being traded in the market, it will do a IPO (initial public offering of firm's shares), instead, a project will do an ICO (initial coin offering) to raise funds to start the project. There are, however, still important difference between alt-coins behind these projects and stocks. In particular, two: (1) there is no promise to, in case of liquidation of the project, use the assets of the firm to repay investors, and (2) the markets are, so far, unregulated. The second difference actually is important, a large part of the price volatility may be explained by inside information, for instance. However, it is likely that regulation will catch up as long as more investors enter the market. The first difference is probably less important as equity holders are the last ones to be repaid in case of firms' bankruptcy and probably there may not be much of the firm left to repay them.

3.3 About the limited issuance of crypto-currencies

It is important to highlight that defenders of Bitcoin (and crypto in general) argue that the promise of a maximum supply of coins, and the decentralization of decisions to change rules, give coins the stability they may need to be widely accepted medium of exchange.

This may be true for a given instrument, but nothing prevents close substitutes of any currency/project to enter the markets. Hence, limited supply cannot be taken for granted as long as similar (perfectly substitutable) assets may emerge without limits.

3.4 The Riksbank e-krona project

One of the most advanced projects of a CBDC is the one developed by the Sveriges Riksbank. The e-krona would be the digital currency supplied by the Sveriges Riksbank to complement cash in a context in which the use of cash is declining.

The project program started in 2017, analyzing the need for a digital currency and in 2020 started the pilot program in collaboration with Accenture. At this point the e-krona became a token on a distributed network based on the blockchain technology. In this way, the e-krona is a uniquely identifiable unit of value exchangeable one to one with the Swedish krona. To access the e-krona, the user needs to have a digital wallet and to use it has to communicate with the network. Moreover, each token is used only one time which would imply the e-krona y consumed and a new token would be issued to the recipient.

The Riksbank is the only issuer who is related to the distributors of the e-krona that make it available to end-users. In practice (for the user) it would look similar to a private bank deposit account. At the moment of writing this paper, the e-krona is only available to banks and other financial institutions that are part of the RIX payment system (i.e. the Swedish payment system to settle payments among financial institutions). Further details about the project are in The Riksbank e-krona project, reports 1 and 2, available at https://www.riksbank.se/en-gb/payments--cash/e-krona/.

In this section I wanted to describe the different variants of digital assets to highlight that even thought there may be different drivers (to some extent) behind their price fluctuations, all of these may be considered close substitutes in their transaction role. The next section presents the baseline model that can be used to analyze the impact and role of crypto assets.

4 A model with digital currency

In this section we present the baseline model. The model has the objective of including crypto assets and CBDC used for transaction purposes.

The baseline economy considered in this paper builds on Fernández-Villaverde (2010). The model's notation, presentation and description in this paper follows very closely the model's section in Gomes and Seoane (2017). Here, I extend their setup to include crypto assets. The model is a medium scale New-Keynesian model with financial frictions as in Bernanke et al. (1999) (BGG). We extend this setting to account for a demand for money and liquid assets. We will extend the definition of money to include deposits, cryptocurrencies and CBDC. The key agents in the economy are the households, entrepreneurs, final goods' producers, producers of intermediate goods, financial intermediaries and the government.

4.1 Households

Households consume, c_t, decide hours worked l_t and choose the portfolio of financial assets that include deposits in a financial intermediary, fiat currency and crypto assets (potentially issued by the private sector or by the government in the form of CBDC). Households own firms in the economy that make a lump sum distribution of profits F_t and pay lump sum taxes, T_t. Additionally, to introduce a role for money we assume that there are transaction costs to the purchase of consumption goods that depend negatively on our broad measure of liquid assets. Households' problem can be written as,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log(c_t) - \psi \frac{l_t^{1+\varrho}}{1+\varrho} \right\},$$

subject to the budget constraints for all $t \geq 0$,

$$(1+s_t^c)c_t + \frac{Q_t^{btc}}{p_t} btc_t + \frac{a_t^d}{p_t} + \frac{M_t}{p_t} + \frac{d_t}{p_t} = w_t l_t + R_{t-1}^a \frac{a_{t-1}^d}{p_t} + R_{t-1}^d \frac{d_{t-1}}{p_t} + T_t + F_t + \frac{M_{t-1}}{p_t} + \frac{Q_t^{btc}}{p_t} btc_{t-1} + tre_t.$$

Here tre_t is a net transfer from (to) entrepreneurs, to be defined later. Additionally, p_t denotes the price level and w_t denotes the real wage per unit of labor. Miners profits (i.e. producers of crypto assets) from buying and selling crypto, are transferred in a lump sum fashion to the households and included in F_t.

In this economy we assume that the demand for liquid assets comes from a transactions cost technology. That is, the larger the holdings of liquid assets, the lower are the costs associated to consumption purchases. We follow the literature, for instance Kumhof and Noone (2018) and assume,

$$s_t^c = Av_t + \frac{B}{v_t} - 2\sqrt{AB},$$

with

$$v_t = \frac{c_t}{a_t},$$

and

$$a_t = \left(\omega^d \left(\frac{a_{d,t}}{p_t} \right)^{\mu_d} + \omega^{btc} (q_t^{btc} btc_t)^{\mu_d} + (1 - \omega^d - \omega^{btc}) m_t^{\mu_d} \right)^{1/\mu_d}.$$

That is, a aggregates the liquid assets that includes deposits in financial intermediaries, money issued by the government and a digital currency, whose supply can be private or public. If the supply of crypto assets is private, we refer to it as btc_t and should enter as $q_t^{btc} btc_t$ given that one unit of btc_t may not need to exchange for one unit of currency. Instead, if the crypto assets is publicly supplied, the price would be always equal to 1 as we assume it is issued by the same authority that issues currency, under the same conditions and provide the same service.

The functional form of a implies that liquid assets may be substitutes or complements, depending on the value of μ_d. Moreover, as written here, an increase in the preference towards crypto asset would crown out cash. We will consider this case and a case in which increases in the share of crypto assets crowds out deposits.

4.2 Final Good Producer

The firms' side of the economy is standard for New-Keynesian models. We assume there is a unique final good in the economy that can be used for consumption and investment. This final good is produced by competitive firms using intermediate goods according to the following production function:

$$y_t = \left(\int_0^1 y_{it}^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}.$$

Here, ϵ determines the rate of substitution between varieties and y_{it} are a continuum of intermediate inputs. The demand of each input depends on their price relative to the aggregate price,

$$y_{it} = \left(\frac{p_{it}}{p_t} \right)^{-\epsilon} y_t.$$

The technology determines the price level as,

$$p_t = \left(\int_0^1 p_{it}^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}.$$

4.3 Intermediate good producers

Each variety i of the inputs used for the production of the final good is produced using labour and capital combined in a Cobb-Douglas production function:

$$y_{it} = e^{z_t} k_{it-1}^{\alpha} l_{it}^{1-\alpha}.$$

Here k_{it-1} is the rental capital and z_t is the productivity shock, which we assume it follows an AR(1) process.

$$z_t = \rho^z z_{t-1} + \sigma^z \epsilon_t^z, \quad \epsilon_t^z \sim \aleph(0,1).$$

Optimizing with respect to capital and laber, the optimal capital-labor combination is

$$k_{t-1} = \frac{\alpha}{1-\alpha}\frac{w_t}{r_t} l_t$$

with the marginal cost given by

$$mc_t = \left(\frac{1}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\right)^{\alpha}\frac{w_t^{1-\alpha} r_t^{\alpha}}{e^{z_t}}.$$

The intermediate goods are produced by firms that operate in competitive monopolists markets and, hence, are able to set prices. We assume a price friction, in particular we assume that firms can update prices with probability θ (Calvo price stickiness). Hence, when choosing prices, the firms solve the following maximization problem:

$$\max_{p_{it}} \mathbb{E}_t \sum_{\tau=0}^{\infty} (\beta\theta)^{\tau} \frac{\lambda_{t+\tau}}{\lambda_t}\left\{\left(\prod_{s=1}^{\tau}\frac{1}{\Pi_{t+s}}\frac{p_{it}}{p_t} - mc_{t+\tau}\right) y_{it+\tau}\right\}$$

subject to

$$y_{it+\tau} = \left(\prod_{s=1}^{\tau}\frac{1}{\Pi_{t+s}}\frac{p_{it}}{p_t}\right)^{-\epsilon} y_{t+\tau}.$$

Here, λ_t denotes Lagrange multiplier on the household's problem and Π_{t+s} is the inflation rate.

4.4 Capital Producers

For simplicity, we assume there exists a sector of the economy that produces final capital goods by purchasing th final good (investment) and the un-depreciated capital stock. As in Gomes and Seoane (2017) and Fernández-Villaverde (2010), the capital producers are competitive and buy un-depreciated capital, x_{t-1}, and new investment ,i_t, to produce:

$$x_t = x_{t-1} + \left(1 - S\left[\frac{i_t}{i_{t-1}}\right]\right) i_t.$$

$S[\cdot]$ is an adjustment cost function. The producers of capital sell the newly produced capital stock to entrepreneurs at a price q_t.

The profit maximization problem of capital producers is to maximize

$$q_t\left(x_t + \left(1 - S\left[\frac{i_t}{i_{t-1}}\right]\right) i_t\right) - q_t x_t - i_t = q_t\left(1 - S\left[\frac{i_t}{i_{t-1}}\right]\right) i_t - i_t.$$

4.5 Entrepreneurs

Entrepreneurs operate in a costly state verification environment as in Bernanke et al. (1999). In order to purchase the newly installed stock of capital they combine internal funds, n_t (net worth), and external funds, b_t (private debt). Their balance sheet is,

$$q_t k_t = n_t + \frac{b_t}{p_t}.$$

Entrepreneurs receive an idiosyncratic productivity shock ω_{t+1} that follows a log normal distribution $F(\omega)$ and shifts the rented capital. We assume that $E_t(\omega_{t+1}) = 1$, and has a dispersion $\varsigma_{\omega,t}$ that follows and AR(1) process, such that:

$$\varsigma_{\omega,t} = (1 - \rho^{\omega})\varsigma_{\omega} + \rho^{\omega}\varsigma_{\omega,t-1} + \sigma^{\omega}\epsilon_t^{\omega}, \quad \epsilon_t^{\omega} \sim \aleph(0,1).$$

The interpretation of this shock is that it is a financial shock. A higher dispersion of idiosyncratic productivity implies that entrepreneurs default more often, driving up the external finance premium.

The average return of entrepreneur is

$$R_{t+1}^{k} = \frac{p_{t+1}}{p_t}\frac{r_{t+1} + q_{t+1}(1-\delta)}{q_t}.$$

The optimal debt contract is such that the return R^l_{t+1} gives zero profits to financial intermediaries,

$$[1 - F(\bar{\omega}_{t+1})]R^l_{t+1}b_t + (1-\mu)\int_0^{\bar{\omega}_{t+1}} \omega dF(\omega)R^k_{t+1}P_t q_t k_t = \bar{s}R_t b_t,$$

where $1-\mu$ is the fraction of the return that the financial intermediary recovers in case of default. $\bar{s}$ is an average spread charged by financial intermediates.

The problem of the entrepreneur is to choose a leverage ratio and default cut-off in order to maximize the expected net worth given the zero-profit condition of the intermediary. The entrepreneurs net-worth evolves as

$$n_t = \gamma^e \frac{1}{\pi_t}\left[R^k_t q_{t-1}k_{t-1} - \bar{s}R_{t-1}b_{t-1} - \mu\int_0^{\bar{\omega}_{t+1}} \omega dF(\omega)R^k_t q_{t-1}k_{t-1}\right] + w^e,$$

where γ^e is the survival rate of entrepreneurs.

Every period, some entrepreneurs will exit the economy. In this case, they transfer their net worth to households and the households will fund incoming entrepreneurs. The term tre_t in the households' budget constraint is the net of these operations, which is given by

$$tre_t = (1-\gamma^e_t)n_t - w^e.$$

4.6 Financial Intermediaries

Financial intermediaries operate in a competitive environment and collect deposits from the households and lend them to entrepreneurs. Hence,

$$a_t = b_t$$

The intermediaries lend at rate R^l_t but recover only R_t due to corporate default. We assume they face operational costs such that they provide zero net return to households' deposits every period ($R^a_t = 1$), which is in line with the actual return on checking accounts (i.e. the intermediaries will make zero profits). So the return on deposits for the households is 1 in gross terms. Yet, in our context, due to the shopping technology, households' deposits relax the shopping costs, so households will hold them.

4.7 Government

We will take the most standard assumptions regarding the government behavior. Assume the government follows an interest rate rule,

$$R_t = R + \psi_\pi(\Pi_{t-1} - \bar{\Pi}) + \psi_\pi(\ln(y_t) - \ln(\bar{y})) + \varepsilon_t^r$$

where $\bar{\Pi}$ is the inflation target and ε_t^r is the monetary policy shock that follows an AR(1) process:

$$\varepsilon_t^r = \rho^r \varepsilon_{t-1}^r + \epsilon_t^r \quad \epsilon_t^r \sim \aleph(0,1).$$

In our exercises we will study the impact of a monetary policy shock under different assumptions. We consider also a tax rule,

$$\ln(\tau_t) = \ln(\tau) + \psi_d(\ln(d_{t-1}) - \ln(\bar{d})) + \varepsilon_t^\tau.$$

ε_t^τ is the tax shock, in the setting in Gomes and Seoane (2017) we assume it follows an AR(1) process as,

$$\varepsilon_t^\tau = \rho^\tau \varepsilon_{t-1}^\tau + \epsilon_t^\tau \quad \epsilon_t^\tau \sim \aleph(0,1).$$

Here, however we will not consider tax shocks as part of our main exercises. For the government spending rule, we assume that it has a systematic component that responds to government debt. Also in Gomes and Seoane (2017) we assume an exogenous autocorrelated shock to g_t that follows,

$$\ln(g_t) = \ln(\bar{g}) - \psi_g(\ln(d_{t-1}) - \ln(\bar{d})) + \varepsilon_t^g,$$

with

$$\varepsilon_t^g = \rho^g \varepsilon_{t-1}^g + \epsilon_t^g \quad \epsilon_t^g \sim \aleph(0,1).$$

However, we will not consider it in this version of the model.

The path for taxes and government spending imply a path for government debt and real money supply through the government's budget constraint:

$$m_t + d_t = g_t + \frac{m_{t-1}}{\Pi_t} + \frac{R^d_{t-1}}{\Pi_t} d_{t-1} - \tau_t.$$

Here seigniorage is defined as $s_t = m_t - \frac{m_{t-1}}{\Pi_t}$ and it captures the real amount of goods that can be purchased by printing money. In this constraint we have not make explicit the existence of CBDC as m_t is cash. In section 6.3 we rewrite the definition of seignionare to account for digital currency (m^d_t).

Depending on the coefficients of the monetary and fiscal policy rules, we are in an active/passive regime. In this paper we will assume that the government follows an Active Monetary Policy rule and a Passive Fiscal Policy.

4.8 The crypto asset market

We abstract from the production side of crypto assets. Instead, we assume the supply of crypto is perfectly elastic at an exogenously determined price. Given the close substitution between privately supplied assets, this does not seem to be a bad approximation even when each type of assets has a limited supply. This is clearly a simplifying assumption but allow us to directly target the price level of crypto assets, which is our focus. The alternative possibility would be to model a production technology, subject to productivity shocks, that would generate the price as an equilibrium object.

We assume the price of crypto follows an AR(1) process

$$\log(q^{btc}_t) = (1 - \rho_{btc}) \log(q^{btc}) + \rho_{btc} \log(q^{btc}_{t-1}) + \sigma_{btc} \epsilon_{btc},$$

Production of crypto-assets is costless. It is straigthforward, however, to assume that the economy finds it costly to mine crypto-currency by modelling an adjustment cost, internalized or not.

4.9 Aggregation

The aggregation and market clearing conditions are straight-forward in this model. Market clearing in the goods markets is

$$y_t = c_t + i_t + g_t + \mu G_{t-1}(\bar{\omega}_t)(r_t + q_t(1-\delta))k_{t-1},$$

where $G_t(\bar{\omega}_{t+1}) = \int_0^{\bar{\omega}_{t+1}} \omega dF(\omega)$. Furthermore, the aggregation of production across firms implies that

$$y_t = \frac{1}{v_t} e^{z_t} k_{t-1}^{\alpha} l_{t-1}^{1-\alpha}$$

where $v_t = \int_0^1 \left(\frac{p_{it}}{p_t}\right)^{-\epsilon} di$ is a price dispersion index. Finally, market clearing in the capital market is given by

$$x_t = k_t.$$

4.10 Discussion: advantages and limitations of the setup

The model developed in this paper is stylized but I believe it can serve as a benchmark model for the study of crypto-assets in general, and CBDC in particular. The transaction technology, which is at the core of the demand for crypto, is embedded into an otherwise standard medium scale New-Keynesian model with financial frictions and fiscal and monetary policy. The current environment could be extended to one where we could target economies with low interest rates, banking sector and policy changes, among other features of interest.

We want to study the implications of a preference change where consumers/households decide to operate (purchase consumption goods) using crypto-assets rather than money or deposits, that is, we want to analyze a preference change towards digital payments. For that purpose we take as given the features of the crypto market: highly volatile and with a very elastic supply (new ICO of crypto-assets are not prohibited and fully decentralized).

In this setting, we will consider the possibility of emergence of a central bank digital currency, that is a perfect substitute of crypto-assets, but with a relative price of one with fiat currency, producing seigniorage for the central bank and whose supply is fully centralized. Hence, we want to answer two questions

Table 1: Calibration

Parameter	Description	Value
β	Discount factor	0.99
$\bar{\Pi}$	Target inflation	1.0074
S_0	Adjustment costs of capital	0
ϱ	Frisch elasticity related parameter	0.5
δ	Capital depreciation rate	0.01
ς_ω	Average volatility of entrepreneur shock	0.5
α	Capital share intermediate production	0.22
θ	Calvo parameter	0.8
ϵ	Input substitution	10
$\bar{s}$	Average spread	1.0025
γ_e	Entrepreneurs exit coefficient	3.67
B/K	Debt-to-capital ratio	1/3
d/y	Government debt over annual GDP	0.6
$\bar{g}/y$	Government consumption over GDP	0.2
B	Transaction costs	1
μ	Bankruptcy costs	0.12

1. Suppose preferences switch towards a more extensive use of digital currency and less of fiat money and deposits: which are the macroeconomic impact and which is the impact of public finances due to the forgone seigniorage resources? How does a change in price of crypto assets affect the economy?

2. Suppose the central bank provides a digital currency that crowds out the crypto-asset as a medium of exchange/store of value and is a fully substitute of cash. What are the implications for the transmission of monetary policy shocks?

5 Parametrization

The parametrization I use for this model is fairly standard in various dimensions and is mostly from Gomes and Seoane (2017), and shown in Table 1.

We assume additionally that the response of the nominal interest rate to inflation is 2.5, and the response of taxes to debt is 0.03. Other policy coefficients are set to 0.

Given how recent is the adoption of crypto-assets as part of the portfolio of investors, the parametrization of the liquidity function is more than challenging. For this reason, we take a rather conservative possition and calibrate the shares given by $\omega_d = 0.75$ and $\omega_{btc} = 0.025$.

That is, the share of crypto in the total portfolio is rather marginal, additionally agents hold mostly deposits rather than cash in their portfolios.

Additionally, an important parameter is μ_d as it determines the elasticity of substitution between liquid assets. We assume that the instruments, in their liquidity providing role, are mildly complements $\mu_d = -2.75$.

6 Some interesting model's implications

In this section we use the model to study the qualitative implications of adopting the crypto assets for transaction purposes in economies where it may crowd out the use of cash or the use of deposits in financial intermediaries, as well as the impact of crypto assets price changes. Then we study the impact of introducing CBDC on the transmission of monetary policy shocks.

Our objective in postulating these questions is to think whether the introduction of crypto-currencies and its adoption by the public would matter in macroeconomic terms and whether the public response, i.e. the provision of a CBDC, would affect also the transmission of monetary shocks. By no means these questions exhaust the potentially interesting issues to address with this type of models and several key avenues is left for future research. Due to the limits on the calibration of some key model's parameters, we are interested particularly in the qualitative responses rather than the quantitative implications.

6.1 Increasing the share of crypto assets in transactions

What is the impact in the economy of an increase in the use of crypto for transactions? To study this question we shock ω_{btc}, that is, the share of crypto that is combined with deposits and cash for the provision of liquidity services. We do it for two cases, one in which the increase in crypto share crowds out deposits,

$$a_t = \left((1 - \omega^m - \omega_t^{btc}) \left(\frac{a_{d,t}}{p_t} \right)^{\mu_d} + \omega_t^{btc} (q_t^{btc} btc_t)^{\mu_d} + (1 - \omega^m) m_t^{\mu_d} \right)^{1/\mu_d},$$

and one where it crowds out cash, as presented in the model section,

$$a_t = \left(\omega^d \left(\frac{a_{d,t}}{p_t} \right)^{\mu_d} + \omega_t^{btc} (q_t^{btc} btc_t)^{\mu_d} + (1 - \omega^d - \omega_t^{btc}) m_t^{\mu_d} \right)^{1/\mu_d}.$$

We assume to run this exercise that ω_t^{btc} follows an AR(1) process in logs, with a volatility of $\sigma_\omega = 0.03$ and a persistence of 0.98. That is, a shock represents a very modest, but persistent, increase in the preference to use crypto assets for transaction purposes.

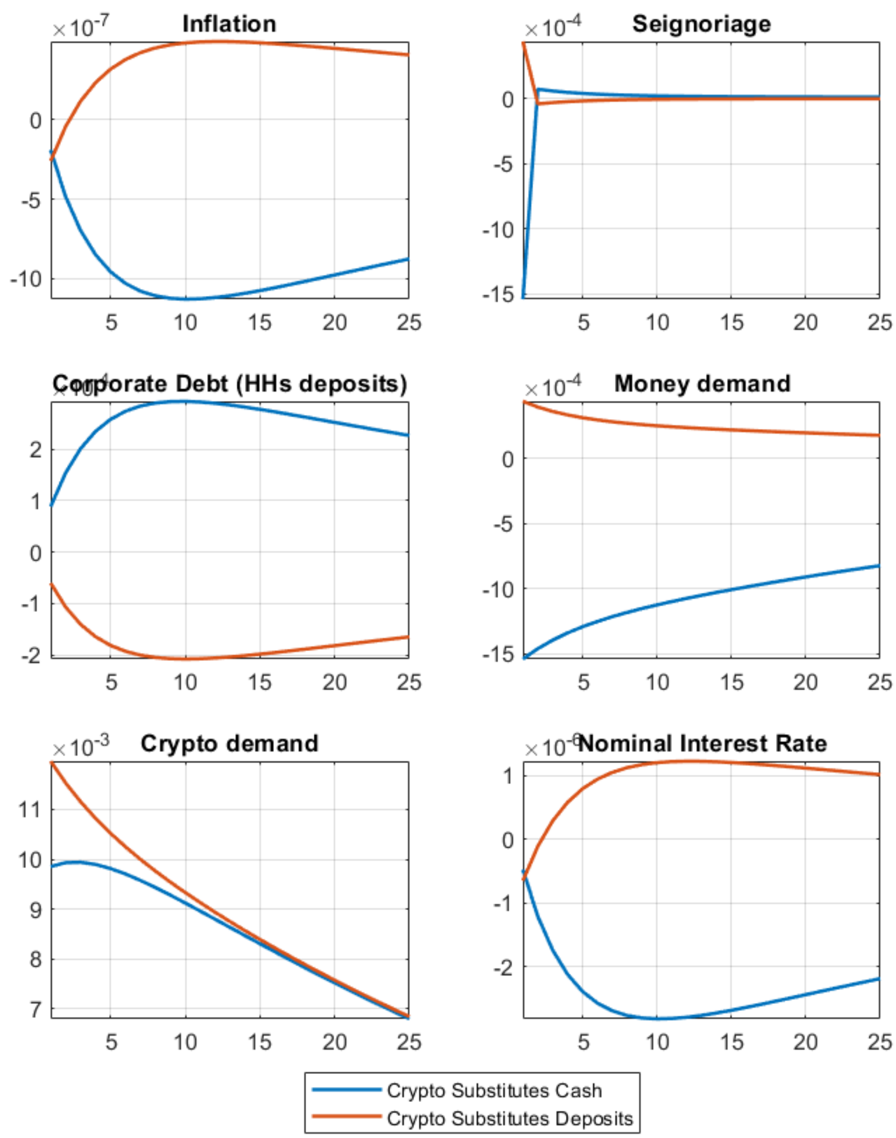

Figure 1: Impulse Response Function to a 1 std $\log(\omega_t^{btc})$

Figure 1 presents the impulse response to a 1 standard deviation increase in $\log(\omega_t^{btc})$. The blue line plots the dynamics when the increase in $\log(\omega_t^{btc})$ decreases the share of cash and the orange line decreases the share of deposits. What would happen in reality is not obvious and in principle when people starts using crypto for transactions more, this may crowd out any or all other transaction instruments.

Given that the share of crypto is rather small and the volatility of ω_t^{btc} shocks is parameterized to a small number, the absolute response are also small. Nevertheless the signs and persistence of the Impulse Response Functions contain information. In both cases, there is an increase in the demand of crypto assets, with opposite impact on the demand for money and deposits.

In our context, the drop/increase in deposits, affects entrepreneurial debt, generating real effects in the economy through the financial market. When substituting for money, the increase in crypto demand, due to the complementarity assumption between means of payments, pushes deposits up, which ease the financial constraints of entrepreneurs. On the other hand, has a negative effect on seigniorage collection due to the drop in money demand, dragging inflation down and reducing the nominal interest rate because of the Active Monetary Policy rule.

The bottom line of this analysis suggests that in the absence of a CBDC, a switch in the preferences of the private sector to use crypto assets for transaction purposes has macroeconomic effects, both real and nominal. The impact itself depends on which assets does crypto crowds out: if it crowds out government liabilities it will have an impact on public finances whereas if it crowds out financial intermediaries liabilities will affect on the leverage of the entrepreneur.

6.2 The impact of crypto price increases

This section studies the impact of changes in the crypto price when the economy has adopted it. That is, even with a small number of transactions, we show that the use of crypto makes the economy vulnerable to price shocks. The impact of the shock increases with the share of transactions done with crypto (assuming $\sigma_{btc} = 0.05$ with a persistence of 0.98). We present the dynamics for the case in which crypto would substitute cash or deposits but as we do it with ω_t^{btc} constant, their responses, of course, coincide.

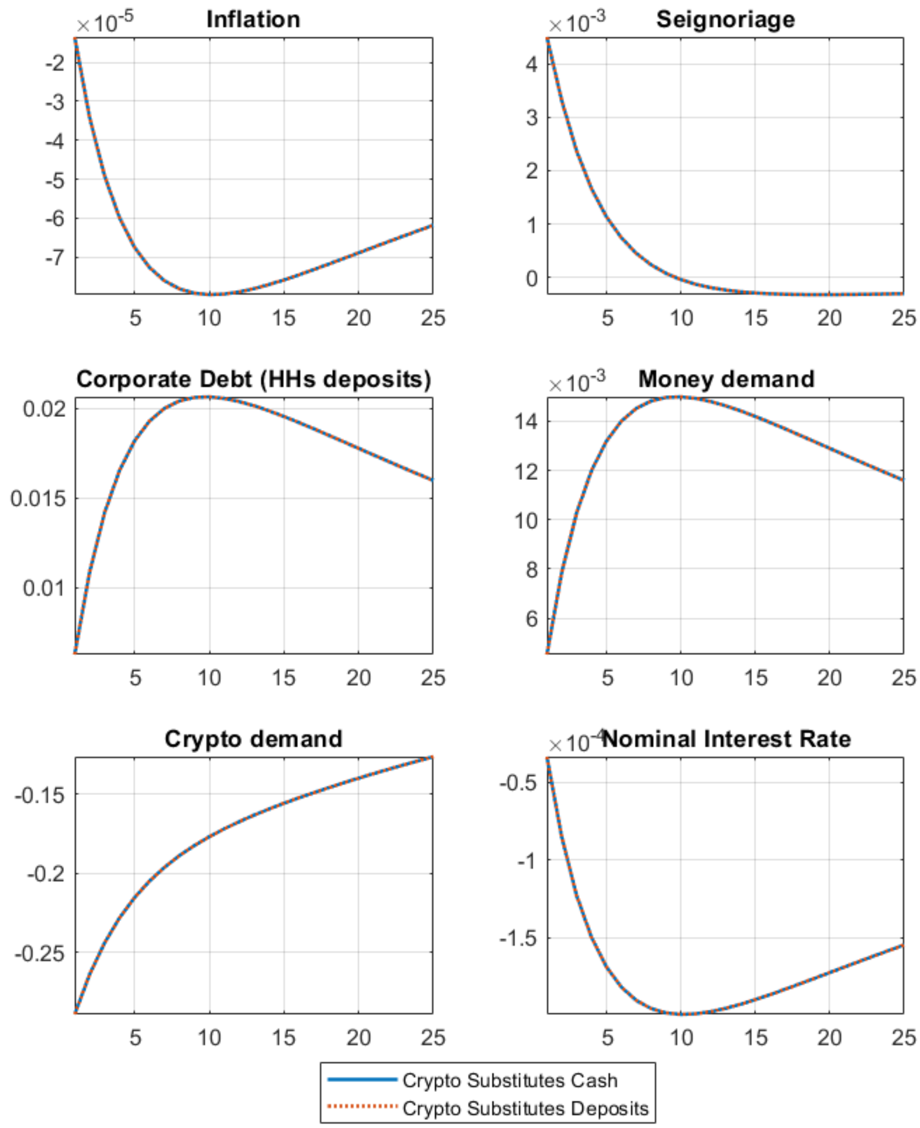

Figure 2: Impulse Response Function to a 1 std increase in the log of the price of crypto

An increase in crypto prices make it a more expensive means of payments, that is why its unit demand falls. However, the price increase allows crypto to provide more liquidity services. Moreover, by complementarity this has a positive impact on the demand of both money and deposits, allowing the government to increase seigniorage and the financial sector to provide more corporate debt.

A price drop, by linearity, would have the opposite impact. The use of crypto assets, in this way will matter for aggregate macroeconomic volatility, the crypto volatility would percolate to the volatility of the whole macroeconomy.

6.3 Central bank digital currency: the transmission of monetary policy shocks

For this exercise we introduce a central bank digital currency. With both cash and CBDC, we are expanding the set of assets that are issued by the government and works as money. In this context, the definition of seigniorage is now given by $s_t = \frac{((m_t+m_t^d)-(m_{t-1}+m_{t-1}^d))}{\pi_t}$. Naturally, we assume no price shock to the digital asset, this is not privately supplied anymore and we assume the price of money in terms of digital currency is 1, as they provide the same service and is issued by the same agents under identical conditions. Here we will compare the three economies, the ones with crypto assets and no CBDC and the one where CBDC fully crowds out the demand of crypto assets.

We study the impact of a 1 standard deviation positive shock to the nominal interest rate under our calibration that is an active monetary policy regime (assuming no persistence and a volatility of 0.003). The main results are in Figure 3 that presents the Impulse Response Function after the monetary shock. The shock implies a tightening of the monetary policy and has negative real effects, in that sense, the impact of the shock is fairly standard. In the context of trading costs, a consequence of a contractionary monetary policy is that there are less needs for means of payments as the households decide to reduce current consumption in exchange for future consumption. Consequently, in the three scenarios there are drops in households deposits, money demand and crypto demand. Given that the policy is contractionary, both inflation and seigniorage fall following an increase in the interest rate. In the case of the economy with CBDC, the ones represented by the dotted orange line, we assume that the share of CBDC to total government liabilities remains constant. In contraposition, it can be seen that the economy with crypto implies that crypto demand falls more than what should fall to keep the share of digital assets to cash constant, implying that during a contractionary monetary policy shock the households adjusts relatively more their crypto demand than the money demand.

In comparison with the case without CBDC, it can be seen that the recovery in the seigniorage is faster and stronger after the first period than without CBDC. This is so because the monetary policy shock has a mild impact on CBDC which is a source of seigniorage revenue.

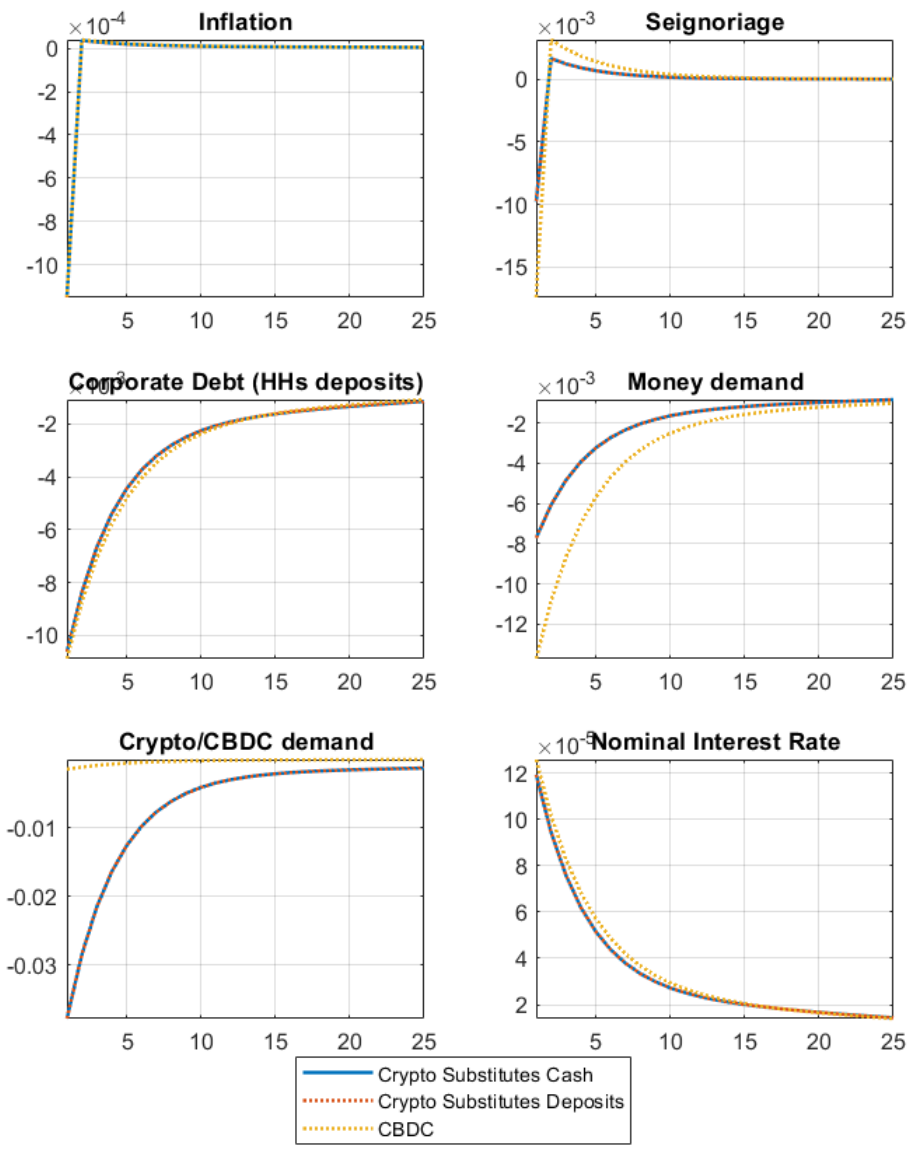

Figure 3: IRF to a 1 std monetary policy shock (R_n)

7 A few remarks

This paper provides a brief discussion about crypto assets and CBDC from a practical approach and a brief review of the literature about modelling choices. The literature is, at this point, starting to grow fast and so far has focused on theoretical approaches using the New Monetarist setting, banking crisis models, and to a lesser extent models that are suitable for quantitative analysis.

I introduce an extension of the standard New-Keynesian model with Financial Frictions that can serve as a baseline model to study the quantitative implications of introducing CBDC. In this model, CBDC or crypto assets are assumed to have a role in transactions. Households need to pay transaction costs when purchasing consumption goods. The transaction costs decrease with the liquidity of the households which depends on their holdings of deposits, cash and digital assets. Using the model with a standard calibration under the assumption of a mild complementarity between assets in the liquidity function, I show that the impact of an increase in the use of crypto assets, in the absence of CBDC, have different effects on the economy in the case in which crypto assets crowd out financial intermediaries deposits compared to the case in which it crowds out cash issued by the government. When crypto crowds out cash, the government suffers a loss in the collection of seignoriage. On the other hand, if crypto crowds out deposits, there is a negative impact on the financing of corporate firms. We also show that introducing CBDC or not will affect the transmission of monetary policy shocks.

The model in this paper has a small scale and the key assumption is that crypto assets are used for transactions. The objective of the model is to start discussing modelling choices in the standard New-Keynesian model and to highlight that there are several important aspects that could be considered in such an stylized model. There are various additional lines of work on crypto assets that should be addressed in future work, and could be done taking this type of models as base labs.

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