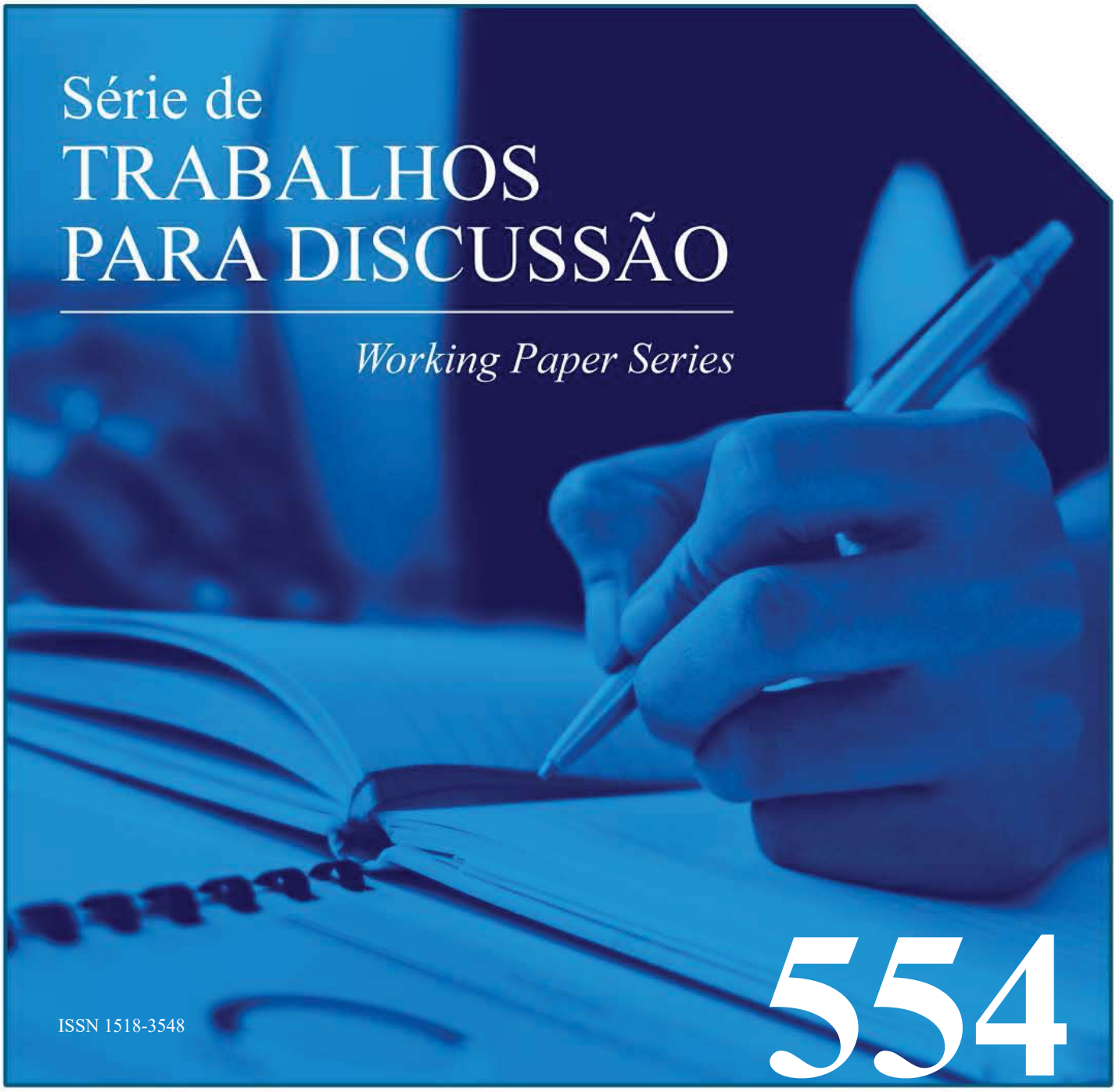


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# *A Few Things You Wanted to Know about the Economics of CBDCs, but were Afraid to Model: a survey of what we can learn from who has done*

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# Non-technical Summary

A universally accessible and redeemable Central Bank Digital Currency (CBDC) may deliver the digital transformation of a centuries-old technology: paper money (or simply cash). If issued, the new currency form will coexist, moreover, complement, the existing one, at least until gentle phase out voluntarily occurs. There shall not be a *fiat-lux* moment, rather a managed transition that promotes the expected welfare gains while mitigates unintended risks and disturbances. Such management then becomes continuous since the CBDC demand shall float influencing and being influenced by economic cycles.

If issued, the new currency form will attempt to preserve necessary and sufficient sovereign presence in payments markets alongside private digital money holdings in deposit accounts or digital wallets. Again, public and private issuers are expected to keep coexisting, besides coordinating with each other, since both have their own expertise and comparative advantages. The issuing central bank interacts with other economic agents, being those in the real sector, in the financial sector and in cross-border jurisdictions. Its independence and credibility shall benefit (or suffer) from how well it manages and improves liquidity provision through its new creation towards social optimality.

Even the colloquial speech acknowledges that the design of a CBDC has a technological, a legal and an economic dimension. The rigorous investigation shows that, under a sound legal framework and over safe virtual rails, a central bank is not designing a new instrument, rather, a *new economic order*. Whereas there is a range of views on whether such move shall be needed or shall be desirable, the only consensus is that its potential issuance should be carefully studied.

To counteract the uncertainty that is inherent in any innovation, academics and central bank researchers have been active in developing models of a prospective economy, or at least of prospective markets, where a fiat currency in digital form coexists. Irrespective of whether such a proposal entails a positive or negative stance, I contend that it is possible to infer from this body of work: opportunities, risks, and policy guidelines.

I have analyzed here twenty-nine economic modelling exercises. Despite being substantively informative, research has not cohered into a comprehensive understanding of the economics of CBDCs yet, because essential questions remain unaddressed. However, I have identified knowns, i.e., what models imply, and unknowns, i.e., what models omit or oversimplify. I have found that our analysis can give focus to further economic research that can steer ongoing legal and technical design efforts.

# Sumário Não Técnico

Uma Moeda Digital de Banco Central (CBDC) universalmente acessível pode proporcionar a transformação digital de uma tecnologia centenária: papel-moeda (ou simplesmente dinheiro). Se emitida, a nova forma monetária pretende coexistir e complementar a existente, pelo menos até que uma obsolescência voluntária e gradual ocorra. Não haverá um momento *fiat-lux*, mas sim uma transição administrada que promova os ganhos potenciais de bem-estar enquanto mitiga riscos e perturbações não intencionais. Tal política para a oferta torna-se então contínua, uma vez que a demanda por CBDC deverá flutuar influenciando e sendo influenciada pelos ciclos econômicos.

A nova forma de moeda facilitaria preservar a presença soberana necessária e suficiente no mercado de pagamentos, juntamente com outros meios digitais sob emissão e custódia de entes privados. Novamente, espera-se que os emissores públicos e privados continuem coexistindo e sobretudo coordenando-se, pois ambos contam com expertise e vantagens comparativas próprias. O banco central emissor interage com outros agentes econômicos, seja no setor real, no setor financeiro e em jurisdições transfronteiriças. Sua independência e credibilidade podem ser beneficiadas (ou prejudicadas) pela forma como gerencia e melhora o fornecimento de liquidez através da sua nova criação.

Mesmo o discurso coloquial reconhece que o projeto de uma CBDC tem dimensões tecnológica, jurídica e econômica. A investigação rigorosa mostra que, sob um arcabouço legal sólido e sobre trilhos virtuais seguros, um banco central não está projetando um novo instrumento, mas uma *nova ordem econômica*. Considerando que há uma série de opiniões sobre se tal movimento será necessário ou desejável, o único consenso é que sua emissão potencial deve ser cuidadosamente estudada.

Para mitigar a incerteza inerente a qualquer inovação, acadêmicos e pesquisadores de bancos centrais têm se empenhado em desenvolver modelos de uma economia prospectiva, ou pelo menos de mercados prospectivos, onde coexiste uma moeda fiduciária na forma digital. Independentemente de tais propostas implicarem um posicionamento favorável ou desfavorável, sustento que é possível inferir desse corpo de trabalhos: oportunidades, riscos e diretrizes de política.

Analisei vinte e nove exercícios de modelagem econômica. Não obstante ser substancialmente informativa, a pesquisa ainda não convergiu para um entendimento abrangente de uma economia com CBDC, pois questões essenciais permanecem abertas. No entanto, identifiquei respostas que os modelos fundamentam e questões que os modelos omitem ou simplificam demais. Essa análise pode dar foco às pesquisas econômicas futuras visando orientar os esforços simultâneos de design técnico e jurídico.

# *A Few Things You Wanted to Know about the Economics of CBDCs, but Were Afraid to Model: A Survey of What We Can Learn from Who Has Done*[*]

*Marcelo A. T. Aragão*[**]

**Abstract**

To mistarget and to mistime the issuance of a Central Bank Digital Currency (CBDC) can be detrimental to welfare. This holds even for tentative experiments under controlled conditions since this may prompt unintended expectations by economic agents. To counteract the uncertainty that is inherent in any innovation, academics and central bank researchers have been active in developing models of a prospective economy, or at least of prospective markets, where a fiat currency in digital form coexists. Irrespective of whether such a proposal entails a positive or negative stance, we contend that it is possible to infer from this body of work: opportunities, risks, and policy guidelines they imply (or fail to address). This paper, therefore, is a survey of this model development activity that, we aim to show, results in a better understanding of the economic implications of a CBDC. For this purpose, we have selected and reviewed twenty-nine proposals. I have classified them with respect to motivations, preoccupations, and foundations, observing what they conclude regarding the potential for coexistence with private alternatives and for harm to policy mandates. I have identified knowns, i.e., what models imply, and unknowns, i.e., what models omit or oversimplify. I have found that our analysis can give focus to further research that can steer the ongoing legal and technical design efforts.

**Keywords:** Central Banks and their Policies, Central Bank Digital Currencies, Monetary Policy, Fiscal Policy, Financial Stability, Policy Coordination, Economic Modelling, DSGE, New Monetarist Models, Search-Theoretic Models of Money, Banking Models, Bank Runs, LDA Analysis.

**JEL Classification:** E17, E37, E42, E44, E47, E52, E58, E63, F47, G21



[*] *I acknowledge the fundamental contributions from Michael Kumhof, Scott Hendry, and Fabia Carvalho in early debates during 2017 and 2018. I very much appreciate the guidance from Alvaro Fernandes to sharpen the scientific argumentation in this survey.*

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*"...when the value of money changes, it does not change equally for all persons or for all purposes" J. M. Keynes (1923)*

## 1. Introduction

Central banks world-wide may be about to lead a transformative journey. Their goals in doing so are bolder than their stabilizing policy functions would demand. Moreover, if they do show a resolve to move, markets will follow suit and adapt. The wake of this economic transformation shall be felt across economies and, therefore, across societies. Whether they are proposing or responding to transformations matters less than the prospect of their resolve to move, and this has been speculated often and broadly (Economist 2021).

The technological features of digital currencies have been studied and there have been pilot projects already implemented. One may even learn the dos and don'ts regarding this kind of innovation from existing cryptoassets and private currencies. One may even replicate part of their technological approaches in order to streamline the implementation of a public-led alternative. However, the economic consequences of a retail *Central Bank Digital Currency* (CBDC) are more difficult to foresee simply because it lacks precedent.

Before committing to such a journey, policy makers may well benefit from the body of work in the field of economic modelling that already exists. These models may still suffer from being pioneering, they may be incipient and even wrong, yet they may still be useful before venturing into the uncharted digital dematerialization of cash, as George Box would say.

The issuance of central bank digital currencies poses substantive challenges. They imply the need to connect macro and microeconomics. They may cause a reconsideration of the current consensus on monetary, macroprudential, fiscal and foreign exchange policies, that is, everything that feeds into or stems from central banks' strategic positioning. Most importantly, it may significantly impact the economy and, therefore, peoples' lives in permanent, structural, ways. The mere outlook of potential issuance already brings about potential rewards and risks. It stands to reason that we must try to estimate them in a well-informed and well-argued manner in order that we can better

target some of the rewards and better forecast the best time for their reaping as well as we can more effectively avoid or mitigate some of the risks.

This paper is a survey of economic models that address retail central bank digital currencies. The goal is to identify evidence as to whether there currently exist economic models that provide a comprehensive and compelling treatment of what might constitute a whole new economic instrument for central banks and of how such instruments might fit in with the existing ones. We have gathered evidence by studying twenty-nine proposals and we have aimed to cast such evidence in the form of actionable insights, thus going beyond the educated guesses that have dominated the debate so far. Hence, we set ourselves to organize this body of literature and, in doing so, to identify the knowns (what consequences the models imply), and the unknowns (what models omit or simplify). The knowns should suggest policy guidelines; the unknowns should suggest topics urgently requiring more research.

While assessing such a large number of model proposals may seem comprehensive, our analysis reveals relevant gaps mostly due to the need to contend with the complexity of CBDC issuance, which, in turn, leads to simplifying assumptions and these, in their turn, lead to limitations in the economic arguments that a model provides the basis for. We conclude that economic modelling has already achieved many advances, yet more studies are still required to accompany the technological and the legal developments.

We first introduce CBDCs in Section 2. In Section 3, we explain that technological, legal and economic aspects must all be explored in tandem, but in this survey, we focus on the latter. In Section 4, we explain that only an agnostic analytical stance, i.e., neither one of advocacy nor one of opposition, allows a rigorous, impartial separation of opinion and well-grounded conclusions. In Section 5, we recommend background references that can help the reader in following our analyses and the argument that such analyses underpin. In Section 6, we explain the analytical framework we have used to categorize and relate the individual proposals that we survey. In Section 7, we first elicit the motivations, the concerns, and the foundations of identifiable groups of closely related individual proposal. In Sections 8 and 9, we elicit from each proposal what potential they have in terms of underpinning economic thought about CBDCs and we highlight their main distinctive contributions. In Section 10, we generalize the advances in knowledge that stem from our analyses in terms of coverage, i.e., what models imply and what models omit or simplify. We conclude, in Section 11, by assessing whether there has been

sufficient progress in economic modelling so as to provide a sound basis on which to decide when and how to design and issue a CBDC. Finally, we complement with two technical notes that are orthogonal but related to the main goal of the survey. In Appendix 1, we describe the results of a topic coverage study that tries and reconstructs the recent evolution in thinking about CBDCs. We contrast the topics addressed by the proposals that we have surveyed and the topics that most frequently appear in the public pronouncements of salient policy makers. This provides indirect but relevant evidence on comprehensiveness and alignment between research and policy interests. In Appendix 2, we study how the implications of the survey map onto economic agents since this allows us to identify potential omissions in the body of research we have surveyed.

## 2. What do we mean by a Central Bank Digital Currency?

The central bank balance sheet is the ultimate means of settlement in a national economy, thereby its size and its composition are state-contingent to the economy outlook. Any policy that exogenously change the central bank balance sheet shall alter the future economic path, perhaps with unanticipated consequences.

Most of the recent debate about Central Bank Digital Currency (CBDC), e.g., in CPMI & MC (2018), BIS (2020b), can be resumed to how central bank digital liabilities (CBDL) are to be managed in the future, since a CBDC is but a new digital form of CBDL, alongside cash and reserves. Such management is of economic interest (Bindseil, 2004), and of operational interest. Here we study its economic perspective and, e.g., CPMI (2017) Auer et al. 2020 and Auer & Böhme (2021) study its operational one.

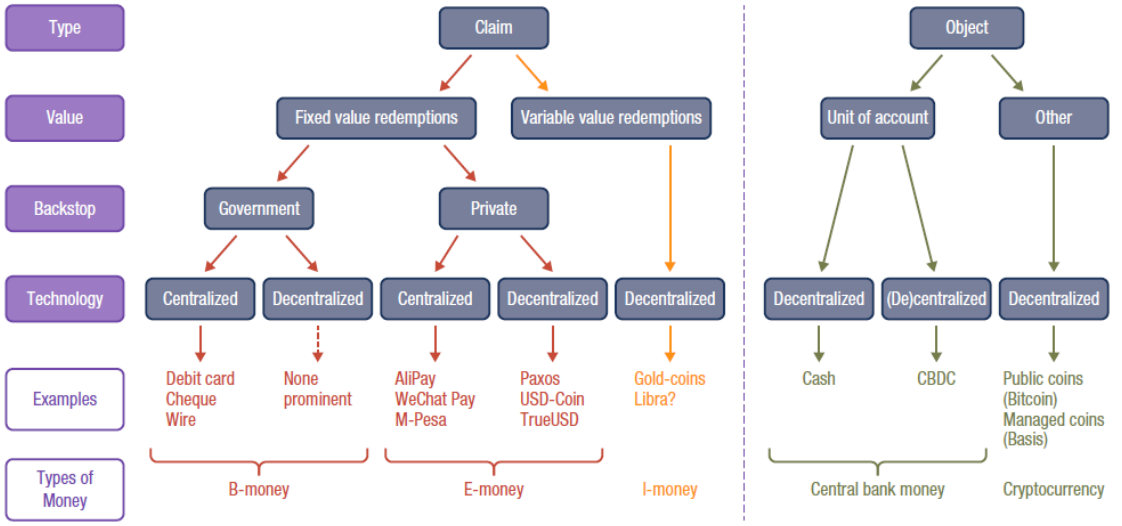
There are at least four possible developments. First, no new CBDL is introduced. This will not prevent the evolution of payments infrastructure, given the opportunities that recent instant payment schemes provide (Bech & Boar 2019). The likes of banks and non-bank financial institutions (NBFI), including fintechs (BCBS 2017), may still be licensed to issue *digital currency* against collateral holdings in the central bank. Adrian & Mancini-Griffoli (2019) name this new class of monies "*synthetic-CBDC*" and insist that it endows innovation, efficiency, and inclusion opportunities within foreseeable economic implications. Moreover, Adrian & Mancini-Griffoli (2021a, 2021b) claim smooth coexistence with the existing classes of inside and outside monies (Lagos 2006).

Second, a new CBDL is introduced, but it is accessible only to banks, and perhaps selected NBFI. Bech & Garratt (2017) classify this as wholesale CBDC because it is

central bank issued, digital, peer-to-peer, but not universally accessible. Its introduction may lay the foundation for the next generation of real-time gross settlement (RTGS) and may enhance "*safety and speed and potentially simplify the post-trade clearing and settlement*" BIS (2020a). Since it substitutes for established wholesale payment schemes, by design, and since it serves the same providers, the economic impacts of a wholesale CBDC tend to be gradual, anticipated and scaled to match expected economic growth.

Third, and of sole interest here, a new CBDL is introduced: it is not "synthetic" like the first case; and it is universally accessible, unlike the second case. This has been deemed retail CBDC by Bech & Garratt (2017). A retail CBDC is an imperfect substitute for other CBDL: cash and reserves; for commercial bank liabilities: demand deposits; and for other private means of payments: cryptocurrencies or stablecoins (Benigno, 2019). Features of the instrument and prerogatives of the issuer make imperfect the substitution. Not only does this novelty differ as means of payment, but also it differs as store of value. It is neither subject to duration risk, unlike bonds, nor to risks of bank runs, nor to insurance limits, unlike bank deposits, nor to inflation risks, unlike cash, at least when it is remunerated. Figure 1 illustrates how CBDCs compare to other types of monies.

**Figure 1**: Money Trees Adrian & Mancini-Griffoli (2019)




Source: IMF Staff.
Note: CBDC = central bank digital currency.

The fourth development is an extension to the second and/or the third, whereby foreigners can hold and transact with CBDC. A new settlement network can then be established for cross-border trade and transfers (CPMI**,** 2020). Such facility may depend on central banks to agree about standards, protocols, and legal framework (Auer et. al

2021). Moreover, it may require that the CBDC balance at least partially matches the central bank foreign assets holdings and/or liquidity swap lines.

BIS (2018) and Kiff et al. (2020) offer the interested reader comprehensive background about CBDC. Economist (2021) offers journalistic accounts of the subject.

## 3. What do we mean by Economics of CBDC?

In this paper we focus on retail CBDC, assuming an issuance demand that is sizable enough to matter for economic dynamics and for portfolio rebalancing. Two questions justify our concern about a retail CBDC:

- how endogenous would be its demand with respect to other economic aggregates, therefore, how to time a policy to manage its supply (in the initial and in the subsequent issuances) that *do not lean against* existing policies, at least;
- what other public and private liabilities it substitutes for, therefore, how to target a policy to manage its supply that *do not harm* working financial functions, at least, liquidity, maturity, and risk transformations.

Thus, by economics of CBDC we mean *the design of a new policy* **P5** *to stabilize CBDC* supply to meet an exogeneous CB mandate. Therefore, **P5** must coordinate with:

P1. **Monetary policy** and its role to stabilize price level (or inflation)

P2. **Macroprudential policy** and its role to stabilize financial liquidity flows, thereby suiting credit provision and mitigating systemic risk (financial resilience)

P3. **Fiscal policy** and its role to stabilize employment (perhaps in complement to monetary policy)

P4. **Foreign exchange policy** and its role to stabilize foreign financial flows (sovereign resilience)

We choose in this survey the economic models that allow us to investigate if a central bank can exploit a retail CBDC to complement or to reinforce any of the other policies **P1**- **P4**. We examine which unintended risks can interfere with the best implementation of these policies **P1**- **P4**. Hence, we compile model theoretical arguments. We follow Carapella & Flemming (2020), but we exceed them in depth and breadth of analysis.

The reader can rightly argue that the contribution to other public policies goals, such as the following, should weight more in the decision of introducing a retail CBDC:

- Financial inclusion (Gopane, 2019, CPMI & WB, 2020);
- Privacy (Garratt & van Oordt, 2020) and consumer protection (Mancini-Griffoli et al. 2020);
- Rights of access to money as a public good (Armelius et al. 2020, Prates 2021, Cunliffe 2021);
- Industrial policies that foster innovation, efficiency, resilience, and competition (Ingves 2020, Panetta 2020, BoE 2020, BoC 2020, BoJ 2020, Usher et al. 2021);
- Prevention policies anti-money laundering and against terrorism financing (Rogoff, 2016);
- Geopolitical positioning or influence (Brunnermeier et al. 2019a, 2019b and Ferrari et al. 2020) and safeguarding monetary sovereignty (ECB 2020).

Albeit rational and cogent, the support for such motivations tends to be argumentative at most. Bordo & Levin (2017), Berentsen & Schär (2018) and Mancini–Griffoli et al. (2018) and many others uphold such potential benefits, but their rationale lacks formal backing to support an impartial, objective, and quantitative assessment. For instance, financial inclusion is intuitively welfare improving, but its connotation varies as audiences do. Moreover, how much inclusion should be prioritized over? how much inclusion offsets risks to optimal policy design? One cannot draw more than beliefs.

We shall not delve into the private versus public political debate by siding either with Hayek (1976) or Friedman & Schwartz (1987).

We avoid pitching CBDC as response to cryptocurrencies (Yermack 2015, He et al. 2016), to so-called tokenomics (Cong et al. 2019), or to so-called stablecoins (Adrian 2019, G7 WG 2020, G30 WG 2020), despite model-based assessments of competitiveness in Fernández-Villaverde & Sanches (2018) and Benigno et al. (2019).

We leave references, but we do not discuss these motivations henceforth. We also acknowledge that there are relevant technology design considerations in Auer & Böhme (2020), Auer et al. (2020), Bindseil (2020) and Allen et al. (2020). Whether it is cryptographic token or segregated account (Garratt et al. 2020) imports to substitutability and demand. Nevertheless, we will refrain from this dilemma. There are legal design

considerations in Bossu et al. (2020), Prates (2021) and Wang & Gao (2021) with respect to issuance mandates, privacy, finality, and legal tender definitions and limitations.

Technological and legal designs entail from choices within five core features defined by CPMI (2018): availability, anonymity, peer-to-peer, interest-bearing and volume restrictions. These choices will stem from a formal mandate, with clear time and target, imposed on the issuer, the central bank, conforming its independence and its policy scope.

In short, we survey to gather economic evidence that may underpin 'why' questions, not 'how-to' questions about implementation features or about redesign requirements of the legal tender.

## 4. Analytical stance

We subscribe to the opinion that "*introducing a CBDC is a political decision rather than a technical decision*" of Balz (2020). We ground our view that CBDC is neither an economic imperative nor is a consensual choice on the following:

- Monetary policy in cashlessness is possible, as known since Woodford (2000) and Friedman & Kuttner (2010), supported by pragmatical evidence;
- Unconventional monetary policy (UMP) has been effective, even when zero lower bound (ZLB) was binding, as shown by Borio & Zabai (2020), without eliminating paper currency, as debated in Agarwal & Kimball (2015);
- Countercyclicality can be implemented through monetary, macroprudential and fiscal policies, according to Feldstein (2009) and Reis (2020);
- Equivalence of private and public money, which Brunnermeier et al. (2019a), Niepelt (2020a, 2020b), or Fernandez-Villaverde et al. (2020a) demonstrate, can be interpreted in either direction: to support a neutral introduction and to claim a redundant endeavor;
- So far, estimations of welfare improvements, stemming from issuing a CBDC, seem less replicable in reality than estimation of policy disruptions;
- So far, there is no projection for public digital money demand, nor evidence of its preference over private digital money, only a prospective consultation (BoE 2021b). *Vollgeld* referendum is an anecdote of some discomfort (Bacchetta, 2018), so is the controversial "*Sistema de dinero electrónico*" (Patiño, 2017, Arauz et al. 2021).

The above does not imply that a retail CBDC is not useful nor desirable. It only implies that policy makers must exert discretion on benefits and risks balance to decide if either a regulatory or an operational role suits the needs of most.

The goal of our analysis is, as is the goal of the body of surveyed research, to better describe and delimit the decision space. The decision to issue a CBDC must consider its targets and its timing. Such a decision will likely be more appropriate, beneficial, and effective if it is based upon evidence that we can identify, collect, organize and present regarding whether the current economic research on CBDC provides sufficient backing to warrant a forward move. Were the current modelling exercises to cohere into a comprehensive understanding as how and when a CBDC would be beneficial then its economic preconditions would have been understood. Otherwise, and by the same token, the evidence would suggest that there is a need for further research on either to improve the coherence of different approaches, or to improve the comprehensiveness of coverage, or both. Either way, this paper aims at contributing an answer to this question. Henceforth "CBDC" means "retail CBDC," unless stated otherwise.

## 5. Assumed foundational background

Money has adapted to the needs of people and its form has changed substantially throughout history. Money will do so as the needs keep evolving. So shall monetary theory. Thus, before surveying papers, we invite the reader to review recent literature.

Because CBDC is a monetary instrument, its economic aspects depend on the long-run relationship on money and prices (Stella et al. 2021); on their policy implication (Ngotran, 2016, Walsh, 2017); on the money creation in the private markets (Gross & Siebenbrunner, 2019); and on the money transactions (Lagos & Zhang, 2018).

Because a CBDC policy may complement the unconventional toolset, review Bernanke (2020) for policy-makers' perspective, and El-Erian (2016), for the private market perspective of central bank current challenges. Because it may allow for countercyclical responses, refer to Bartsch et al. (2021) about policy complementarity and to Reis (2020) for policy interplay.

Because CBDC reraises the debate about the coexistence of public and private monies in payment systems, so it is worthy revisiting its previous round during the early design of RTGS, e.g., in CPMI (2003). Because it offers to households another liquidity choice, scan behavioral decision issues, for instance, in Schwartz (2004).

Because a CBDC may induce a new order, or a new organization in the intermediation markets, we recommend Jakab & Kumhof (2015), Greenbaum et al. (2016), BIS (2018), FSB (2017) and BIS (2020a). Because issuance may change balance sheet allocation, we also suggest Bindseil (2020). Because it may affect liquidity management, read Werner (2014) and Cœuré (2018). Finally, since the universal balance sheet access asks for extra central bank protagonism, reflect on the debate in Borio (2019).

## 6. Analytical framework

We seek to expose answers and omissions from economic model analysis. So, we examine what their authors infer about the prospect of a CBDC to accomplish its well-intended economic benefits. Since authors have different views of what would be the desirable equilibrium, we select the desiderata preempted by BIS (2020b). It is summarized in Section 6.1. Since their inferences are model dependent, we build the stylized views of the economy and of their transmission channels, whereby we can relativize the soundness and completeness that underpin their claims and arguments about the desiderata. These views are described in Section 6.2.

### *6.1. Desiderata for retail CBDCs*

Seven central banks of the developed economic jurisdictions subscribed the following principles in BIS (2020b):

B1. "Do no harm," i.e., a CBDC "*should not interfere with or impede a central bank's ability to carry out its mandate for monetary and financial stability*".

B2. Coexistence, i.e., a CBDC "*should complement one another and coexist with robust private money"* and cash as long as there is sufficient demand.

B3. Innovation and efficiency, i.e., a CBDC should contribute to "*create a safe, efficient, and accessible*" system of payment services, wherein economic agents are free to choose between means of payment upon convenience.

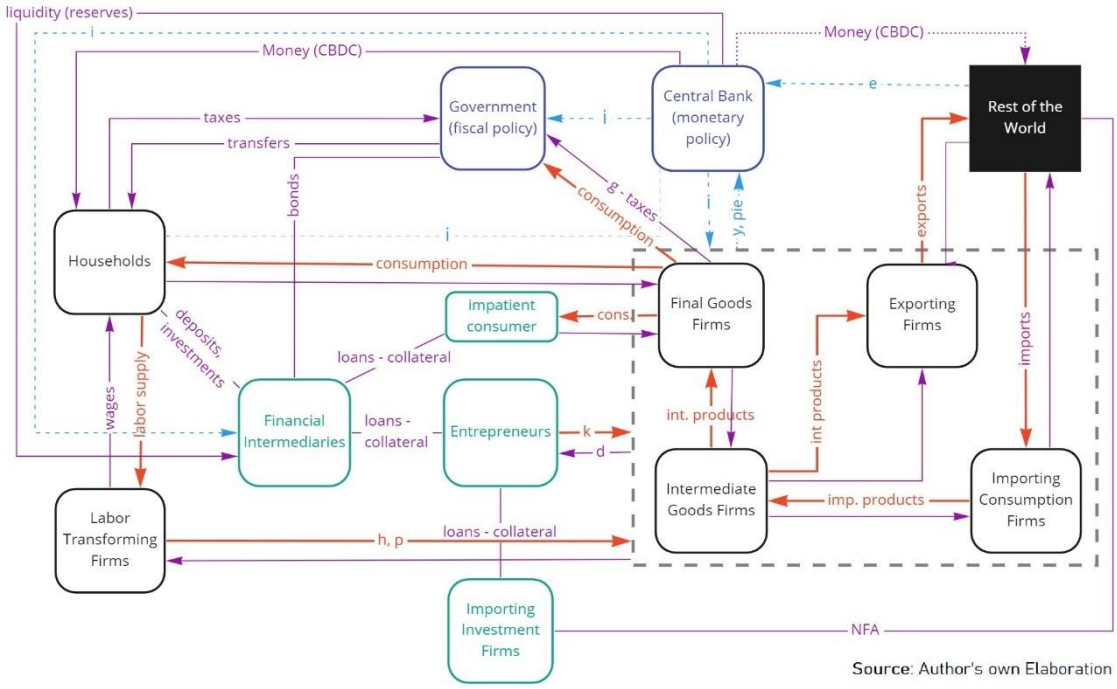
For each model, our analysis will also seek to discern what each model implies, or its simplifying assumptions fails to, regarding **B1**–**B3**. We break down the analysis of **B1**, by underscoring what can be inferred from models with respect to policies **P1**–**P4**.

### *6.2. Stylized views of economies and of their transmission channels*

We will map each model specification onto the proposed stylized view of the economic dynamics in Figure 2. This mapping should help discerning model simplifications and limitations, thereby relativizing conclusions. For instance, if a model assumes a combined monetary and fiscal authority, then it simplifies the interplay between their respective policies and the risk differential between money and government debt. Simplifying model assumptions sharpen the argument but yield analytical gaps.

Arrows denote real flows (red), financial flows (purple) and aggregated information flows (dashed blue) from both demand and supply sides. We group agents as domestic and the rest of the world. Rounded squares denote real sector (black), financial sector (green), and government (blue) agents. The financial sector agents are specialized roles of either household or firms. The central bank endows liquidity to households in the form of money (perhaps, CBDC) and to financial intermediaries in the form of reserves. Narrow banks are an operational device that could be placed in between central bank and households. A capital market with safer entrepreneurs is omitted since none of the survey models features one. We look on economic flows, rather than on payment transactions.

**Figure 2**: Stylized view of agents and their real, financial and information flows

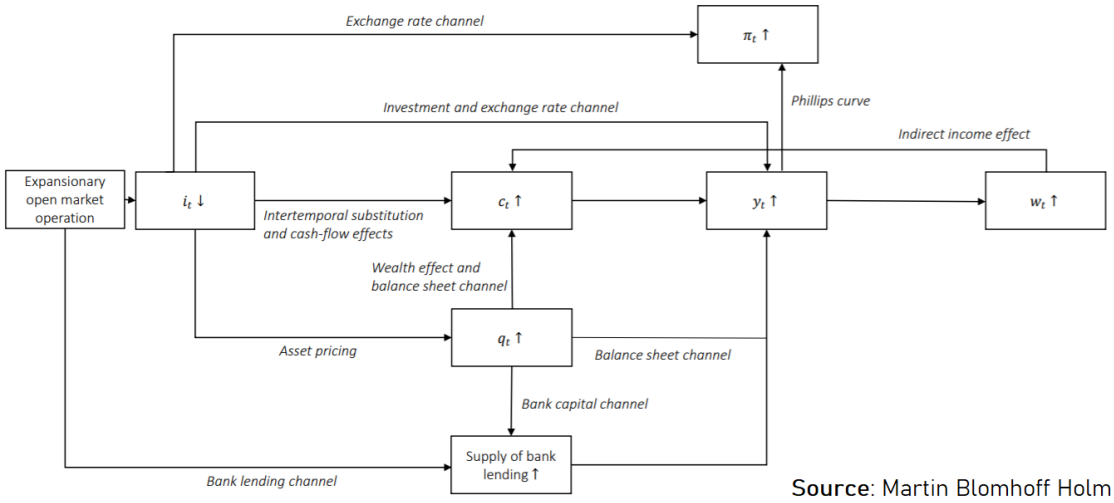



Households may have utility for currency, for example, to smooth intertemporal budget constraints, to offer credit collateral, or to confront cash-in-advance frictions to consumption. The first two benefit from the store of value function while the last one

benefits from the means of payment function. Such utilities justify the economic relevance of a currency and suggest how it can be modelled. Thus, we propose in Figure 2 a view only sufficient to allow for all possible utilities. In Figure 2, most of the dynamics of interest here involves the flows among the central bank, households and financial intermediaries. Households that act as entrepreneurs or impatient consumers connect the real and financial sides of the economy. Central bank policies target these connections. They propagate policy effects onto other flows and influence agent behaviors, in a continuum. Thus, these very flows offer measurement opportunities to assess policy effectiveness. Liquidity provision price and quantity also influences agent behavior in proportion to volume of the central bank supply response. Christiano et al. (2012) offer a deeper explanation of economic modelling strategies that resulted in Figure 2.

We will identify the transmission channels in Figure 3 that each surveyed model captures, aiming at relativizing their results. Squares denote variables and arrows denote transmission channels in Figure 3. Arrows inside the square denote the direction of the effect. These transmission channels capture only the macro, aggregated level. However, Kumhof & Noone (2018) and Piazzesi & Schneider (2020) capture the micro, representative agent level through stylized balance sheet accountings of funds transfers.

**Figure 3**: Stylized view of the relevant monetary transmission channels




Source: Martin Blomhoff Holm

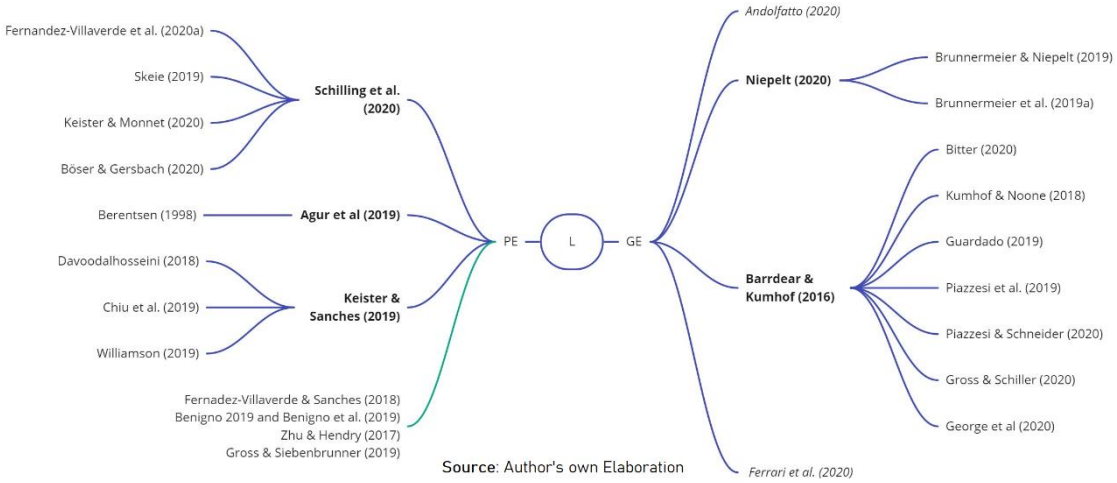
CBDC may impact all transmissions channels in Figure 3 since they jointly converge into a dynamic equilibrium. Notwithstanding, arguments favoring or opposing a CBDC issuance tend to start with the bank lending, then lead to the balance sheet channel. Bank capital channel is relevant to discuss the likelihood of bank runs. Cash flow

effects are often overlooked but meaningful to quantify the aggregated maturity shortening due to more currency, less credit. Wealth effects would be meaningful without issuance sterilization. The relevance of the exchange rate channel grows if CBDC becomes accessible to non-residents, besides its stabilization role.

## 7. A broad classification of the literature on economics of a CBDC

The 29 surveyed papers are organized observing intention, theoretical foundation, and thematic convergence, as depicted in Figure 4.

**Figure 4**: surveyed literature




In Figure 4, we divide the surveyed models between partial (left) and general equilibrium models (right), because the choice of theoretical foundation reveals the policy emphasis on either market or macroeconomic issues, respectively. We chose then two general equilibrium models: Barrdear & Kumhof (2016) and Niepelt (2020b); and three partial equilibrium models: Agur et al. (2019), Keister & Sanches (2019), Schilling et al. (2020) and Benigno (2019). These five either influence subsequent or subsume previous works. Two more works introduce original perspectives: Andolfatto (2018) and Ferrari et al. (2020). Five other works provide pertinent insights by modelling private currencies rather than CBDC: Zhu & Hendry (2017), Fernández-Villaverde & Sanches (2018), and Benigno et al. (2019). The remaining papers are examined to corroborate, to complement and to nuance the key claims. We cluster them around the five references. Thus, we arrange the 29 papers into six sets (5+1) and two singletons by opposing cohesion and decoupling.

This organization already conveys some information, for example, models that emphasize a monetary perspective tend to impart a balanced evaluation, while models

that emphasize a macroprudential perspective tend to split at odds. The choice to depart from the bank run model of Diamond & Dybvig (1983) portents a cautionary stance, while the choice to depart from a model that accommodates a central bank activism, e.g., from Gertler & Kiyotaki (2015), suggests a subtle advocacy. Some models were designed to explore implications, e.g., Barrdear & Kumhof (2016), while others to prove its viewpoint, e.g., Niepelt (2020b).

We show in Appendix 1 a Latent Dirichlet Allocation (LDA) Analysis (Blei et. al, 2003) of the same surveyed literature. This alternative topic analysis exercise yields a different yet complementary cluster categorization. **P1-P4** policy emphasis seems to dominate as a discrimination criterium rather than theoretical foundation, yet four out five reference works also spawn to different topic clusters. Barrdear & Kumhof (2016) and Schilling et al. (2020) fit in the same topic cluster, but they share the closest message and coverage. The fourth topic cluster concentrates most of the currency competition models with or without CBDC. Thus, the induced and the curated literature organizations bear some coherence.

Henceforth the analysis seeks to uncover which **P1-P4** policies the works consider, which B1-B3 BIS principles they address, what omissions they admit or exhibit, what unrealistic assumptions they make, possibly implicitly, what stance (i.e., cautionary, neutral, enthusiastic, etc.) they state or avoid declaring. We narrow the concerns using the partial equilibrium models in Section 9, then we broaden the analysis using the general equilibrium ones in Section 10.

## 8. Partial Equilibrium: market specific microeconomic models

Partial equilibrium models separate concerns and develop arguments with control and conciseness. Works either focus on a competitive CBDC against private monies, hence on the core principle **B3** – *innovation and efficiency*; or they focus on financial system potential disruption, hence on the core principle **B2** – *coexistence.*

### *8.1. Retail CBDC in Banking Models inspired by Diamond & Dybvig (1983)*

The model setup in Schilling et al. (2020) modifies the one by Diamond & Dybvig (1983) to impose that all contracts are nominal, thereby stablishing a feedback mechanism between the price level and the loan portfolio, in line with Allen et al. (2014), who argue that price level variations allow full sharing of aggregate risks. This buildup recognizes

the balance sheet transmission channel to inflation as in Figure 3, hence it connects macroprudential and monetary policies (**P2** and **P1**).

The model specification simplifies the flows in Figure 2, since it omits private banks and subsumes financial intermediation in a central bank with the monopoly of supplying liquidity, via deposits or via CBDC. Hence, the central bank confronts both the issues of maturity transformation and the exposure to liquidity demand shocks induced by private agents "spending" shocks (or *runs*). Later, this simplification is relaxed, and the results still hold inasmuch as the central bank retains the dominant position in liquidity provision among private intermediaries. In short, Schilling et al. (2020) model the classic role of the lender of last resort (LOLR), enhanced by a significant CBDC issuance.

A central bank has a consequential advantage over private intermediaries because it controls the price level in a nominal setup. So, the central bank can decide how to respond to shocks: either by rationing the liquidation of real assets; or by adjusting the price level; or by issuing more currency to deliver on obligations and missing its inflation target. It may then face either a classic run (as a bank would) or a price level run. However, it can prioritize the policy objective and decide accordingly. Its menu of policy choices creates a trilemma: price stability, financial stability (i.e., absence of runs) and efficiency (i.e., socially optimal liquidity allocation in the sense of Friedman 1969). Schilling et al. (2020) show that only two, never three, objectives can be assured simultaneously. Economic agents learn *ex ante* the central bank tradeoffs, moreover they learn its preference. If the central bank commits according to its mandate to primarily guarantee price stability, then the trilemma is reduced to the classic Diamond-Dybvig dilemma: classic bank runs can no longer be ruled out or the liquidity allocation is suboptimal.

In the presence of private banks, all liquidity providers must coordinate to avoid runs that threat financial stability. If coordination is unattainable due to heterogeneity and to regulatory and information frictions, then the central bank can deter runs as long as the CBDC has replaced a sufficiently large share of the deposit market. The model solution implies a challenge to accomplish both the core principles **B1** and **B2**.

Fernandez-Villaverde et al. (2020a) start with a similar setup whereby a central bank becomes a competing financial intermediary by issuing a CBDC. They demonstrate that in normal times any "*set of allocations achieved with private financial intermediation will also be achieved with a CBDC*". Such monetary neutrality is voided in the event of

a large distress, e.g., one that preludes an aggregate bank run, since the central bank has extra powers to prevent such runs. Depositors internalize ex-*ante* the central bank is safer than private commercial banks, and rationally shift their preference from deposits to CBDC. The central bank delivers on stability, yet it lacks the investment expertise, so the CBDC attractiveness may crowd-out banks and deviate from optimal risk and maturity transformation.

Skeie (2019) also extends Diamond & Dybvig (1983) to model a different market organization, with respect to the stylized in Figure 2. The setup captures the competition between a public digital currency, e.g., a synthetic CBDC as in Section 2, with a private one, e.g., Bitcoin as in Nakamoto (2009). He assumes both can provide liquidity services. The public one is subjected to distortionary inflation, at central bank discretion, while the private one is not, because it is deflationary by design. Skeie (2019) shows that both can trigger financial disintermediation, dubbed *digital currency runs*, thereby damaging optimal allocation of maturity and risk. However, the central bank can elastically supply liquidity to prevent public digital currency run, but it cannot (shall not) prevent it for the private one. Therefore, households face a hypothetical tradeoff: between monetary and financial stability in public and private currency competition. Equilibrium depends again on the balance of central bank's mandate about monetary and financial stability.

Böser & Gersbach (2020) also draw from Diamond & Dybvig (1983) to model a particular refinancing friction that may create the incentives to a CBDC to substitute for private deposits. Non-diversified, competitive banks face an idiosyncratic risk, and may default in case of aggregate distress. However, the central bank insurance offered to depositors is only partial because it imposes haircuts, caps, etc., by model assumption, but it is complete to its issued CBDC, by money definition. This safety differential creates micro-incentives for lessening intermediation, creating less deposits, and reducing consumption during bad equilibrium, i.e., crises.

Together those four works add a cautionary note against the introduction of a CBDC at scale with respect to the **B2** core principle – "*coexistence*" when exploring macroprudential implications (**P2).** All four warn that the safety and stability differentials that central bank has over private intermediaries may suffice for the real side agents to entrust their liquid asset to the former rather than to the latter. Perhaps such change of preference may compromise the core risk and maturity transformation services that the latter provides but the former does not through CBDC. All but Schilling et al. (2020)

abstract from real side and activity based monetary transmission and explore the CBDC contractionary effect on the bank lending channel.

On the optimistic side, Keister & Monnet (2020) study the introduction of CBDC as an information revealing mechanism about the quality of bank assets and liquidity position. A reduced information asymmetry may contribute to more efficient regulation, thus to financial stability. The model setup assumes a moral hazard incentive for banks to hide their private information, but also incentives for depositors to pool their resources to insure against bank idiosyncratic liquidity risk. Once a CBDC is introduced, in contrast, the central bank has a new source of information: the flow of funds into this digital currency and its equilibrium interest rate can be observed and contrasted to historical levels to reveal the state of the financial system, in anticipation to central bank supervision. Pfister (2017) heeds that the central bank information gains derived from CBDC adoption costs the commercial banks information loss, turning them more dependent on the central authority for information and for financial backing as well.

Keister & Monnet (2020) show that a CBDC affects the efficient distribution of resources in the economy. They do not exclude risks argued by the previous four works. However, they tout the unintended harbinger of a bank run as an informational opportunity. By observing a large and sudden inflow of funds into its digital currency, the central bank can then infer the financial conditions of banks. This information can trigger proportional policy response in times of stress. The faster a response is, the more likely its effectiveness is. CBDC policy design shifts towards promoting financial stability, therefore improving welfare.

### *8.2. Retail CBDC in Network Effects Models inspired by Katz & Shapiro (1985)*

Network externalities are relevant for digital money demand. Berentsen (1998) recognizes this fact in an early investigation using a simple monetarist model. Although he expects a "*negligible"* future demand for digital money, he reckons that an eventual widespread use would affect demand for banks reserves negatively if digital currency substitutes for bank deposits, and positively if digital currency substitutes for cash. Much would depend on central bank reserve requirement policy reaction. Fernández–Villaverde & Sanches (2019) also reinforce networks effects as a requirement for cryptocurrencies to be a competitive means of payments.

Agur et al. (2019) discuss financial stability (**P2**) from the same theoretical setting: *network effects*. These effects gain relevance as payment evolution depends on scale. Their setup is simple with respect to the stylized view in Figure 2. They model households and competitive firms and banks, but no government, and none of the monetary transmission channels in Figure 3. Social value is derived from banks funding firms' projects. Their setup is also static, hence also omitting the feedback transmission channels in Figure 3. Their emphasis is on households' utility and on central planner welfare maximization. Households have heterogeneous preferences over anonymity and security in payments. Thus, CBDC fits into a continuum of households' preferences between two extremes: cash and deposits. Two other metrics are weighted in the households' choice for liquidity services: its network effects and its interest-bearing feature.

Agur et al. (2019) claim that CBDC has welfare value due to its ability to blend features of cash and deposits, whereas it has welfare costs to the extent that it crowds out the demand for cash and deposits. The CBDC interest rates push substitutability closer to deposit, while network effects, closer to cash. The optimal design for a CBDC shall balance these two forces so that the CBDC introduction does not significantly compromise the extreme alternatives. This modelling aligns with the core principle (**B2**).

Agur et al. (2019) infer that the interest-bearing feature is sufficient to sort the tradeoff between preserving variety in payment instruments, in the face of network effects, and reducing negative externalities upon financial intermediation.

### *8.3. Retail CBDC in a Search-Theoretic Models of Money inspired by Lagos & Wright (2005)*

Keister & Sanches (2019) adapt the search-theoretic monetarist model of Lagos & Wright (2005) but impose an investment friction that creates borrowing constraints to banks, inasmuch as they cannot fully realize the cashflow return of the projects they fund, as in Kiyotaki & Moore (1997, 2005). The limited pledgeability might be due to default, imperfect collateralization, information asymmetries, etc. Keister & Sanches (2019) study how the introduction of a CBDC can dislocate the equilibria of monetary and macroprudential policies (**P1**, **P2**). Thus, they corroborate findings in Schilling et al. (2020). Each new equilibrium is predicated on a set of design features. They concern about the bank lending channel in Figure 3. They measure for each equilibria the welfare

in terms of activity level and the level of financial disintermediation, the deviation in the monetary and in the macroprudential policies implied by the introduction of a CBDC.

Their setup is meant to study the core principle **B1** – "*do not harm*" by simulation opposing sets of CBDC design decisions. They propose a model of decentralized markets rather than a model of the economy like the one in Figure 2. The central bank manages inflation via monetary policy rule (**P1**), and controls CBDC interest rate when it is introduced as a second monetary policy after its issuance. The central bank also manages liquidity supply by choosing the design of the CBDC. Banks create outside liquidity by granting loans, thereby contributing to the level of activity. Households can be buyers and sellers. Initially, two types of meetings can occur in decentralized markets. In one type, the seller of goods is only able to verify cash and, in the other type, the seller can only verify bank deposits (digital payments). So, the sellers' heterogeneity induces the households' preference among liquidity alternatives.

Opposing CBDC design features determine the following three new equilibria:

d1. A retail CBDC that perfectly substitutes for cash fosters an increase in the production and exchange of goods that used to be purchased with cash but has no effect on other types of exchange or on investment.

d2. A retail CBDC that perfectly substitutes for bank deposits shall crowd them out, thus banks respond to lower deposit demand by supplying less loans and by raising private interest rates, which, in turn, depresses investment and activity through lending channel.

d3. A retail CBDC that partially substitutes for both cash and bank deposits also ensue transactions gains and disintermediation losses. The net welfare results will depend on the optimal, dynamic setting of the CBDC interest rate.

The first equilibrium dominates when financial frictions are high and when credit provision is key to support the aggregate level of activity, the third dominates otherwise.

Chiu et al. (2019) extend the work of Keister & Sanches (2019) to study its implications on bank funding costs, lending, investment, and output. They assume the same space of CBDC design features to design distinct scenarios. However, the model also considers the competition level in the deposit market as an additional parameter. Their results confirm that if the CBDC rate is sufficiently high, banks can only compensate for the rising funding cost by raising the lending rate, which would lead to a depressing in lending channel, confirming the inference by Keister & Sanches (2019).

Originally, Chiu et al. (2019) find that a moderate interest rate on the CBDC may increase bank deposits and loans if the deposit market is not perfectly competitive. In this case, a CBDC alternative limits banks' market power. This effect is observed even if it is not used in equilibrium because CBDC serves as a viable outside option to bank deposits. Banks tend to match CBDC interest rate with better deposit rates. This incentivizes depositors, while banks switch from intensive margin to extensive margin profitability in normal times. Overall, the demand for bank deposits becomes more elastic with respect to the deposit rate. This is analogous to the argument of Lagos & Zhang (2018) for an efficient monetary policy even if the equilibrium is cashless. Therefore, the coexistence becomes a discipline that leads to more efficient credit provision.

Davoodalhosseini (2018) pursues a different strand, studying the competition between CBDC and cash. Likewise, he builds on the framework by Lagos & Wright (2005). He models a decentralized market for good and a centralized one for exchanges through payment instruments: CBDC and cash. Davoodalhosseini (2018) departs from the base model since there is preference for holding some liquidity, and since consumers incur costs for holding real balances in CBDC, but not for holding cash. Unlike the usual assumption that CBDC operation would be cheaper than cash operation, his model captures the net loss of utility that would convince agents to stick to cash. For instance, agents may value anonymity, technology independence, habit preservation etc., provided that the shift to CBDC is perceived to be costly. The model setup also captures a net gain for the central bank if it could convince agents to switch to CBDC. For instance, the central bank could monitor portfolios and adjust monetary policy accordingly. It could transmit its monetary policy upon a larger base, or it could achieve a better liquidity allocation, etc., provided that there is a tension between agents and the central bank. These arguments are reiterated in Davoodalhosseini et al. (2020).

Cash only equilibrium implies production level distortion caused by the defensive behavior of preserving real balances against inflation. CBDC only equilibrium implies a loss of social utility. When cash and CBDC coexist in equilibrium, the endogenous choice of payment instrument may constrain the monetary policy (and the welfare may be lower) if compared with the equilibrium in which only one means of payment is available or valued. Thus, the coexistence is only justified when policy is little constrained. Otherwise, the size of the CBDC opportunity cost will determine the central bank maximization problem of which instrument(s) to issue. The extension that captures the arguments in

Rogoff (2016) hints against coexistence. Finally, in another extension, the coexistence is best the least CBDC is a substitute for cash. Note that Davoodalhosseini (2018) does not model bank deposits or monetary transmission channels.

Williamson (2019) starts with a similar search-theoretic model of money by Lagos et al. (2005). He computes the equilibria considering cash, CBDC and now deposits. He studies how the CBDC issuance might change the effects of monetary policy and the optimal behavior of the central bank. Thus, he concerns about the **B1** principle. Unlike Davoodalhosseini (2018) but like Rogoff (2016), he presumes that cash is more costly due to security and storage issues, alongside with illegal and evasive behavior risks. This first assumption leads to a welfare improving equilibrium when CBDC substitutes for cash. He assumes that commercial banks react to adverse incentives, hence cause market inefficiencies. Likewise, this second assumption leads to a welfare improving equilibrium when CBDC substitutes for deposits. The second assumption is predicated on the central bank being more trustworthy and on using more efficiently the aggregated stock of collateral to match outside money than private banks use them to match inside money. Unlike all other surveyed works, he assumes that a central bank has an efficiency differential beyond the stability differential, without digressing into moral hazard or adverse selection frictions. Therefore, his model allows the central bank to hold all government debt[1] and, at discretion, enough private assets, to provide sufficient endogenous liquidity.

The research works from Zhu & Hendry (2017), Fernandez-Villaverde & Sanches (2018), Benigno (2019), Benigno et al. (2019) employ similar frameworks, but their setups assess the implications of public and private means of payments competition, without considering a CBDC per se. Benigno (2019) postulates that competition may incentivize monetary discipline and improvements in government money, including its digitalization. Their shared concerns contribute to the backing of a CBDC issuance to counter the relevance of private digital schemes, thereby preventing power constraints and welfare distortions to the monetary policy. They mostly oppose "*coexistence*" (**B2**) for the sake of a "*do no harm*" assurance (**B1**).

[1] *This amounts to $27,7trn in 2020 Q4 according to U.S. Department of the Treasury.*

### *8.4. An overview of market specific microeconomic models*

We tabulate the works in this Section 8 into Table 1 according to the framework in Section 5. For each, we mark which policies (**P1-P4**) it investigates. For each, we interpret its results with respect to core principles (**B1-B3**) (BIS 2020b). For each, we classify then according to stance and we summarize in a single brief sentence their main research contribution for the benefit of the reader, even running the risk of misrepresenting them.

**Table 1**: Summary of the surveyed literature in Section 8

| research work | Affiliation [1] | Survey Cat.[2] | Policies P1 | P2 | P3 | P4 | Core principles B1 | B2 | B3 | CBDC stance[3] | main research contribution |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Schilling et al. (2020)** | AC | **PE1** | ✓ | ✓ | | | ✗ | ✗ | | cautionary | Trilemma: price stability, financial stability, and efficiency |
| Fernández–Villaverde et al. (2020) | AC | **PE1** | | ✓ | | | ✗ | ✗ | | cautionary | Monetary neutrality is voided in large distresses |
| Keister & Monnet (2020) | AC | **PE1** | | ✓ | | | ✗ | ✓ | | persuasive | Information revealing mechanism about banks |
| Skeie (2019) | AC | **PE1** | | ✓ | | | ✗ | ✓ | ✓ | cautionary | Digital currency runs harms allocation of maturity and risk |
| Böser & Gersbach (2020) | AC | **PE1** | | ✓ | | | | ✗ | | cautionary | Refinancing friction incentivizes substituting deposits |
| **Agur et al. (2019)** | IMF | **PE2** | | ✓ | | | ✗ | ✗ | | neutral | Policy action should counter the loss of utility with CBDC |
| Berentsen (1998) | AC | **PE2** | ✓ | | | | | ✗ | | neutral | Network effects are relevant to the demand for monies |
| **Keister & Sanches (2019)** | CB | **PE3** | ✓ | ✓ | | | ✗ | ✗ | ✓ | neutral | CBDC features can dislocate the policy equilibria |
| Chiu et al. (2019) | CB | **PE3** | | ✓ | | | | ✗ | | persuasive | Coexistence disciplines noncompetitive banks |
| Davoodalhosseini (2018) | CB | **PE3** | ✓ | | | | ✗ | | | cautionary | Interest-bearing can sort the networks effect tradeoffs |
| Williamson (2019) | AC | **PE3** | | ✓ | ✓ | | ✗ | ✗ | | persuasive | CB manages liquidity better for banks react to adverse incentives |
| Benigno (2019)* | AC | **PEX** | ✓ | | | | | | ✓ | NA | Competition disciplines policy and improves money |
| Benigno et al. (2019)* | AC | **PEX** | ✓ | | | | | | ✓ | NA | Competition disciplines policy and improves money |
| Fernández–Villaverde & Sanches (2018)* | AC | **PEX** | | ✓ | | | | | ✓ | NA | Private arrangements can be efficient and stable under free entry |
| Gross & Siebenbrunner (2019) | AC | **PEX** | ✓ | | | | | | | NA | Monetary policy's bearing will not be reduced in cashlessness |
| Zhu & Hendry (2017)* | CB | **PEX** | ✓ | | | | ✗ | | ✓ | NA | Private currencies prevent monetary policy optimality |

[#] Excluded from the core principles analysis because they do not study CBDCs

Policies: P1. Monetary; P2. Macroprudential; P3. Fiscal; P4. Foreign exchange. BIS (2020b) Core Principles: B1. "Do no harm"; B2. Coexistence; B3. Innovation and efficiency.

[1] AC=Academic Institution; CB=Central Bank; IMF=Int. Monetary Fund

[2] Author's classification proposed in Section 7, GE=General Equilibrium, PE=Partial Equilibrium

[3] Author's assessment of net balance of benefits and risks

None in this section excludes the risks of aggregate bank runs. They provide compelling evidence that currency competition with CBDC depends much on how its static features design and its dynamic policy management determine substitutability. However, Keister & Monnet (2020) anticipate less information asymmetry between commercial and central banks, sufficient to mitigate macroprudential risks and offset negative externalities of coexistence, while both Chiu et al. (2019) and Williamson (2019) claim a net welfare gain in partial disintermediation of noncompetitive banks. In short, coexistence **B2** brings risks, but depending on established market organization and on CBDC policy management, those might be downside or upside ones.

## 9. General equilibrium: economy wide macroeconomic models

### *9.1. A retail CBDC in an infinite horizon general equilibrium model*

Driven by similar concern that motivates the works in Section 8.1, Bitter (2020) extends the infinite horizon general equilibrium model in Gertler & Kiyotaki (2015) to study whether a CBDC may increase the risk of an aggregate bank run, a key concern of macroprudential policy (**P2**). Bitter (2020) contraposes the arguments in Keister & Sanches (2019) and in Fernandez-Villaverde et al. (2020a) by siding with Kumhof &

Noone (2018), Meaning et al. (2018) and Piazzesi et al. (2019) to assert the relevance of the "*asset side*" that accommodates a CBDC liability. She attributes prevailing concerns about the risk of a bank run to inferential biases of partial equilibrium exercises.

Besides considering government bonds as the eligible asset for accounting identity as Barrdear & Kumhof (2016) do, Bitter (2020) also investigates the CBDC issuance against loans to banks (LOB) or corporate asset purchases (CAP). These two new policies have precedent: providing liquidity to banks as lender of last resort (LOLR) and providing liquidity to non-banks via credit easing (CE), respectively. Both nonetheless impart in extra assumption of risk into the central bank's balance sheet when compared to sterilization against government bonds, as Barrdear & Kumhof (2016) propose.

The above setup models households, banks, and a central bank only, and their respective financial flows with respect to Figure 2. It captures the capital, the banking lending, and the balance sheet channels in Figure 3. Households consume and split savings among investing in capital, holding bank deposits, or acquiring CBDC. Banks are more efficient to manage productive assets, but they are subject to a leverage constraint. They maximize profits by investing funds from households and the central bank (under LOB policy) into productive assets. The monetary authority can clear the markets by issuing CBDC to households and funding firms directly or indirectly, under CAP or LOB policies, respectively.

The introduction of a CBDC does not change the steady-state level for aggregate output and prices. However, it leads to balance sheet and portfolio changes for household savings, bank funding and capital investment, thereby causing a reduction in bank profits, since CBDC partially substitutes for deposits. However, if a sufficiently large shock hits the economy (crisis), a bad equilibrium emerges which is characterized by a bank run to the aggregate banking system. The central bank can resort to both LOB and CAP policies to counter the shock and stabilize financial flows, with partial success, "*by reducing it more to its fundamental part*". It then cushions the decline in bank capital and net worth, defers the emergence of bank runs, but also shifts the relative weight of the welfare loss more towards households. Thus, the central bank absorbs financial risk out of the markets into its balance sheet, inasmuch as LOB and CAP assets are riskier than CBDC liability is. The absorbed risk differential is great in time of crisis. In short, CBDC policies can help offsetting the stability problem that CBDC issuance contributed to.

### *9.2. A retail CBDC in an overlapping generations model (OLG)*

Andolfatto (2018, 2020) combines a model of government debt with a model of monopoly bank into a single overlapping generations model (OLG). Its design comprises afresh of blocks and flows with respect to Figure 2 and 3, comparable to Bitter (2020). He abstracts from, for instance, government purchases, but keeps the interest expense of the government debt. These simplifications are only sufficient to examine a single macroprudential concern (**P2**): the risk of disintermediation, like models in Section 8.1 did. However, unlike they all do, but Chiu et al. (2019), Andolfatto (2020) assumes a non-competitive banking sector, yet without regulatory capital constraints. Hence, banks do not pass CBDC interest rate changes automatically through deposit rates. Since they do not accept profitability reduction, CBDC competition does not disincentivize banks to supply credit. Like models in Section 8.3 and Ferrari et al. (2020), the setup assumes coexistence with cash. However, it goes further to introduce a household heterogeneity: "*only relatively rich workers have access to deposit money, while relatively poor workers are compelled to use cash*". Besides this heterogeneity, households are indifferent to CBDC, deposits and cash, except for costs differences.

Assuming this setup, a CBDC interest rate policy, a reserve rate policy, bank monopoly power and CBDC competition entail the following conditional equilibrium:

a) no discouragement to bank lending, provided that the CBDC interest rate is set independently of the reserve rate, or is set below that;

b) marginal increase in credit and deposits supplies if a regulatory liquidity constraint binds for the monopolistic bank;

c) no demand for cash, without hindering monetary policy, provided that CBDC is made costless (cash has no intrinsic utility as Davoodalhosseini (2018) assumes);

d) no incentive to aggregate runs, but reduced bank monopoly profits, provided that the central bank set its policies to compete against the monopolist.

Andolfatto (2020) concludes that an active and competitive policy making can avoid harming banking functions, even improve them, and a cost wedge on CBDC can avoid harming cash existence. So, on the central bank success lies the answers to core principles **B1** and **B2**. Andolfatto (2020) abstracts monetary policy from his model, hence his results cannot be interpreted as a contraction to Schilling et al. (2020)'s trilemma.

### *9.3. A retail CBDC in an RBC model*

Niepelt (2020b) refines the arguments introduced in Brunnermeier & Niepelt (2019), Niepelt (2020a) and goes beyond Williamson (2019) and Bitter (2020). He addresses one macroeconomic "*do-no-harm*" question, namely "*the difference between bank issued inside and central bank issued outside money*". He models the debate surrounding the Swiss "*Vollgeld*" initiative (Bacchetta, 2018), regardless of alternative instantiations, e.g., segregated funds (Tobin**,** 1985), Chicago Plan (Benes & Kumhof, 2012), CBDC, or more generally his own reserves for all (RFA) proposal. In any of these, the fractional reserve banking system is at least partially replaced as a means to retain the public monetary sovereignty and remove the root cause of financial crisis: aggregate runs. Niepelt (2020b) seeks foremost to demonstrate monetary neutrality: *"when a fiscal-monetary policy implements an 'initial' equilibrium with inside money then an alternative fiscal-monetary policy with more outside money and with transfers implements a 'new' equilibrium with the same allocation and prices and less inside money*." In the proposed new equilibrium, a central bank provides liquidity services to households upon demand, as well as excess liquidity to banks to fund credit provision whenever demand exceeds supply of deposits. Thus, banks retain their intermediation functions, provided that they do not create money "*out of thin air*". In this new market organization, the central bank commands the relationship between depositors and lenders, for holding savings from households and for lending to banks, more often than it must do in "*last resort*". Brunnermeier et al. (2019a) elaborate further on modelling implications to propose that CBDC issuance should substitute for inside money creation[2], reclaiming to public the rents on such operations, favoring capital to lending financing, and avoiding the negative externalities of bank runs. Unlike most surveyed works, commercial banks arguably enjoy no meaningful advantage.

Niepelt (2020b) introduces a real business cycle (RBC) model, with discrete time, finite or infinite horizon, and pseudo-wedges that represent frictions, to support the public and private money neutrality claim. The model setup features the domestic blocks in Figure 2 without fiscal and monetary authority separation. A CBDC also enters in the household utility function. The specification features a policy rule that sets the spread on reserves over policy rate. In equilibrium, this spread should compensate for non-

[2] *Fed's balance sheet would swell from $8trn to $21.5trn if it absorbs $16.8trn in deposits (Economist 2021)*

competitiveness in banking sector and for partial internalization of the benefits of holding reserves. Both distortions create incentives for holding deposits above, and for paying interest rate on deposit below social optimum. Another policy rule sets the level of deposit subsidy. In equilibrium, this subsidy incentivizes banks to correct to the optimal level of liquidity provision.

The optimal coordination of all three policy rules makes feasible for the monopolist fiscal and monetary authority to solve a reduced dilemma between price level and optimal allocation, since aggregate runs are excluded, by market design. The coordination links monetary and macroprudential policies (**P1** and **P2**) and allows for the outcome of the principle **B1** - *do no harm* in the macro level, but at the expenses of policy coordination and a complete overhaul in the micro level.

Under the hypothesis that private and public liquidity exact the same resource costs (in the sense of Friedman, 1969), the model solves for a post CBDC equilibrium with portfolio and balance sheet rearrangements (micro level), but with similar prices and employment levels (macro level), with respect to pre-CBDC equilibrium. The new equilibrium is as follows.

a) Households' balance sheet does not change in size but in composition among deposits, CBDC, and capital.

b) Banks' balance sheet shrinks for holding less reserves while providing same level of credit. Banks lose the rent on issuing liquid liabilities at operating costs. Niepelt (2020b) deems this rent an implicit social subsidy.

c) The central bank lends to banks enough to compensate for b), at interest rates as lower as deposit rates would be without a CBDC. The CBDC seigniorage plus the reduced operating costs of excess reserves shall fund these loans. The central bank balance sheet expands accordingly.

Therefore, the model settles for a *monetary neutrality* where a CBDC and the associated policies warrant a monetary sovereignty, reclaiming in competition with private liquidity services, which are arguably suboptimal. Niepelt (2020b) concedes that the following may invalidate neutrality: limits in transfers, partial substitutability of monies, information differentials, and collateral requirements differentials and central bank refinancing frictions (Gersbach & Böser, 2020).

### *9.4. A retail CBDC in a DSGE model*

Barrdear & Kumhof (2016) assume that a CBDC coexists with a complex banking system and competes with demand deposits, in a standard DSGE model with nominal and real rigidities, including prices and wages stickiness, and nominal contracts. There is no cash (since it is a tiny fraction of broad money), neither reserves, but there are demand deposits. There is an efficient capital accumulation technology for real savings. So, CBDC is "means of payments" rather than "store of value". Like Bitter (2020) replicates, households optimize among bank deposits, investment holdings and CBDC, subject to their budget constraint. Investors dispute two real assets: land and capital. Banks do not hold CBDC in their balance sheet but accept CBDC as collateral. So, CBDC has another utility to households besides consumption.

Banks abide by macroprudential capital regulation, unlike any other surveyed work. Demand deposits are created by banks to fund loans and asset purchases, as in Gross & Siebenbrunner (2019). Demand deposits incur on distortionary markups, because they are created out of costly credit, and that is how banks affect the real economy. Their effects are equivalent to consumption and capital income taxes, therefore, there is some convenience in holding some liquidity in the form of CBDC. In the model, CBCD clears against the difference between income and spending plus the difference between loans and deposits grows, thus its stock fluctuates as the liquidity fluctuates in the economy.

The setup comprehends all, but only, the domestic agents and flows of a closed economy in Figure 2. Likewise, it comprehends all transmission channels in Figure 3, including wealth effects, but foreign exchange passthrough. Barrdear & Kumhof (2016) study the long-run and the cyclical macroeconomic effects in the presence of a CBDC, and how government should implement monetary, macroprudential, and fiscal policies (**P1**-**P3**) alongside a new CBDC policy rule. Such rule can be either an interest rate rule (assuming an interest bearing CBDC) or a quantity rule (assuming otherwise). Both rules are defined endogenously, forward-looking (no smoothing), in terms of nominal economic variables, but allowing for exogeneous policy discretion, akin to target setting.

The economy experiences two liquidity trade-offs:

- *To borrow to create deposits or not*? This entails that borrowing and deposit rates adjust to achieve equilibrium;

- *To hold CBDC instead of bank deposits or not*? This entails that CBDC rate (or supply) adjusts to achieve equilibrium, according to the CBDC policy rule.

The equilibrium for the first tradeoff relies on private agents optimizing behavior, whereas for the second tradeoff relies on the central bank stabilization role. This specification brings central bank to the forefront of liquidity management providing CBDC as a policy instrument rather than only a retail payment one. This empowers the central bank mandate to stabilize financial flows, thereby fostering full employment. Notwithstanding, a new countercyclical instrument requires policy coordination with the usual stabilization policies **P1, P2** and **P3**. Moreover, it requires an issuance sizable enough to contribute to the stabilization of the business cycle.

Barrdear & Kumhof (2016) simulate with an initial CBDC stock equivalent to 30% of US GDP[3]. Further changes to CBDC supply are of countercyclical motivation. No functional economy can absorb such a lump of monetary liquidity[4]. They propose a sterilization mechanism. CBDC is issued only against eligible assets: exchanged on a par with government bonds (Bitter, 2020 assumes more flexible choices). This swap between debt and currency implies transferring stocks from the fiscal to the monetary authority. This expects a new institutional arrangement to address the treat to the usual mandates; the balance sheet risk assumption; and aggregated maturity shortening in the economy.

The initial swap is comparable to a quantitative easing (QE). The subsequent countercyclical supply dynamics are comparable to open-market operations (OMO), but with non-banks. This implementation leads to steady-state output gains as the net result of the following drivers.

a) Negative spreads between CBCD and government bonds for the latter is defaultable, the former is not, by design. The smaller government debt is, the less risky, the cheaper it rolls over, but with diminishing fiscal returns.

b) Larger seigniorage flows from a larger central bank balance sheet. The extra source of fiscal funding is assumed to partially replace distortionary taxes.

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*[3] USA GDP totals $21trn in 2020 Q4 according to* ***Bureau of Economic Analysis***

*[4] For sake of comparison, in Brazil, cash is at 3,8%, reserves is at 6,1%, and government bond in central bank balance sheet is at 18% of GDP at current prices in the end of 2019, while cash is at 3,4% of broad money (M4).*

c) Lower CBDC transactions costs on immediate consumption, assuming that spreads, regulation, imperfect competition, and collateral requirements weight on deposit transactions costs.

d) Higher borrowing spread due to reduced supply of bank deposits, as households switch to CBDC, corroborating the results shown in Section 8.1.

A model simulation results that (c) and (d) compensate for each other, and that the distortionary taxes reductions (b) plus the real equilibrium policy rate decreases in a more stable and less debt-strained economy sum almost 3% of GDP in the long run. This simulation is also informative about the transitory effects. After a large CBDC swap, zero maturity liquidity is excessive, activity heats up, thereby inflation spikes. The structural benefits (a) and (b) will dominate after a few years span.

More interesting than this baseline simulation is the coordinated benefits of an extra countercyclical policy instrument to assure price and output stability. A CBDC policy rule is shown to help smoothing shocks to the credit cycle and to demand for liquidity. The latter shock leads to a flight to safety in which households demand more CBDC. For instance, if the central bank can reduce the spread relative to policy rate (or alternatively, increase the quantity of CBDC) to satisfy this demand, the reduction in real economic activity is less severe, attenuating the decline in spending and therefore in welfare. A CBDC discretionary stimulus in response to an event akin to the great financial crisis (GFC) is also shown to effective match an unconventional monetary policy response by also moving rates away from zero lower bound (ZLB).

The model also provides evidence that a countercyclical CBDC policy most directly affects monetary conditions. Its ability to dampen fundamental fluctuations that originate on the real side is however more limited. The same is shown for consumption demand shocks, investment demand shocks and technology shocks. Furthermore, CBDC policy countercyclical effectiveness is greater the least is the substitutability between CBDC and bank deposits. This complements the search theoretic results in Section 8.3.

This DSGE exercise also provides evidence about the *interest-bearing* core feature (CPMI 2018), mentioned in Section 3. In the response to credit cycle shocks, a CBDC price rule does only slightly better in comparation to a quantity rule. In the response to liquidity demand shocks, the opposite happens under a price or a quantity rule. This reiterates policy trade-offs between financial and fiscal stability, intertemporal trade-offs,

whilst an interdependence of monetary (**P1**) and fiscal policies (**P3**) increases in the presence of a CBDC.

The CBDC policy design is challenging also for the lack of precedent and empirical evidence. Barrdear & Kumhof (2016) suggest then to "*be preferable to initially issue CBDC under a quantity rule in order to let the market establish a reasonable range for CBDC interest rates. After an appropriate period of time, policy could then switch, if desired, to a price rule that could take these lessons into account*."

This didactic exercise underscores the relevance of a well design policy rule to operate liquidity through a CBDC. Without one, a central bank has to overreach its usual policies to encompass CBDC supply management. In turn, an extra mandate with the same toolset compromises the "*do no harm*" principle in BIS (2020b). So, a more comprehensive setup supports the same conclusions repeated later in Agur et al. (2019) and Bitter (2020).

George et al. (2020) extended the model in Barrdear & Kumhof (2016) to a small open economy (SOE). Their simulations corroborate the aforesaid findings:

- a CBDC with an adjustable interest rate (price rule) is welfare-improving, with respect to the welfare function given by *Schmitt-Grohé & Uribe (2007)*;
- a quantity rule delivers the best welfare outcome for society, but with uneven distributional effects between households and financial investors;
- an imperfect substitutability between CBDC and bank deposits is key for the effectiveness of CBDC policy as an ancillary monetary policy instrument.

A countercyclical CBDC policy rule also aids financial stability, especially if credit provision remains within the purview of the existing intermediaries, while only partially removes *too-big-to-fail* concerns. So, a CBDC rule complements (**P1**) and (**P3**) and influences in the macroprudential policy (**P2**). Barrdear & Kumhof (2016) discuss bank runs into CBDC**,** but they do not debate fiscal runs into CBDC. Like Bitter (2020), they argue that the likelihood of a bank run is more evident in partial equilibrium models, without asset side checks and balances. Notwithstanding, they concede hard limitations to the countercyclical framework at extremes:

- Negative CBDC interest rates are politically undesirable (monetary policy issue);
- Scarcity of eligible assets (a similar QE implementation issue);

- Unwillingness to accept deposits against CBDC collateral (a regulatory and interoperability issue).

In short, Barrdear & Kumhof (2016) provide comforting evidence about the "coexistence" and "innovation and efficiency" principles (**B2-B3**), but with caveats. There are two approaches to design a CBDC to mitigate these caveats. One is to impose regulatory constraints, like Kumhof & Noone (2018) suggest. The other is to reinforce central bank stabilizing role, like Niepelt (2020b) supports.

Kumhof & Noone (2018) propose four conditions that may mitigate macroprudential concerns, in particular, unintended balance sheet implications:

a) CBDC pays an adjustable interest rate (CBDC price policy);

b) CBDC and reserves are distinct, and not convertible into each other;

c) commercial banks offer no guaranteed, on-demand convertibility of deposits into CBDC (nor does the central bank);

d) the central bank issues CBDC only against eligible securities.

Kumhof & Noone (2018) experiment with the three variations of the model in Barrdear & Kumhof (2016) to evidence support for these four conditions. In fact, conditions (a) and (d) were already explored there, and in Bitter (2020). These three variations can be associated with different access design features (BIS 2020b):

- Access through banks and narrow banks corresponds to synthetic CBDC by Adrian & Mancini-Griffoli (2019) or to indirect CBDC architecture by Auer & Böhme (2020);
- Universal access corresponds to a hybrid *CBDC* architecture by Auer & Böhme (2020);
- Access only to financial institutions corresponds to a wholesale CBDC.

Kumhof & Noone (2018) propose a secondary private market, i.e., where "*households and firms can freely trade bank deposits against CBDC, and that the private market can freely obtain additional CBDC from the central bank, at the posted CBDC interest rate, and against eligible securities*". This novel financial market infrastructure (FMI) advances on core principle **B2**, although, it turns a retail CBDC closer to a "security", further from a "currency". In addition to legal challenges, this exposes another trade-off:

the more a CBDC suits financial markets, the more it substitutes for public and private debt instruments. Moreover, the less it may suit real markets, hence the less it may foster financial inclusion goals.

A run on a single bank is more likely because of the presence of CBDC "*reduces to zero the search cost of finding a low risk (or indeed risk-free) provider of liquid assets that can, unlike cash, be held at large volume at low cost*". Moreover, a run could unroll at higher speed and larger volume, both during normal and market stress times. However, Engert & Fung (2017) conjecture that banks may respond *ex ante* to the presence of CBDC and the credibility threat of a run by reducing their risk taking or holding higher capital buffers. Kumhof & Noone (2018), anticipating Keister & Monnet (2020), claim that depositors in an individual troubled institution can be repaid in safe CBDC early on. Thus, the targeted overruling of condition (c) is a central bank discretionary policy to facilitate resolution, thereby lowering contagion risks. The same hindrance is later exposed in the CBDC trilemma postulated by Schilling et al. (2020).

Aggregate runs that reduce the absolute volume of deposits during confidence crisis can only succeed through asset-side adjustments of banks. Under CBDC price rule, any nascent increase in CBDC demand can be eliminated by a drop in CBDC interest rate. Keister & Monnet (2020) revisit a similar argument. The interest rate on bank deposits relative to the policy rate and to the CBDC interest rate can also adjust if a flight to CBDC safety depletes bank deposits. Because deposit interest rate constitutes the marginal cost of funding, competitive banks may pass this increase on to borrowers by charging higher lending rates, dissuading the demand for credit. The resulting credit cycle shock may spiral downwards. This is the most recurrent threat in the CBDC literature. However, this is exactly what the countercyclical CBDC policy Barrdear & Kumhof (2016) designed to smooth.

This framework cannot rule out extreme cases when CBDC price policy reaches potential limits: highly negative, politically unsustainable interest rates or critical scarcity of eligible securities. Then the deposit-CBDC parity might break. There are historical precedents for equally extreme actions: convertibility curtailing, capital controls, and bank nationalizations. However dire, Kumhof & Noone (2018) also claim that those bad equilibria seem less likely than partial equilibrium models hint at. In short, core principle **B3** can be reconciled with **B1**, provided that proper regulatory constraints uphold.

While Barrdear & Kumhof (2016) briefly hint that a CBDC policy can work as an

unconventional monetary policy tool, two other modelling works narrow the focus to the zero-lower bound (ZLB) problem: Guardado (2019) and Gross & Schiller (2020). Each proposes adaptations to include CBDC into the New Keynesian framework by Gertler & Karadi (2011). Hence, both setups include the domestic agents and flows in Figure 2, but a unique fiscal and monetary authority. The optimization problems are simpler since the number of contracts and investment technologies is smaller and the prudential framework is likewise simplified.

Guardado (2019) addresses the monetary policy concern (P1). Her experiments show that the introduction of an interest bearing CBDC, while providing the policy maker an additional tool for monetary policy, it may help overcoming the obstacles related to the passthrough of negative interest rates, turning monetary policy more effective at extreme depressive outlooks. Furthermore, she argues that *a CBDC rate might not lead to reliable and expected results from the point of view counter-cyclical policy, due to wealth effects*. Such caveat was not examined in Barrdear & Kumhof (2016).

Gross & Schiller (2020) address macroprudential issues (**P2**). They study the impact of CBDC on bank funding during a ZLB regime. They choose money-in-the-utility-function specification, inspired by Sidrauski (1967), as were Barrdear & Kumhof (2016). However, they assume a set of three looser hypotheses about substitutability. CBDC interest rate, policy rate and government bonds rate follow a strictly increasing order of nominal remuneration. CBDC and bank deposits are perfect substitutes. CBDC and government bonds are riskless. Moreover, their model design induces a household preference for CBDC relative to bank deposits in distressing times. With that, they show that the central bank can react to a crisis, stimulate the economy, only if it can set a negative CBDC interest rate. Thus, they argue that CBDC price policy can be an effective monetary tool (**P1**).

Surveyed experiments show that banks call on their LOLR when struggle with a decreasing supply of deposits. The central bank can choose to fully compensate inasmuch as a drop in deposits only implies "*a shift in composition of bank funding, but no contraction of banks' balance sheets*". The central bank can choose instead to reduce the CBDC interest rate to disincentivize monetization. This decision lowers the demand for CBDC, while it may not incentivize the holding of substantially more deposits. Thus, the CBDC coexistence may reduce aggregate deposits, an interest-bearing one may reduce

more, and a central bank that endogenously commits to its LOLR role may reduce even more. Therefore, CBDC price policy is less effective as a macroprudential tool (**P2**) as it may be as an ancillary, monetary policy tool (**P1**). These observations corroborate the model theoretical findings in Niepelt (2020b) with a worrying twist: CBDC policy alone may not offset financial stability risks. Hence, substitutability, convertibility, and issuer credible commitments are also required, as Kumhof & Noone (2018) argue.

Piazzesi et al. (2019) present a NK DSGE model with nominal rigidities and a banking system. Like simpler models with respect to the view in Figure 2, it specifies a single, central monetary and fiscal authority and domestic agents and flows. Unlike simpler models, the central authority may provide liquidity to banks (reserves) and households (CBDC). It decides on the interest rate on its liquidity services (**P1**), it also controls the liquidity supply (as "nominal anchor"), and it adjusts lump taxes to satisfy budget constraint (**P3**). Hence monetary policy has a direct and indirect transmission, since the central authority targets the interest rate on short safe bonds that are held by banks to back inside money. Households buy some of these bonds and hence pay a convenience yield to banks for their safety or liquidity. This convenience yield distorts the asset pricing channel in Figure 3 and represents a disconnection that hinders the monetary policy passthrough. Households mix both liquidity services, since CBDC as outside money can be rationed while inside money is not. The setup implies that the structure of the banking system, bank liquidity management, and central authority operating procedures matter for the transmission of policy. Comparing the baseline model with CBDC to a counterfactual without CBDC demonstrates such operational relevance. Moreover, it drafts monetary implications of the CBDC by contrast to existing banking systems. This aspect has not been explored yet in the literature and these issues provide a pragmatical complement to Kumhof & Noone (2018).

In a floor system, when reserves are abundant, a central authority controls the reserve rate and the reserve supply. The interest rate policy is weaker, but the quantity of reserves can serve as an independent policy instrument. The short rate disconnect further implies that policy need not respond aggressively to inflation, without inviting self-fulfilling fluctuations. In a corridor system, when reserves are scarce, central authority sets reserve rate but targets interbank rate. The supply of reserves adjusts to achieve target rate. Banks must manage liquidity differently since they face liquidity shocks and leverage constraints that limit overnight borrowing. Then, reserves are more useful for handling

liquidity shocks than other assets. Interest rate policy is more powerful in a corridor system because its rate level directly influences banks' cost of liquidity. As liquidity management becomes more costly, banks lower the supply of inside money which increases households' cost of liquidity. Piazzesi et al. (2019) show that the difference can be quantitatively relevant, especially when the model allows for a simple "cost channel" – inside money and consumption are separable complements in households' utility.

All models display the same basic transmission mechanism. The responses in the model with CBDC are closer to the model with a corridor system. Provided that CBDC supply is also rationed by coordinated policy, no harm might be done (**B1**). Features like nominal rigidities in bank balance sheets, bank market power, liquidity management strategies and elasticity of deposit supply explain the response heterogeneity.

Piazzesi & Schneider's (2020) follow-up work uses the same setup to emphasize macroprudential policy (**P2**) implications instead. They conclude that "*if the central bank offers CBDC but not credit lines, then it interferes with current payments technology that exploits complementarities between deposit taking and credit lines. As a result, increasing CBDC may reduce welfare even if the central bank can provide deposits more cheaply than commercial banks.*" Their skeptical assessment disputes core principle (**B2**).

### *9.5. A retail CBDC in a DSGE model for a Small Open Economy*

Modelling exercises so far specify closed economies. The DSGE model in George et al. (2020) simplifies the one in Barrdear & Kumhof (2016) and accommodates the following interactions between the domestic and world economies, thereby allowing for CBDC policies and foreign exchange policies (**P4**) to interact:

- *trade and capital accounts*, i.e., firms import intermediate capital goods as production inputs and export final consumption goods to the world;
- *financial accounts*, i.e., financial investors borrow from the world by issuing foreign-currency denominated bonds (foreign debt) and pay prevailing interests.

An uncovered interest parity condition (UIP) connects domestic and foreign interest rates. This setup completes the stylized economy depicted in Figure 2 and transmission channels in Figure 3, but groups heterogeneities in the firms and in the financial agents. It also abstracts monetary and fiscal authorities into a unique government agency that coordinates fiscal, monetary and CBDC policies to achieve its countercyclical objectives.

In the model, a foreign exchange rate shock passes through to prices, to the CBDC interest rate, to the deposit rates, and then to the bank deposit rates. Through this transmission mechanism the shock affects the CBDC supply and the loan stocks.

George et al. (2020) confirm that an imperfect substitutability between CBDC and deposits improves the effectiveness of applying CBDC as a secondary policy instrument. They provide uneven evidence of welfare gains, which shift either to households, in a CBDC quantity rule regime, or to financial investors, in a CBDC price rule regime. Moreover, the two regimes entail similar responses of nominal variables (e.g., exchange rate, and risk premium) to a hypothetical foreign interest rate shock. However, the two regimes entail distinct responses to an export demand shock. For both shocks, policy, deposit and CBDC rates fluctuate differently. Volatility is always smaller if the CBDC price policy is active.

Ferrari et al. (2020) accommodate a CBDC in the two-country DSGE model from Eichenbaum et al. (2017) to analyze international transmissions. On the internal perspective, George et al. (2020) investigate idiosyncratic responses in a country that has issued a CBDC and interacts with world economies. Hence, they stress the contribution of CBDC to the absorption of external shocks. On the cross-border perspective, Ferrari et al. (2020) investigate idiosyncratic responses in a country that interacts with another, which, in turn, has issued a CBDC. Hence, they stress the contribution of CBDC to the propagation of shocks onto foreign countries, i.e., spillovers. We can form a two-sided view if we understand both.

The DSGE setup in Ferrari et al. (2020) includes usual blocks twice, for domestic and for foreign countries, instead of one rest-of-the-world block as in Figure 2. Country models are simpler and calibrated according to Eichenbaum et al. (2017). The CBDC is issued only in the home economy but it can be purchased in both, conditional on policy restrictions that home government may enforce onto foreigner households. The model assumes price stickiness, incomplete financial markets, and imperfect UIP due to the cost friction of holding foreign asset (bond or CBDC). The main transmission channel in Figure 3 is modeled. The model departs from Eichenbaum et al. (2017) where households have utility for cash and for CBDC. CBDC design features include interest-bearing and caps on foreign holdings.

Model exercises explore calibrations where the CBDC is closer to cash, to deposits or to a combination of the two, in terms of relaxing liquidity constraints, in the spirit of

Agur et al. (2019). Ferrari et al. (2020) extend the analysis to situations where the CBDC circulates not only at home but also abroad to investigate:

- the international transmission of standard monetary policy and technology shocks in the presence and absence of a CBDC with alternative design features;
- the optimal monetary policy in the two economies and compare household welfare in the presence and absence of a CBDC with alternative design features.

The main mechanism in the presence of a CBDC is a cross-currency asset pricing relationship which defines the policy rate in the foreign economy as a mark-up on the remuneration of the domestic CBDC, in the spirit of the currency competition in Benigno et al. (2019). In fact, Benigno et al. (2019) conjecture further that a global cryptocurrency may create sufficient arbitrage to justify a monetary policy synchronization between countries. This mechanism captures the arbitrage conditions implied by foreigners flying to domestic CBDC safety in cases of relative disequilibrium between countries. Model simulations show that this mechanism manifests itself as:

a) larger exchange rate movements and large capital flow volatility due to overshooting after a shock;

b) the policy rate in the foreign economy moves more strongly, and in opposite direction to exchange rate as a sole defensive response (without macroprudential capital controls or foreign reserve cushion interventions);

c) the rise of the policy rate should lead to tighter financial conditions in the foreign country, with adverse consequences on consumption and investment.

In short, the presence of a CBDC may amplify foreign spillovers, thereby increase international linkages. Simulations show that a flexible CBDC interest rate and limits on foreign holdings can dampen such "harm" exporting (**B1**). Therefore, the domestic issuance of a CBDC increases asymmetries in the international monetary system by reducing monetary policy autonomy in foreign economies. Results may differ if both countries issue their CBDCs or if home country narrows the guarantees to non-citizens.

### *9.6. An overview of economy wide macroeconomic models*

Although Bitter (2020) argues that partial equilibrium models tend to overestimate the likelihood of aggregate runs, general equilibrium models still attribute sound financial stability to either stringent design constraint, e.g., Kumhof & Noone (2018), or central

bank intervening more strongly and more often, e.g., Niepelt (2020b). Nevertheless, the works surveyed in Section 9 provide richer information about macroeconomic policies. In particular, these classes of models allow for discussing the implications of a CBDC to fiscal and foreign exchange policies (P1-P4) whilst those classes in Section 8 cannot.

We insert in Table 1 the works reviewed in Section 9 to complete Table 2.

**Table 2**: Adding the summary of the surveyed literature in Section 9

| research work | Affili-ation [1] | Survey Cat.[2] | Policies P1 | P2 | P3 | P4 | Core principles B1 | B2 | B3 | CBDC stance[3] | main research contribution |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Schilling et al. (2020)** | AC | **PE1** | ✓ | ✓ | | | ✗ | ✗ | | cautionary | Trilemma: price stability, financial stability, and efficiency |
| Fernández–Villaverde et al. (2020) | AC | **PE1** | | ✓ | | | ✗ | ✗ | | cautionary | Monetary neutrality is voided in large distresses |
| Keister & Monnet (2020) | AC | **PE1** | | ✓ | | | ✗ | ✓ | | persuasive | Information revealing mechanism about banks |
| Skeie (2019) | AC | **PE1** | | ✓ | | | ✗ | ✓ | ✓ | cautionary | Digital currency runs harms allocation of maturity and risk |
| Böser & Gersbach (2020) | AC | **PE1** | | ✓ | | | | ✗ | | cautionary | Refinancing friction incentivizes substituting deposits |
| **Agur et al. (2019)** | IMF | **PE2** | | ✓ | | | ✗ | ✗ | | neutral | Policy action should counter the loss of utility with CBDC |
| Berentsen (1998) | AC | **PE2** | ✓ | | | | | ✗ | | neutral | Network effects are relevant to the demand for monies |
| **Keister & Sanches (2019)** | CB | **PE3** | ✓ | ✓ | | | ✗ | ✗ | ✓ | neutral | CBDC features can dislocate the policy equilibria |
| Chiu et al. (2019) | CB | **PE3** | | ✓ | | | | ✗ | | persuasive | Coexistence disciplines noncompetitive banks |
| Davoodalhosseini (2018) | CB | **PE3** | ✓ | | | | ✗ | | | cautionary | Interest-bearing can sort the networks effect tradeoffs |
| Williamson (2019) | AC | **PE3** | | ✓ | ✓ | | ✗ | ✗ | | persuasive | CB manages liquidity better for banks react to adverse incentives |
| Benigno (2019)* | AC | **PEX** | ✓ | | | | | | ✓ | NA | Competition disciplines policy and improves money |
| Benigno et al. (2019)* | AC | **PEX** | ✓ | | | | | | ✓ | NA | Competition disciplines policy and improves money |
| Fernández–Villaverde & Sanches (2018)* | AC | **PEX** | | ✓ | | | | | ✓ | NA | Private arrangements can be efficient and stable under free entry |
| Gross & Siebenbrunner (2019) | AC | **PEX** | ✓ | | | | | | | NA | Monetary policy's bearing will not be reduced in cashlessness |
| Zhu & Hendry (2017)* | CB | **PEX** | ✓ | | | | ✗ | | ✓ | NA | Private currencies prevent monetary policy optimality |
| **Niepelt (2020a)** | AC | **GE1** | ✓ | ✓ | ✓ | | ✗ | ✗ | | persuasive | Monetary neutrality is valid provided that the LOLR acts |
| Brunnermeier & Niepelt (2019) | AC | **GE1** | ✓ | ✓ | | | ✗ | ✗ | | persuasive | Monetary neutrality is valid provided that the LOLR acts |
| Brunnermeier et al. (2019) | AC | **GE1** | ✓ | ✓ | | | ✗ | ✗ | | persuasive | CBDC can and should reclaim public monetary sovereignty |
| **Barrdear & Kumhof (2016)** | CB | **GE2** | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | neutral | CBDC can be an additional countercyclical tool |
| Bitter (2020) | AC | **GE2** | | ✓ | | | ✗ | ✓ | | persuasive | Asset balance sheet side must sterilize a CBDC issuance |
| George et al. (2020) | AC | **GE2** | | ✓ | | ✓ | ✗ | ✓ | | cautionary | CBDC policies mitigate volatilities in response to foreign shocks |
| Groß & Schiller (2020) | AC | **GE2** | ✓ | ✓ | | | ✓ | | | cautionary | CBDC policy alone may not offset financial stability risks |
| Guardado (2019)** | AC | **GE2** | ✓ | | | | ✓ | | | persuasive | CBDC can be a tool to circumvent ZLB |
| Kumhof & Noone (2018) | CB | **GE2** | | ✓ | | | | ✓ | ✓ | neutral | Suitable regulation can mitigate macroprudential CBDC externalities |
| Piazzesi & Schneider (2020) | AC | **GE2** | | ✓ | | | | ✗ | | cautionary | CBDC interferes with payments, deposit, and credit complementarities |
| Piazzesi et al. (2019) | AC | **GE2** | ✓ | | ✓ | | ✗ | | | cautionary | CBDC has operational relevance to monetary policy implementation |
| Andolfatto (2020) | CB | **GES1** | | ✓ | | | ✗ | ✓ | | persuasive | CBDC competition with monopolistic banks improves on equilibrium |
| Ferrari et al. (2020) | CB | **GES2** | | ✓ | | ✓ | ✗ | | | persuasive | CBDC can magnify shock spillovers to a foreign economy |

[#] Excluded from the core principles analysis because they do not study CBDCs

Policies: P1. Monetary; P2. Macroprudential; P3. Fiscal; P4. Foreign exchange. BIS (2020b) Core Principles: B1. "Do no harm"; B2. Coexistence; B3. Innovation and efficiency.

[1] AC=Academic Institution; CB=Central Bank; IMF=Int. Monetary Fund

[2] Author's classification proposed in Section 7, GE=General Equilibrium, PE=Partial Equilibrium

[3] Author's assessment of net balance of benefits and risks

Overall, most of surveyed works warn about the breach of principles **B1** and **B2**. A CBDC may entail policy adjustments and may induce financial market reorganizations, yet some interpret change as either forthcoming or "creative destruction." Some welcome an emboldened central bank. Thus, breach results should not be interpreted as halt signals. Instead, they underpin a nuanced interpretation of the core principles. An "x" mark for **B1** may only denote that a CBDC policy must be managed and coordinated with other P1-P4 policies. The central bank mandate become more complex and sophisticated rather than unattainable. An "x" mark for **B2** may mean only a potential market reorganization with material portfolio reallocations. Thus, questions like "how much '*harm*' is acceptable, or even desirable?" and "How much intense should '*coexistence*' be?" is a matter of policy decision and discretion, as we anticipated in Section 4.

Not only in the research literature, but also in the policy speech, favorable and contrarian arguments are usually floated in absolute terms. Instead, those should be made relative to the standpoint of different economic agents. An opportunity for one economic

agent might be a threat to another. Each representative agent may size strength and weaknesses differently. We contribute to disentangle claims and show how nuanced they are in Appendix 2. We assign claims to economic agents and we mark them according to the supported found in the combined set of research. Thus, the Appendix 2 is a contextual framing that accompanies Table 2.

# 10. What the synergy between models have informed about economics of a CBDC and have not yet

From evidence we comment in Sections 8 and 9, in special, from conclusions we summarize in Sections 8.4 and 10.6, we can outline a cogent view of an economy with a CBDC. Thereon, we will discuss in Section 10.1 some opportunities and challenges uncovered and we will sketch in Section 10.2 the remaining uncertainty about crucial issues. In essence, the literature offers necessary, but insufficient policy advice.

### *10.1. The knowns: determinants and deterrents*

The prevalent conclusion from this survey is that a CBDC implies economic trade-offs. Furthermore, acceptable equilibria cannot be predicated solely on its design features nor can they be self-fulfilling because they depend on dynamic policy coordination with a defined target for the benefit-risk balance. Ultimately, they depend on the issuers' ability and credibility as much. Hence, outcomes become specific to jurisdictions as are issuers.

Since the economy deviates from steady state, so will do the demand for a CBDC, with respect to the economic cycle (Barrdear & Kumhof, 2016), to shock responses (Schilling et al. 2020) and to competition with other alternatives (Keister & Sanches, 2019). The dynamic adjustment becomes an additional implementation issue. Almost all surveyed works assume a corresponding policy to stabilize issuance. It is meant to avoid overburdening the other stablished policies or blurring their communication and goals.

The main economic benefits of a CBDC stem from a more direct management of liquidity allocation in dispersion and in timing. Benefits can be larger when it contributes to discipline noncompetitive private markets (Chiu et al. 2019 and Andolfatto, 2020). Those can be larger when CBDC liquidity functions implement a countercyclical tool (Barrdear & Kumhof, 2016). The main economic risks of a CBDC stem from less efficient maturity and risk transformation due to competition with specialized intermediaries (Schilling et al. 2020 and Keister & Sanches 2019). Risks can be larger when its issuance

distorts the aggregate maturity and aggregated volume of liquidity. Some view risk as opportunity for central bank to steer macro and micro behavior (Niepelt, 2020).

Almost all modelling, notably Niepelt (2020b) and Barrdear & Kumhof (2016), strengthens the central bank protagonism in order to assure the sound working of an economy with a CBDC. None proposes a new central bank function, but most enhances the traditional ones. For instance, Barrdear & Kumhof (2016) proposal can be understood as "open market operations" with all, in contrast to Niepelt's (2020b) "reserves for all". In the former, the central bank provides liquidity vis-a-vis cash-in-advance friction (Lucas & Stokey 1987). In the latter, the central bank acts as lender of last resort. If asked, it subsidizes losses in bank funding from cost it saves due to less reserve management. Again, it provides sufficient liquidity to transactional needs and to keep maturity and risk transformation at adequate levels (Brunnermeier & Niepelt, 2019).

Modelling exercises show that the economic benefits of a CBDC are proportional to the issuance size (its supply), so are the risks. Most assume that CBDC supply will satiate its endogenous demand, in the sense of Friedman's (1969) efficiency, notably Schilling et al. (2020), Niepelt (2020b) and Barrdear & Kumhof (2016), but Ferrari et al. (2020). Moreover, floating volume makes the central bank mandates more sensitive to optimal policy coordination (**P1**-**P4**). Other exercises explore extreme scenarios, i.e., the targeted replacement of either cash or deposits, driven by a design for substitutability, for example in Keister & Sanches (2019) and Agur et al. (2019).

On the one hand, negative or conditional conclusions about likely harm and unlikely coexistence potential dominate in Table 2. On the other hand, policy makers seem to have settled for some moderation, embodied recently in the core principles **B1**-**B3** (BIS 2020b), to promote a "harmless" approach. In spite of this contrast, the literature also provides working insights about feasibility. For instance, a CBDC could be designed to mitigate structural disintermediation and aggregate (digital) runs under the following conditions.

- Kumhof & Noone (2018) suggest restricting on-demand convertibility between bank deposits and CBDC, thereby making substitutability less perfect.
- Bindseil (2020) reinforces Barrdear & Kumhof (2016) price rule policy and argues for a two-tiered interest rate system that disincentives holding CBDC as a store of value, thereby making substitutability less perfect.

There is a third pragmatical, yet uncharted way in the modelling exercises. Panetta (2018) proposes a limit on the amount of CBDC a single user can hold. Similar view is subscribed by Carstens (2021) when proposes a limited systemic footprint. Now the rationality is different. Besides making substitutability less perfect, because bank deposits have no limits and large insured limits, this cautious and mindful proposal pegs the risk in proportion to the supply volume (or to commitment).

A retail CBDC with transactional or holding caps will diminish both economic benefits and risks, perhaps network effects and systemic relevance, but may deliver on some intangible public policies like those listed in Section 3 or those listed in BIS (2020b). None of the surveyed models have yet simulated constrained schemes. None have simulated central bank currency supply rationing. There are methodological challenges. Limits and caps create asymmetries, discontinuities and raise questions about the endogeneity. There is no data for their empirical estimation and no precedent for their parameter calibration. Hence, model inference becomes prone to arbitrariness.

In a concise statement, the exercises jointly single out two major concerns about a retail CBDC: the central bank's commitment to endogenously match supply to demand by quantity or by price policies; the semi-elasticities of substitution between CBDC with respect to other competing liquidity services. Both shall not be static. Both derive from design (Auer & Böhme, 2020), from policy execution, from issuer credibility, at least.

### *10.2. The unknowns: determinants and deterrents*

The surveyed models have shed light on relevant questions about an economy with a competitive CBDC, but they have not exhausted them yet. We select a set of questions that we would like to be studied in future modelling exercises.

#### 10.2.1. About the Issuer

Irrespective to the chosen scheme, model-based conclusions converge into a central bank with enhanced powers and enhanced responsibilities to directly manage a diverse liquidity composition, perhaps a whopping liquidity pool.

The corresponding CBDC policy interacts with all other four, so policy coordination may be challenging, particularly with volatility and distress. All exercises assume the CBDC policy to follow commitment and not to smooth. Actually, the stablished policies are executed following discretion and smoothing their prescribed decision in low frequency intervals (Dixit & Lambertini, 2003 and Dennis, 2005). It remains unanswered,

firstly, whether the CBDC policy should be conducted differently (MC 2017); secondly, if so, how that would void the computed optimality and neutrality results.

Central banks will more often be the lender of last resort to financial intermediaries to compensate for funding shortages. Besides attracting criticism to a financial system dependency (El-Erian, 2016), the central bank contracts must then be designed to reveal moral hazard issues and to anticipate expectation deviations that might foil policy mandates, particularly where institutional arrangements are deemed less robust.

Furthermore, the financial system is a relevant creditor to fiscal debt, both for portfolio allocation and for macroprudential capital requirement. The CBDC creates a new risk-free asset and collateral. The surveyed exercises warn about competition with demand deposits, but not with government debt. In fact, most models, but Barrdear & Kumhof (2016), abstract the separation between monetary and fiscal authorities. Such abstraction disregards the competition between government and central bank to provide risk-free reference and to supply collateral, as well as it disregards the effects of money supply stimuli (Galí, 2020). Without effective regulation, this leads to fiscal entanglement at best (Schmitt-Grohé & Uribe, 2007); to a balance sheet overhaul for economic agents; to asset mispricing; or to temporary "fiscal run" at worst. All these risks have precedents and have shown material consequences. Quick regulatory fixes may only enhance fiscal repression as intermediaries may be forced to combine a suboptimal portfolio (Reinhart, 2011). Anyway, those implications have not been explored beyond the sterilization scheme proposed by Kumhof & Noone (2018). More studies are needed.

Recent results by Reis (2020) add to the monetary and fiscal tradeoffs. By pursing the core principle B3 – innovation and efficiency, central banks disincentivize the holding of government debt. The more financially developed an economy is, the less lenders choose to invest in inferior capital stock. Rather, if there is enough good private credit, they prefer to lend their funds to entrepreneurs, earning returns in the superior technology. Hence, less appetite for "safer" governments bonds and for fiscal debt financing. On opposite direction the central bank larger footprint may require fiscal support (Del Negro and Sims, 2015).

Therefore, the central bank legal mandate to issue a CBDC (Bossu et al. 2020) must be robust and must sharpen the independence with respect to treasury.

### 10.2.2. About households and firms

Keynes referred to "*certain habits of business and banking*". None of the models captured such adoption friction but assumed elastic adjustments in the presence of CBDC. This may not be realistic. Habits may postpone eventual inclusion benefits and sufficient network effects. Habits may protract the anticipation of technological shocks (the introduction of an efficient CBDC). Habits differ by income, education, demographics and geographics. One size fits all designs may undesignedly widen inequalities.

Widely publicized initiative on CBDC (as compiled in Auer et al. 2020) instills ex ante market adjustments of the spirit in Schmitt-Grohé & Uribe (2012). So, central banks should already map implications of CBDC in market organization and financial flows years before CBDC were to be issued. Moreover, model exercises that compute only equilibrium conditions inform little about the dynamics during a CBDC introduction. Again, Barrdear & Kumhof (2016) are an exception by warning about an initial inflation overshoot. However, they elicit only the effects of a large swap of CBDC and government debt. More gradual path dynamic should also be simulated accounting for the tension between habit and anticipation.

Davoodalhosseini (2018) conjectures that CBDC might be socially costlier than cash. Although disputed, this claim hints at two tradeoffs that ought to be better assessed: how much households value anonymity (Garratt & van Oordt, 2020); how much households would react to an adverse CBDC policy. Underpricing a CBDC can distort preferences, thereby substitutability. CBDC real value can be neither static nor universal. On par convertibility with cash regardless of utility differentials can be interpreted as an opaque subsidy. Supply rationing can be interpreted as a distortionary transaction tax that may trigger Ricardian behavior and compromise fiduciary credibility.

Keister & Sanches (2019) and others assume that a CBDC can fit within the substitutability interval limited by cash and demand deposits. The closer CBDC fits to the either limit, the more it substitutes for. Hence, to provide both as alternative services would be less cost-efficient, but both might comprise a more resilient payments infrastructure through redundancy. Davoodalhosseini (2018) showed that CBDC may fully replace any other if it perfectly substitutes and if CBDC is sufficiently supplied. However, no study has yet investigated what would happen if there were a menu of public and private alternative means of payments, nor how would pairwise elasticities of

substitution equilibrate supply and demand of each. This begs also for studies to estimate frictions resulting from the mismatch between retail and wholesale payments.

Most modelling exercises assume representational agent and reason on aggregate responses. Carapella & Flemming (2020) rightly argue for modelling heterogeneous agents (Kaplan et al. 2019). At most, Williamson (2019) introduces binary preference heterogeneity; Andolfatto (2020) introduces consumer income heterogeneity, while Chiu et al. (2020) and Keister & Sanches (2019) assume final goods producer heterogeneity. George et al. (2020) also show that CBDC policy distributes welfare unevenly. Nevertheless, all of them oversimplify heterogeneous, dynamic responses that may determine the targeting and the timing success and may warrant the accomplishment of the core principles. However, they offer rather aggregate welfare estimations. Furthermore, none explores the distribution of impacts in a heterogeneous financial sector. However, the distribution, not only the aggregate impact, matters for economic output, as Berger & Sedunov (2017) show.

#### 10.2.3. About the aggregate economy

The modelling exercises assume some level of aggregate monetization. If CBDC design grants some (pseudo-) anonymity then the economy will face unintended textbook externalities (Mishkin, 2014). More worryingly, this may lead to some short-termism that enhance welfare by stimulating exchange and consumption. Such movement may suit advanced, yet stagnant economies, with abundant, cheap liquidity (through QE and CE) and fewer long-term projects that need maturity transformation. An emerging, developing economy needs more fractional transformation out of deposits. Hence, that begs for studies to estimate the suitable level of aggregate monetization with respect to country heterogeneity. US economy calibrations warrant no global assessment.

An exuberant level of risk-free liquidity may distort assets pricing with known consequences. This may also structurally lower neutral interest rate, thereby reducing policy space. Subdued policy increases risk aversion and precautionary savings. Thus, a CBDC touted to be an innovative means of payment may become an idle store of value instead, replicating what seems to be happening in the cryptoasset ecosystem.

#### 10.2.4. About the interaction across jurisdictions

Only Ferrari et al. (2020) and George et al. (2020) address CBDC in the context of national relationships. Ferrari et al. (2020) leave three open questions. If both domestic

and foreign countries have issued CBDC, would its specific policy help mitigate a foreign shock (despite coordination challenges)? Would a CBDC suffice to revert the logic of spillover direction (from larger to small open economy)? Would CBDC disincentivize currency competition but rather incentivize a multi-CBDC arrangement, like Auer et. al (2021) propose? George et al. (2020) may favor a promising answer for the first only.

These two works abstract country idiosyncrasies. There are tradeoffs between fitting a CBDC to jurisdiction needs (and weaknesses) and participating in a global interoperable arrangement designed to favor cross-border efficiency (Auer et al. 2021). Like we state about fiscal policy (P3), we lack studies about foreign exchange policies (P4) in the presence of CBDCs.

#### 10.2.5. About technicalities

All surveyed models rely on calibration. There is no empirical data to have them estimated, especially elasticities of substitution. Calibration cannot be expected to be constant overtime. By principle, the very CBDC is meant to change habit, labor disutility and discount factors parameters, at least. Therefore, much remains unknown about the path dynamics of a CBDC, consequently about the central bank effort to stabilize and coordinate along the time. Under ignorance, volatility shall lead to suboptimal, welfare decreasing states, even though steady state implies a favorable balance.

## 11. Conclusions and final considerations

We have analyzed twenty-nine economic modelling exercises that incorporate digital currencies in Sections 8 and 9. We have used the framework in Section 6 to contrast them. Despite being substantively informative, taking this body of research as a body of evidence, we cannot but conclude that such evidence is not compelling yet, either towards CBDC issuance being beneficial or towards the precise targets and timing of that issuance. Research has not yet cohered into a comprehensive understanding of the economics of CBDCs, because essential questions remain unaddressed, for example, those in Section 10.2. The research task is, therefore, incomplete and must focus on addressing gaps in current knowledge, ideally aligning itself with the declared intentions by policy makers insofar as the analysis reported in Appendix 1 suggests a degree of decoupling between what they aim at delivering with and what researchers aim at explaining.

More recently, there have been suggestions that a learning-by-doing approach, confined to small scale trials, is an attractive way forward. Albeit valid in principle, such pilot projects, if carried out without a sound understanding of the economic foundations underlying their deployment, may fail to reveal either the full potential of benefits or the inherent severity of risks, or both.

Currency is a form of memory (Kocherlakota, 1998), irrespectively of digital or physical reification. Cash is widely predicted to gradually lose relevance (Armelius et al. 2020). Markets may move elsewhere. Liquidity pools may leak from the regulatory perimeter in the wake of business innovation running over its fringes into real sector. The whole idea of reimplementing a better "cash" might not be so creative after all. This needs to be checked before little and late but none of the surveyed works did. Again, models can offer inexpensive counterfactuals with "*brave new worlds*" (Lagarde, 2018b).

Most of works surveyed here acknowledge the consequent prominence of a central bank if a retail CBDC happens to be more relevant than cash to the economy. They disagree whether the entailed political implications are materially positive or not. Short scale issuance can be safe enough to contain such externalities. However, reputational, credibility and independence risks to the monetary authority do not require much value or volume, but one single blunder, in particular if outside a sound legal framework.

True to the agnostic stance stated in Section 4, and with an optimistic view of the digital future, we suggest that the evidence that we have gathered with this survey makes a compelling case for more model-theoretical research that can strengthen the support for a commitment to CBDC issuance, i.e., "*[to] get it right [rather] than to be the first*" (Powell, 2020).

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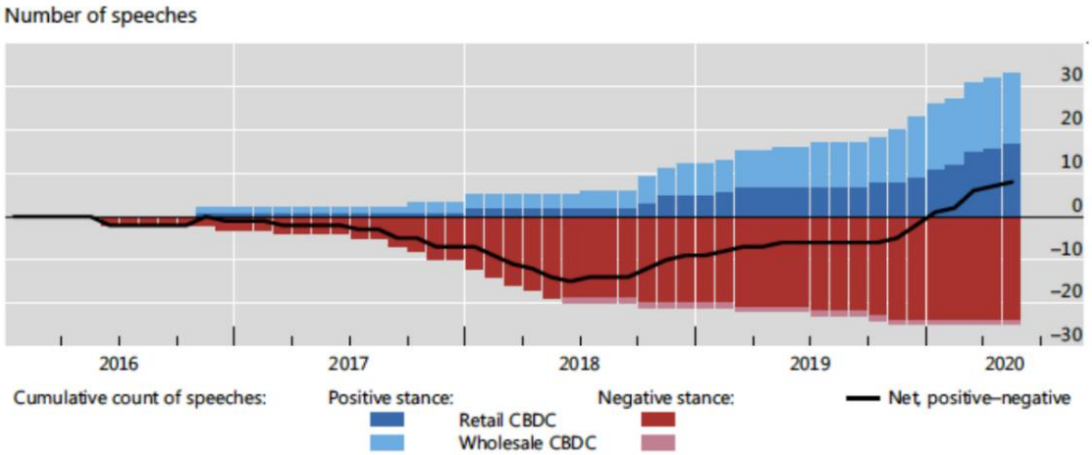
## Appendix 1. Topic analysis of thinking evolution and alignment

Research on CBDC is not detached from the policy context. At least since 2016, policy makers from central banks and from IMF and BIS have communicated their thinking about CBDC alongside academics.

Auer et. all (2020) compiled and organized 149 speeches from 2016 to 2020 by searching for the keywords "CBDC," "digital currency" and "digital money" in official communication. They judge and score each by their message. The score takes a value of –1 if the speech stance was clearly negative or if it was explicitly said that there was no plan at present to issue digital currencies. It takes a value of +1 if the speech stance was clearly positive or a project/pilot was launched or was in the pipeline. Other speeches have been classified as neutral and omitted from the counting depicted in Figure A1.

**Figure A1**: Assessment of Speeches on CBDCs by Auer et al. (2020)




We borrowed the same batch of speeches, not to assess stance (Auer et al. 2020), but to extract context. We assume that the discriminant vocabulary can reveal frequent motivations and preoccupations. We intend to check if research on CBDC is aligned to policy makers thinking inasmuch as to provide backing and relief. Given that Auer et al. (2020) claim a meaningful change in tone, we split the batch into two. However, we decide for a more recent break point[5] yielding one set of 77 speeches from 2016 Q1 to 2019 Q2 and another of 72 2019 Q3 to 2020 Q4. We choose 2019 Q2 because the black line in Figure A1 displays then a more obvious upward trend towards a favorable leaning, because 2019 Q2 is the middle in the tone switching from BIS 2019 Survey – "*Proceeding*

[5] *An earlier or later quarter break point will not qualitatively change themes.*

*with caution*" (Barontini & Boar, 2019) to BIS 2020 Survey – "*Impending Arrival*" (Boar et al., 2020), and because the division of documents would be more even (77/72).

We then applied Latent Dirichlet Allocation (LDA) Analysis (Blei et. al, 2003) to the two batches and to the surveyed paper in Sections 8 and 9[6]. Figure A2 presents a visual analysis[7] for assessing topic model quality in the LDA model of the first batch.

**Figure A2**: Topic model quality in an LDA model of Speeches [2016Q1-2019Q2]

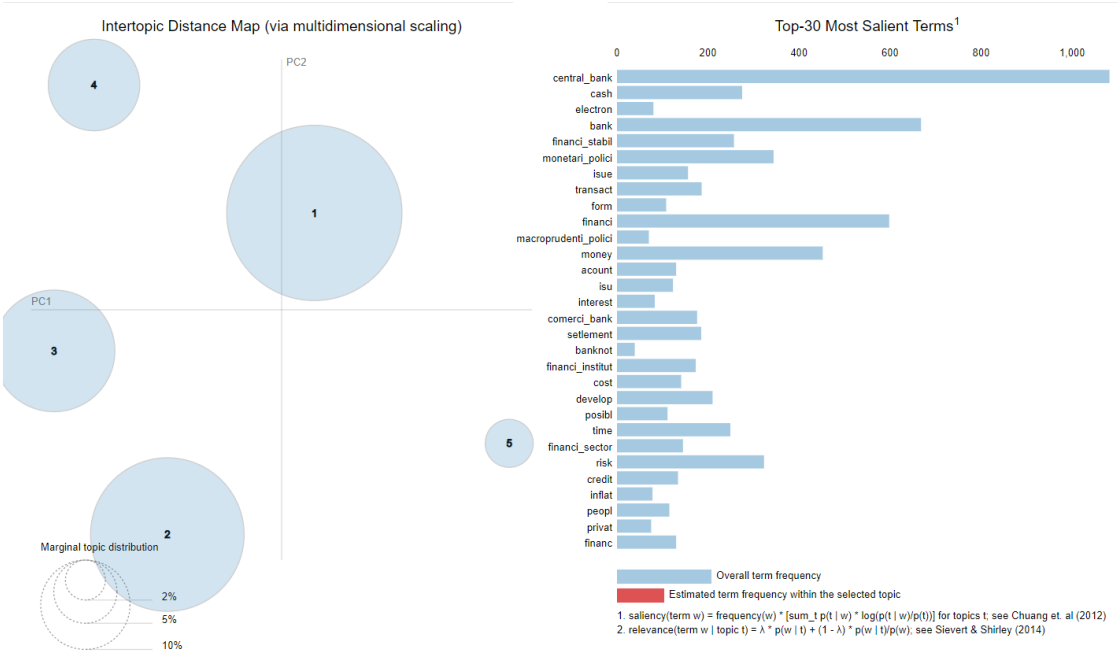



Figure A2 highlights topic clusters whose centers' distance denote more dispersion, hence a more diversity in salient vocabulary. Among the top 30 most discriminant terms we found usual policies: "monetary" and "macroprudential" as well as "inflation" and "financial stability". In one side, terms include "banks," "accounts," "interests" and "credit"; on the other, terms include "cash," "banknotes" and "settlement". "Risk" and "cost" are also salient in the speeches. None seem extraordinary in policy communication, but "electronic" seems, as an earlier denotation for "digital currencies". Noteworthy is also the stem from "possible" and "possibility".

Drilling down into each topic, from the most to the least prevalent, we found more information about drivers and concerns, where the subtle "electronic" expands into a more

[6] *We favor comparability rather than model fit. Thus, we choose the same number of topic clusters, the same hyperparmeter calibrations, and the same set of stop-words and context unspecific words to be removed before lemmatization. We remove the most common verbs and adverbs, document specific nouns, like 'section', 'page', 'website', etc.; and entity names like country and central banks names.*

[7] *The correct interpretation can be learned by reading Chuang et al., (2012) and Sievert and Shirley (2014).*

characteristic set of terms that emphasize CBDC implementation, in the most prevalent cluster. The other clusters bring no surprise, as their discriminant terms seem ordinary.

1 "technology," "innovation," "fintech," "distributed ledger" but "risk"

2 "central bank," "money," "cash," "commercial bank" and "non-bank"

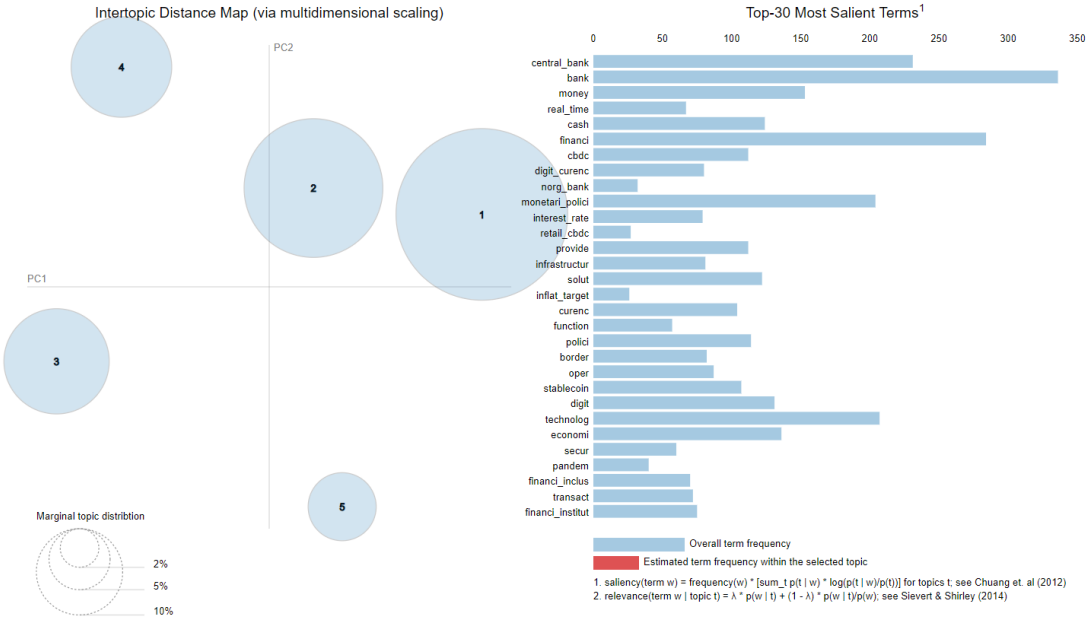
3 "central bank," "monetary policy" and "financial stability"

4 "banks," "monetary policy," "macroprudential" and "financial stability"

5 "cash" and "banknotes" (We write more readable inflexions rather than stems)

Figure A3 presents a visual analysis for assessing topic model quality of speeches in the second, more recent batch.

**Figure A3**: Topic model quality in an LDA model of speeches [2019Q3-2020Q4]




Now we observe that two topics dominate in prevalence and in the nearness. Also, the top 30 most discriminant terms become more revealing of context for including "pandemia" and "stablecoins." They become more characteristic of possible motivations: "innovation," "financial inclusion," and (cross-)"border" (in some experiments, "sovereignty" was also inferred as discriminant). The stem for "security" instantiates an operational class of risk. The stem for "solution" ranks well. Drilling down, from the most to the least prevalent topic, we departure from standard communication with more terms with more specific and precise meaning in the context of CBDC, as follows.

1 "risk", "innovation," "stablecoins," "crypto assets" and "retail"- (CBDC)

2 “technology,” “data” together with “financial inclusion”

3 “money” and “cash”

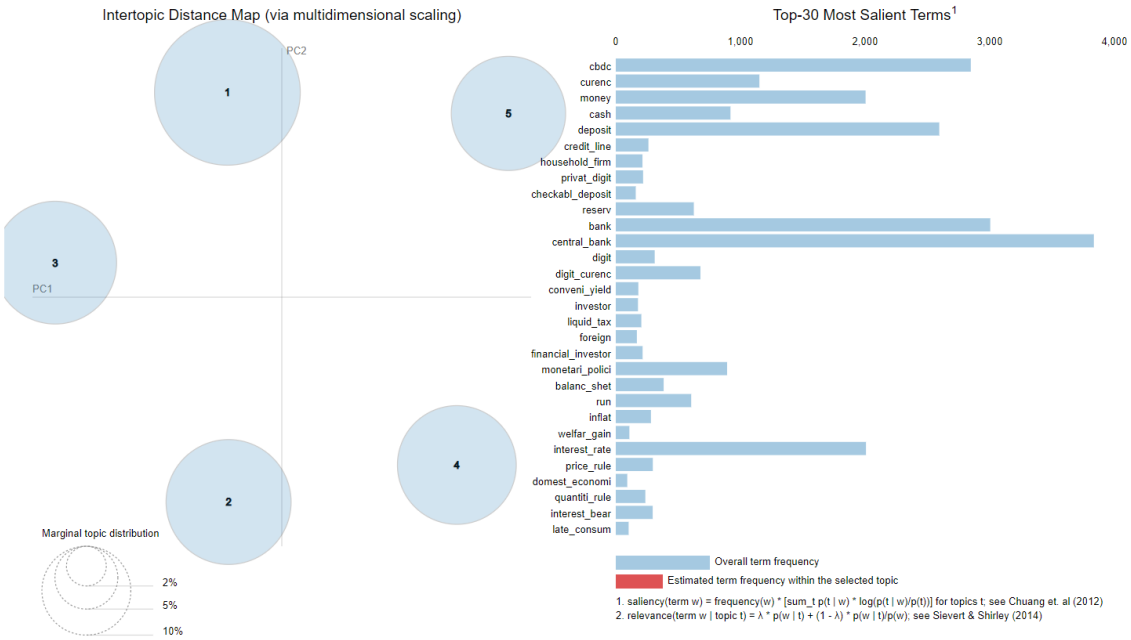
4 “real time” (payments), “infrastructure,” “ICT provider” and (cross-)“border”

5 “monetary policy” and “economics”

Together these seem to corroborate the tone shift claimed by Auer et al. (2020). Otherwise, it is at least a deliberate intention to communicate openly and unambiguously about CBDC research and projects, digressing from the usual policy communication.

Finally, Figure A4 presents a visual analysis for assessing topic model quality of surveyed paper in Section 8 and 9. The sample is smaller, i.e., 28 papers, but each document is lengthier, denser, and employs a more technical vocabulary. Therefore, the comparison with the two previous exercises must be interpreted with care. We can group most of the top 30 most discriminant terms according to their pertinence to policies. Monetary policy (**P1**) is represented at least by “interest rate,” “price,” “quantity rule,” “inflation,” and “welfare gain”. Macroprudential policy (**P2**) is represented at least by “banks,” “credit-line”, “deposits” (also “checkable deposits”), “balance-sheet” and (bank-)“run”. The latter is one of the most studied issue in the surveyed papers, hence salient in every cluster topic. Fiscal policy (**P3**) is represented by “liquidity tax”. Foreign exchange policy (**P4**) is represented by “domestic economy” and “foreign”. Therefore, this evidences the broad coverage of issues in the set of surveyed papers.

**Figure A4**: Topic model quality in an LDA model of the surveyed literature



Drilling down, we can regroup the papers according to their semantic emphasis:

1. The role of central banks to stabilize macroprudential consequences of CBDC.
2. The role of central banks to stabilize the monetary implications of CBDC.
3. Monetary spillovers in small open economies and CBDC competition with cash.
4. Competition from private digital currencies.
5. Welfare changes if CBDC coexists with the incumbent intermediation system.

This topic analysis exercise yields a different yet complementary categorization for the surveyed works with respect to the one chosen in this paper. Moreover, research topics are near to those in the early batch of discourses than they are to those in the latter.

A second batch of literature, outside of our scope, can warrant this late appeal. For instance, we refer to Adrian & Mancini-Griffoli (2019), Auer & Böhme (2020), Auer et al. (2020), BoE (2020) and ECB (2020) to understand the designs and technologies that set a backdrop to remarkable speeches by Broadbent (2016), Lagarde (2018a, 2018b), Carney (2019), Panetta (2020, 2021), Haldane (2020), Villeroy de Galhau (2020), Brainard (2020a 2020b), Richards (2020), Amamiya (2020), Carsten (2021) and Powell (2021). The economic perspective of a potential CBDC issuance still lies on those works surveyed here. Those that funnel motivations and preoccupations to the extent of a shift in focus and mood towards a "*do-no-harm*" "*coexistence*".

Finally, we repeat Table 2, but we annotate the surveyed works with topic clusters in Figure A5. This offers a complementary perspective to the model theoretical one. Note the previously chosen reference works also spawn to different topic clusters, where there is one topic cluster that concentrates most of the currency competition models. Thus, the induced and the curated literature organizations bear some coherence.

**Figure A5**: Topic clusters of the surveyed literature in Sections 8 and 9

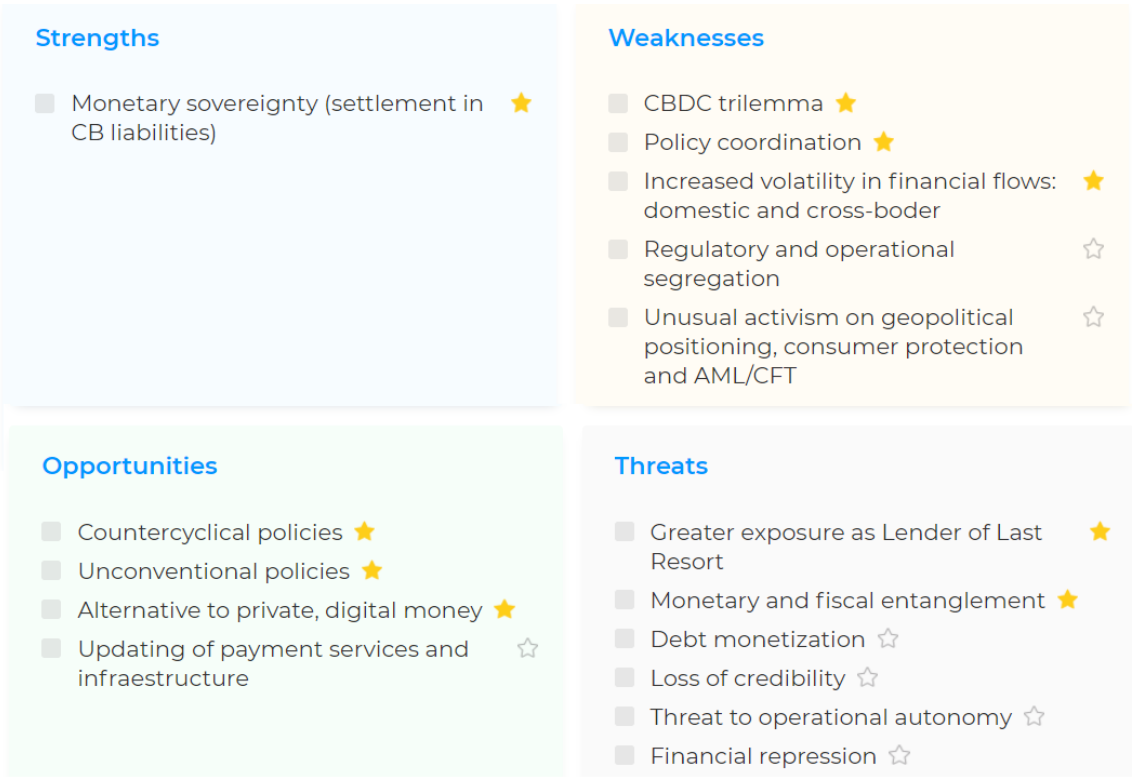

Source: Author's own Elaboration

## Appendix 2: Analytical view per Economic Agent

Benefits and risks of issuing a CBDC have been debated in Sections 11 and 12. Others have been postulated without a model theoretical backing. Nonetheless, they have been generally assigned to a net aggregate welfare. We rather organize the arguments by associating them to the main economic agents in Figure 2, thence to the final beneficiaries or to the obvious stakeholders. In Figures A6 to A8, findings in the surveyed works serve to justify star-marked items.

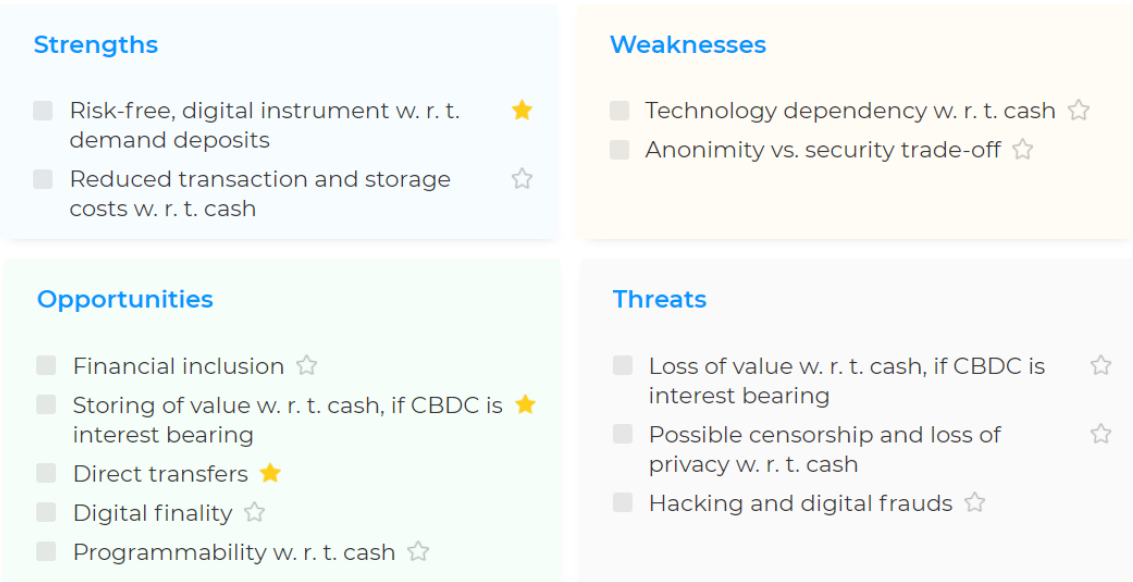
Figure A6 schematically shows that the central bank attracts opportunities and threats. From that we conclude that it would bear the effort required to make a CBDC useful, it would bear some additional responsibilities for issuing one more liability.

**Figure A6**: SWOT analysis from Central Bank perspective




Households and firms, i.e., the real side of the economy, potentially enjoy more gains under more neutral exposure, in proportion to other agents. Note in Figure A7 that most advantages of a CBDC manifest themselves when CBDC is compared to physical cash. The net gain for the real side is less obvious, when a CBDC is prone to substitute for demand deposits since the positive externalities of digitalization are already tangible.

**Figure A7**: SWOT analysis from Households and Firms perspective



The financial side of the economy has the less to gain and the most at stake with the introduction of a CBDC competition. However, there is always opportunities for those fit to adapt, as depicted in Figure A8.

**Figure A8**: SWOT analysis from Financial Intermediaries perspective