CBDCs, BANKNOTES AND BANK DEPOSITS: THE FINANCIAL STABILITY NEXUS

2024

BANCO DE ESPAÑA
Eurosistema

Documentos Ocasionales
N.º 2436

José Ramón Martínez Resano

CBDCs, BANKNOTES AND BANK DEPOSITS: THE FINANCIAL STABILITY NEXUS

José Ramón Martínez Resano [*]

BANCO DE ESPAÑA

(*) The author thanks Ángel Estrada and Carlos Pérez Montes for their comments and suggestions.

Documentos Ocasionales. N.º 2436

December 2024

https://doi.org/10.53479/38457

ISSN: 1696-2230 (on-line edition)

Abstract

This paper explores the financial stability nexus within a monetary ecosystem that has been expanded to include a central bank digital currency (CBDC). The paper examines the new risks associated with the introduction of a CBDC, their mitigants and their potential amplification factors. Economists and academics still seem to be split on the validity of the traditional principle of separating money into two tiers of public and private money, as a structural mitigant of the risks of deposit substitution and banking disintermediation towards CBDCs. The potential amplification of the risks associated with CBDCs through credit-related second-round effects is an additional concern. The systematic study of the risks and mitigants carried out in the paper highlights the importance of partially adapting the two-tier system of money by implementing certain limits, as envisaged in CBDC plans. The endogenous mitigation of the risks through improved bank competition often attributed to CBDCs is uncertain and may be insufficient from a systemic risk perspective. The introduction of exogenous mitigants, like CBDC holding limits calibrated on the basis of a robust methodology, seems instrumental to ensure the consistency of a monetary ecosystem that includes a CBDC. Hence, the paper addresses some fundamental methodological issues related to these limits, such as the rationale for alternative targets for the limits, the influence of disintermediation speed, the time horizons involved in the limitation and adaptation process, and the role of regulatory and market frictions. An illustrative empirical analysis for the Spanish case indicates that financial stability might not be a concern for reasonable levels of CBDC take-up, although the complexity and novelty of this instrument call for a more in-depth analysis in the future.

Keywords: central bank digital currency, digital money, payments, financial stability.

JEL classification: E41, E42, E51, E52, E58, G21.

Resumen

Este artículo explora el nexo de la estabilidad financiera en un ecosistema de dinero ampliado con una moneda digital de banco central (CBDC, por sus siglas en inglés). El documento examina los nuevos riesgos asociados a la introducción de una CBDC, sus mitigantes y sus potenciales factores de amplificación. Los profesionales y académicos todavía parecen estar divididos sobre la validez del principio tradicional de separación del dinero en dos niveles, público y privado, como mitigante estructural de los riesgos de la sustitución de depósitos y la desintermediación bancaria hacia la CBDC. La posible amplificación de los riesgos debidos a la CBDC a través de efectos de segunda ronda relacionados con el crédito es una preocupación adicional. El estudio sistemático de los riesgos y mitigantes realizado en el artículo destaca la importancia de adaptar parcialmente el sistema monetario de dos niveles mediante la adopción de límites, como se contempla en los planes de CBDC. La mitigación endógena de los riesgos fruto de una mayor competencia bancaria promovida por la CBDC que a menudo se aduce resulta incierta y puede ser insuficiente desde una perspectiva de riesgo sistémico. La introducción de mitigantes exógenos, como límites a las tenencias de CBDC calibrados sobre la base de una metodología sólida, parece fundamental para garantizar la coherencia de un ecosistema monetario ampliado con una CBDC. Por lo tanto, el documento aborda algunas cuestiones metodológicas fundamentales relacionadas con estos límites, como la justificación de unos objetivos alternativos para su determinación, la influencia de los distintos tipos de desintermediación, los horizontes temporales involucrados en las limitaciones, la relevancia del proceso de adaptación y el papel de las fricciones regulatorias y de mercado. Un análisis empírico ilustrativo del caso español indica que la estabilidad financiera podría no ser una preocupación para niveles razonables de adopción de CBDC, aunque la complejidad y novedad de este instrumento requiere en el futuro un análisis más profundo.

Palabras clave: moneda digital de banco central, dinero digital, pagos, estabilidad financiera.

Códigos JEL: E41, E42, E51, E52, E58, G21.

Contents

1 Motivation and main contributions

The stability of monetary and financial systems is widely recognized as a complex and potentially fragile social construct. The introduction of retail central bank digital currencies (CBDCs) not only embeds new technology in the provision of central bank money, it also expands retail agents' access to central bank money in a qualitatively new way by boosting competition with bank deposits, something that could have an impact on the current architecture of the financial sector. This paper focuses largely on the stability component of the assessment of the welfare effects of the introduction of a CBDC. Such a focused analysis is particularly relevant when the CBDC in question has a universal scope, as opposed to niche use cases.

This study aims to gather robust insights on the fit of universal CBDCs in the existing monetary and financial system with a view to ensure consistency and stability. The literature on CBDCs is already large but the stability implications of CBDCs remains to be a matter of dispute. The complex ecosystem in which monetary and financial networks work explains to a large extent the uncertainty that surrounds the scope of the stability effects of CBDCs. But a review of the literature also shows that the understanding of the different dimensions of the problem is varied and that some macroeconomic misconceptions could be present (Bindseil, and Senner, 2024). Against this backdrop, the paper proposes a form of structural analysis of the risks, mitigants and amplification factors posed by a CBDC.

The paper examines the stability nexus of universal CBDCs in three domains. The first one covers their effects on the fragility of banks in normal and stress times. The sources of fragility will be argued to call for restricting the amounts of CBDC holdings as main tool for risk mitigation, as indeed envisaged in existing CBDC projects across the world. Restricted money is not a new concept. The downfall of cash use in transactions follows intrinsic technology related restrictions. The main novelty with universal CBDCs is in the rationale and implications of capping the amount of CBDCs in circulation. At a fundamental level, this feature arises out of the need to maintain the consistency of the overall monetary and banking system, particularly in conditions of stress. The technological complementarity between banknotes and bank deposits has traditionally prevented the emergence of consistency challenges, making them a harmonious couple. In fact, the long-standing policy followed by most central banks to fully accommodate the demand of banknotes both in normal and stress times has not entailed noticeable financial stability risks. The degree of complementarity of CBDCs with these forms of money is much less certain, motivating this part of the analysis.

The argument for restricting universal CBDCs as money can also extend to their remuneration. The stability of the money ecosystem appears to be highly sensitive to CBDC remuneration. The universality attribute proves to be instrumental in generating this elevated and permanent sensitivity. A strong substitution (by design) between commercial bank money and the new universal central bank digital money could be prone to cause instability by design. Limits on CBDC remuneration arise as an additional and independent line of defense against those risks.

A second strand of the stability-related arguments made relate to the time horizons needed to lift holding restrictions and (gradually) accommodate the underlying demand for a CBDC. The uncertainty regarding its disintermediation effects, mainly through the substitution of bank deposits with CBDC, may advice to accommodate the underlying demand of CBDCs just gradually. But foresight of additional substitution of deposits can be a source of risks ex-ante due to moral hazard of the banks involved in the distribution of the CBDC or to accelerated substitution by depositors. In parallel, the impossibility to replicate with a CBDC the "safety valve" role for the monetary system typically played by banknotes during certain major crisis (both economic and cyber) also raises the question of their coexistence with banknotes.

A third aspect of the stability nexus connects the fragilities and restrictions of CBDCs with the nature of public-private cooperation in the monetary and financial system. The two-layered monetary system[1] has traditionally shielded commercial bank money from a competing public money offer, something that CBDCs would shake. The paper frames the restrictions of CBDC holdings and remuneration as necessary alternative mitigants of the structural risks that they entail. These mitigants should also influence positively the new governance of CBDC projects strongly reliant on co-opetition.[2] Additionally, the paper clarifies that the two-money layered money system does not limit public interventions when market failures in the money mobilization framework justifies their actions. Inertia of the technology of payments infrastructures due to network effects ("sticky stability") is argued to have been often an important driver of such public action in the past much as it may be now for CBDCs.

The empirical section of the paper highlights the importance of the calibration of CBDC constraints. Achieving an optimal balance of advantages and disadvantages is crucial. Considerations for maintaining financial stability provide a solid foundation for sensibly calibrating the constraints to be placed on CBDCs so that they function effectively and the system remains resilient overall. The precision of calibrations and the credibility of the associated commitments are crucial in influencing the scope of the effective interchangeability of CBDCs with deposits and/or banknotes. The specific impact is contingent upon a variety of factors, including aggregate liquidity conditions, financial frictions at play, and intermediary heterogeneity. The complexity of the issue justifies the cautious approach taken by central banks worldwide as they lay the groundwork for a potential CBDC launch. This approach involves gaining knowledge and insights to guide the eventual development and rollout of a CBDC.

This paper also undertakes an analysis of the potential impact of a retail CBDC on the Spanish banking market. Although its purpose is mainly preparatory and methodological, its conclusions suggest that the implications of a digital euro for financial stability could be

1 A two-layered monetary system refers in a nutshell to the fact that only commercial banks deal with reserves at the central bank while everybody else operates with bank deposits. The use of banknotes has been traditionally the only shortcut to the access to central bank money for non-banks.

2 Co-opetition refers to cooperative competition, i.e. a sort of seemingly contradictory but widespread economic engagement (see Nalebuf, 2021) at the core of CBDCs because commercial banks operate as essential distributors of CBDCs while may be exposed to their disintermediation impact.

acceptable under a sufficiently prudent calibration. The results can only be tentative as the analysis is partial. In any case, the reassuring conclusion does not preclude the presence of potential heterogeneous impact for credit institutions of different sizes.

The paper is structured as follows. Section 2 places CBDCs in the context of the technology shocks on money and underscores the special importance for financial stability of universal CBDCs. Section 3 prepares the ground for the CBDC focused discussion on financial stability risks in section 4. This last section examines systematically the new risks associated to the CBDCs, the uncertainty and challenges that surround potential mitigating factors and the potential of fragility outcomes in the banking sector in the form of slow and fast disintermediation. This section underscores the importance of holding limits on CBDCs and their robust calibration as exogenous structural mitigants of risks. The section also highlights the impact of uncertainty on the dynamics of lifting holding restrictions and the questions that this raises. Section 5 emphasizes the importance of calibration of limits based on a practical application for the Spanish banking system and section 6 concludes.

2 CBDCs and the digitization shock to money, banking and payments

Digitization has been reshaping economies for several decades now. The momentum and scope of these changes are currently in full march thanks to a diversity of technologies. Their evolution since the rapid expansion of the internet era in the late 90s has given rise to new use cases and business operational models, including e-commerce, social media, and investment platforms. The majority of these economic shifts driven by digital progress directly impact or necessitate adaptations in the handling of money and payments.

However, the foundational internet infrastructure that facilitated the rise of the virtual world online was established with a fundamental shortcoming in its financial domain, as emphasized by (Andreessen, 2019). The IT protocols enabling seamless interaction in cyberspace did not anticipate the integration of financial transactions. Initially, control over data privacy was also inadequate, but subsequent remediation of payment and data-related vulnerabilities, along with the establishment of comprehensive business models, has propelled online commerce significantly and engendered the emergence of new information intermediaries. Major tech conglomerates have thrived by extensively exploiting unpriced information exchanged on their commercial platforms. The eventual concentration of commerce in these new "islands" of trade was bound to induce significant changes over time in the more fungible aspect of the process – namely, money and payments.

The adaptation of money and payments in response to these developments has followed two main paths of action. The first one has sought to enhance the efficiency and security of a rapidly expanding digital economy through gradual adaptation of processes and systems. The main priorities have been addressing the propensity to fraud and deception present in an online environment. But this gradual evolution has brought also innovative services like instant payment services in many jurisdictions. A second set of transformations have threatened to revolutionize the money system itself. The introduction of non-bank private money by big tech operators to facilitate trade in the new digital "islands" in the form of so- called "stablecoins[3]" has sparked reminiscences of the free money era.

One of the motivations for the implementation of a central bank digital money is to address the risks of an evolution to a monetary system based on risky cryptocurrencies. These instruments have sparked prudential regulation responses[4] to tackle their associated risks, but the adaptation of central bank money to the digital age seems to require additional structural measures, such as CBDCs, that conform to an expanded set of needs for money users. Commercial bank money is also in the process of adapting to the new technologic requirements of the "Finternet era" (Carstens, 2024) by exploring tokenized deposits.

---

3 A stablecoin is a type of cryptocurrency token designed to maintain a stable value, often pegged to a fiat currency, and usually backed by reserves of traditional financial assets.

4 In particular, the FSB and standard setter bodies like the BCBS and CPMI-IOSCO have issued rules to cope with the financial stability risks associated with crypto and more specifically with stablecoins. In particular, the recourse to blockchain rails to effect payments has been subject to the standards of safety regarding financial infrastructures in general.

Unsurprisingly, the need to adapt central bank money to the digital world coincides with a declining use of the central bank money token per excellence, i.e. banknotes. While the circulation of banknotes continues to rise (Shy, 2023), their limited convenience for transactional purposes, especially online, are becoming widespread (ECB, 2024). Central bank digital currencies can address this gap in the money ecosystem by being configured as the digital counterpart to traditional banknotes.

The diversity of CBDC models may be large (Genc, and Takagi, 2024). Universal CBDCs are aimed at establishing a universally enforceable central bank digital monetary instrument as well as the infrastructure that enables its broad penetration and interoperability with all the forms of money. Universal CBDCs thus constitute, together with digital identity and others, a fundamental component of the emerging notion of public digital infrastructures (Eaves, 2024). The focus of this paper is in universal CBDCs.

3 Risks and mitigants in the architecture of money and banking. The path towards CBDCs

The architecture of money and banking has advanced across time along an evolutionary process that integrates functional goals, risks and mitigants thereof. This section examines the novelties introduced by universal CBDCs in this structure and motivates the need of new kind of mitigants that tame new financial stability risks. Table 1 provides a frame of reference for this preliminary analysis that sets the ground for the more in-depth discussion in section 4 of the financial stability issues associated with CBDCs.

3.1 Multiple monetary instruments and banking

The technology underlying the architecture of money shapes its performance and risks. Money can be considered as "memory of economic value" (Kocherlakota, 1998). This definition aligns well with the idea of a digital implementation of money. But the diversity

Table 1
The ecosystem of money attains its functionality and overcomes the risks to money singleness thanks to various

	Free Banking	Banknotes	Bank Deposits	CBDC
Rationale	Fragmented trade Insufficient central powers	Two-tier money with parity Gravitation of powers Spatial gaps in money	Two-tier money with parity: — Borrowed private money Private credit system	Digital shock to money (h): — ¿Back to free banking?
Risks/costs	Real costs of no parity Instability of banks No lender of last resort	Costly exchange technology Safe instrument to run	Deposit contract fragility (e) Growing bank powers (f) Private inertia to coordinate (g)	Substitute of bank money (i) ¿Slow disintermediation? (j) Public and ¿private credit? (k) Fast disintermediation (l): — Leaking pipe in crisis Adoption risks (m): — Coopetition and privacy Cyber
Mitigants	Creation of clearinghouses Emerging tiering: i.e. hierarchy	Two-tier money (a): — Not competing central bank Balance of risks and costs: — Safety valve in crisis (b) Complement of bank money (c): — Privacy and fiat ⟶ trust — Remuneration ⟶ costly storage Robust to diversity of shocks (d)	Two-tier money (a): — Regulation and supervision — Lender of last resort — Presumption of support Correction of mobilization market failures	Limits on: — Holdings and remuneration (n) — Institutional New Two-tier money (o): — Governance of coopetition — Public coordination — Control over convertibility — Recycling and refinancing

SOURCE: Own elaboration.
NOTE: The table attempts to map the main concepts that have shaped the singleness and stability of money under various architectures (column view) The table has an implicit time dimension from left to right and attempts to place in context the features discussed in the text for CBDCs. The numbered circles attempt to highlight relevant issues in the text. (a) is addressed across the whole document due to its role as structural mitigant that is challenged by CBCDsr. (b), (c) and (d) are highlighted because they describe the sources or consequences of the internal balance achieved with banknotes. (e), (f), (g) highlight the main sources of fragility potentially shocked by CBDCs. (h) is covered in section 3.3. The substitution (i) and adoption risks (m) associated with CBDCs are covered in section 4.1 while the potential consequences in terms of slow disintermediation (j) and fast disntermediation (l) are extensively discussed in section 4.2 The role of endogeneous mitigants like the alleged improvement of bank competition (f) thanks to CBDCs and the operation of effects through transformations in bank credit (both dealt in section 4.2) shape the uncertainty on the ultimate outcome. The main part of the paper corresponds to (n) and (o). The need to enforce a reformed two-tier money system leads to the need to impose remuneration limits that emulate the ones of physical banknotes and holding limits that emulate the costs of storing big amounts of physical banknotes. (m) is mainly covered in 4.2 but the governance component (o) is briefly addressed in 4.1.

of money forms witnessed across time underscores the variety of "technologies" that can underpin the performance of a "memory of economic value" and, ultimately, the role of trust as a fundamental factor common to all of them. In particular, banknotes and bank deposits have coexisted for long as two different forms of money with a markedly different technological underpinning but jointly leading to a trusted and single ecosystem of money. That is, one where convertibility at par between the different money instruments is taken for granted. In contrast to such integrated arrangement, bank notes issued separately by commercial banks during the Free Banking period provided a disintegrated and risky implementation of money (Dwyer Jr, 1996).

A diverse but single ecosystem of money, like the one classically conformed by banknotes and bank deposits, reconciles the needs posed by a multiplicity of use cases of money with a requirement that money is convertible at par between modalities. Two broad use cases are the ones corresponding to a medium of exchange and to medium to store economic value. The diversity of technologies underlying coins, banknotes and bank deposits caters to a mix of use cases that exhibit different transaction costs and ancillary services, like remuneration.

The impossibility to pay interest on banknotes has created a financial differentiation with deposits. But maintaining the confidence of convertibility of deposits at par has bound together the ecosystem of payment and saving instruments. Classical models of money as medium of exchange like Baumol-Tobin (Baumol, 1952) rationalize the role of transaction costs in the demand of deposits conversion into banknotes. (Townsend, 1980) provides additional structure by emphasizing the ability of physical banknotes to serve as spatial bridge for the transfer of economic value where commercial bank money does not reach. Digitalization obviously alters this particular logic, but it still requires a reliable convertibility at par.

The storage of economic value in a monetary instrument does not escape either the logic of comparative advantage. On the one hand, storing economic value in banknotes, whose eminent function is to act as medium of exchange, entails unquestionable costs if the alternative (bank deposits) entails a remuneration or if it is safer. But it can be advantageous if it is private control over the monetary medium what matters most to economic agent, be it because of convertibility fears affecting bank deposits or because of privacy concerns.

But the rationale of a balanced ecosystem of money has held up relatively stable despite the secular changes that have taken place in the past. The trade-offs between physical banknotes and bank deposits have evolved across time without fundamentally breaking apart the singleness of money and their complementary relationship at storing economic value (Shy, 2023). This is so even though the transactional rationale for holding banknotes has significantly lost ground as banks and credit card agencies have deployed more effective rails to mobilize commercial bank money.

The risks to the architecture of money have also changed as the composition of use cases of money evolved over time. A tilt in the ecosystem of money towards commercial bank money has entailed intrinsically a shakier foundation for money due to the brittle nature

of demand deposits as input for the production of demand deposits (Diamond, and Dybvig, 1983;Gersbach, and Zelner, 2024).

Over time, the fragility of commercial bank money has led to broader regulatory, supervisory and bank supporting frameworks aimed at containing crisis. Public intervention has thus rebalanced the profile of private money towards a public status and thereby contributed to a diminished incentive to drawdown deposits. On the other hand, the limits of the protections applicable to depositors together with the expansion of money use cases where the privacy of banknotes is central have operated in the opposite direction.

All in all, the complementary nature of the technologies underpinning banknotes and deposits has ultimately held the money ecosystem in balance. Banknotes face an intrinsic limitation to be a competing instrument of bank deposits. The transaction and holding costs associated with physical banknotes thus limit the conditions under which a run on deposits is attractive. In fact, physical banknotes have traditionally been viewed as a sort of "safety valve" for the money system. A drawdown of deposits to banknotes can impose frictions that may automatically limit further outflows and ultimately offer some leeway to gain time and stabilize the system. Consistent with this behavioral pattern, the elastic supply of banknotes, i.e. the accommodation one-for-one in the demand of banknotes, has traditionally counted as important central bank policy to enforce trust in the singleness of money (Champ et al., 1996).[5]

3.2 Structural mitigants of risks: The separation principle and central banking

Section 3.1 has argued that transaction costs and remuneration generate a differentiated ecosystem of physical banknotes and bank deposits that nonetheless exhibits a degree of internal consistency limiting financial stability risks. In a nutshell, such a balanced coexistence is the product of a structural complementarity between public and private money. The fact that physical banknotes could not be remunerated has played an important role in such complementarity. However, the argument takes for granted an institutional setting where public money in general (either in the form of banknotes or of alternative central bank liabilities) and private money (in the form of bank deposits) are effectively separated.

Financial stability concerns have played historically a crucial role in shaping the separation principle. Lower levels of economic and political development have sustained in the past more fragmented monetary systems like the one prevailing during Free Banking period in the United States. Bank notes issued by different banks provided a diverse palette of money instruments that served not only as a medium of exchange, but also as instruments to cover both local and regional trade funding needs. In this system an effective tiering of money is absent. Such a fragmented arrangement for money is well known to entail both real costs and financial stability risks (Dwyer Jr, 1996).

5 This is confirmed, for example, by the statistical regularity that, superimposed to a secular pattern of increasing holdings of banknotes, the balance also exhibits temporary spikes linked with their role as "safety valves" in situations of crisis. A similar historical regularity (no longer valid in general) was the reduction of the likelihood of bank panics when the system of banknote issuance is flexible, because then risk of reserves being depleted and necessitating a halt in cash transactions is lower.

The stable separation between public and private money (tiering of money) can emerge when the financial policies carried by a sufficiently powerful government attempt to permanently direct the powers of the central bank towards this goal. (Goodhart, 1988) lays bare how the tiering of money between central bank reserves and commercial bank money emerged over time as a stable institutional outcome that eliminates the inconsistency that central banks could at some point compete with commercial banks. The supply of deposit-like instruments for savings by governmental institutions with policy powers was thus discarded and, instead, the only public money available to non-banks was banknotes.

The tiering-of-money also planted the seed for gradual development of regulation and supervision to control the risks associated to commercial banking activities, in particular depositary activity. The emergence of central banks in the transition from free banking to modern monetary arrangements is the highlight of the institutional evolution to a regulatory role to ensure the consistency of the ecosystem of money. The modern institutional framework seeks to underpin the trust in the convertibility between different money instruments at par (singleness of money) and ensure the overall financial stability of the system.

The risk that inefficient money mobilization systems could endanger the effective singleness of money underpins the fundamental role of central bank policies in that area. Their powers to enforce coordination and competition between private money issuers as well as their own capacity to provide efficient money mobilization frameworks has remained a mitigant of risks in both retail and wholesale payments. Financial stability considerations have thus long justified a direct involvement of central banks in the provision of rails for wholesale payments. The argument is particularly well established regarding the cash side of wholesale transactions. The interconnected nature of interbank markets and the associated risks to financial stability have led central banks to innovate in wholesale payments, reflecting their complementary relationship with central bank operations (CPMI-IOSCO, 2012). But the case for an episodically active involvement of public actors in the provision and/or configuration of retail payment systems has also a long tradition.

The need of public initiatives in the field of private payment systems is also significant. (Padoa-Schioppa, 2004) elaborates on the indirect role of central banks at shaping payment systems by fostering soundness and competition. But the need is particularly strong when network externalities and coordination failures between commercial money issuers leads to inertial and slow modernization of existing systems. (Leibbrandt, 2004) documents how the provision of payment services in many jurisdictions experiences episodes of technological inertia that explain lock-in in inefficient solutions.

A well-known case study of this problem is the long-time persistence of checks as the most used retail payment instrument in the US, well beyond the time when time when their use was efficient (Humphrey et al., 2000). By contrast, the publicly led initiative to introduce giro payments in the Netherlands at the start of the XX century as a replacement of checks highlights the potential for dynamic efficiency of public powers at technologic turning points.

3.3 CBDCs: new rationale, new risks and new mitigants

As discussed above, CBDCs are in its purest essence a digital replica of physical banknotes. At an abstract level, they should keep ensuring the singleness of money in the digital world. At a more concrete level, their operation in digital environments addresses the use case gaps left uncovered by the latter in the increasingly online world. A common rationale of CBDCs in most jurisdictions is as instruments to advance in the modernization of payments and overcome inertia.[6]

It is difficult to assess whether the wave of CBDC projects worldwide can be framed within the inertia paradigm because the ecosystem of payment services is currently vibrant (McKinsey, 2023). For example, the increasingly widespread private provision of fast payments across the world may led to conclude that payments technology is less sticky than in the past. But the fact that many of these advances typically just take place on the back of publicly provided infrastructure (that leverages public wholesale Real Time Gross Systems) and that organic transformations in bulk segments are still hampered by concentration should lead to caution.

This technological modernization of public money may entail qualitative effects on the ecosystem of money that go beyond the immediate efficiency gains to hold and pay with public money in digital environments. This is particularly the case when the CBDCs are designed with a universal intent, as defined in section 2, broader than that of a digital replica of a physical banknote, to provide with digital public money a range of basic services similar to the ones offered by commercial bank money. The risk mitigation effects brought about by the tiering of money might be thus compromised.

The relationship of complementarity between bank deposits and banknotes can be transformed into one of substitution in relation to CBDCs. The financial stability risks of allowing open competition between fragile commercial bank money and an unrestrained form of CBDC would be high as operational, financial and safety attributes of CBDCs could strictly dominate over the ones of bank deposits. In this context, constraints as regards the remuneration rate of CBDCs or the imposition of limits to their ability to carry economic value will be argued to be fundamental to still mitigate financial stability risks.

The scope and nature of the constraints needed to deal with the new risks posed by CBDCs is still a disputed matter. Their need as well as the role of various mitigants still divides practitioners and academics. The macroeconomic literature seldom articulates a role for explicit regulatory constraints (exogenous mitigants) on CBDCs, placing more emphasis on the expected improvement in competition (endogenous mitigants). On the contrary, practitioners have highlighted the need for regulatory constraints in order to safeguard the stability and the singleness of money in a setting with only partial separation between CBDCs and money applies.

6 In particular, in Europe the impact assessment studies of multiple legislative initiatives adopted by the European Commission with that objective since the inception of the euro confirm the stickiness of various market failures that limit the transition to a more efficient and integrated system (see, European Commission Staff (2013, 2022, 2023))

4 CBDCs and financial stability outcomes: risks, mitigants and amplification mechanisms

A welfare assessment of CBDCs calls for weighing their purpose and benefits, their associated risks as well as their mitigants. The nature of some of these components has been anticipated already in section 3.3. The purpose of the current section is to conduct a more systematic analysis of the relevant factors, with a focus on financial stability considerations.

Section 4.1 elaborates on the role of substitution of deposits and adoption/governance issues as major drivers of financial stability risks. Section 4.2 focuses on the potential for slow bank disintermediation or, equivalently, medium term fragility (4.2.1) and for fast bank disintermediation or, equivalently, short-term fragility (4.2.2).

A summary of the main conclusions of this section is as follows:

— First, net negative effects of CBDCs over financial stability are not an automatic or inevitable outcome of their introduction. The erosion of the capital generation capacity of banks due to the operation of substitution effects and associated funding shocks can be contained with an appropriate CBDC design and the establishment of funding compensation mechanisms (e.g. special refinancing lines).

— Second, the operation of endogenous risk mitigation effects, like expected improvements in bank competition thanks to CBDCs, is uncertain.

— Third, a deliberate policy of limits on CBDC holdings and on remuneration is instrumental to ensure stability against such uncertain backdrop. These conclusions are reinforced when considering the deeper uncertainty associated to potential effects on credit.

— Fourth, overall uncertainty calls for a policy of gradual lifting of constraints on CBDCs across time, i.e., one that matches the pace of transformations in the financial sector and their crystallization in sound outcomes.

4.1 A brief look into the fundamental drivers of risk

Substitutability between CBDCs and bank demand deposits can be a fundamental driver of the activation of fragilities in the banking system upon the introduction of this new type of instrument (see 4.1.1). Additionally, adoption or governance risks are also fundamental drivers of CBDCs' economic performance (see 4.1.2). The failure of a universal CBDC to function as desired would leave unaddressed the financial stability risks that motivated their consideration in the first place (see section 2).

Some specific channels for the materialization of adoption and/or performance risks like privacy and cybersecurity failures also exhibit a systemic profile, but will be addressed

here just in cursory way, as they involve technological design issues away from the financial stability focus of the current article.

4.1.1 Substitutability with deposits

CBDCs exhibit a set of hybrid attributes that renders a priori uncertain their degree of substitutability with bank demand deposits and, hence, their overall impact on financial stability. As discussed above, CBDCs can range from digital analogues of banknotes to instruments with similar characteristics to bank demand deposits. The safety profile of central bank digital currencies (CBDCs) is largely similar to that of demand bank deposits protected by a deposit guarantee program. Indeed, CBDCs could potentially serve as direct replacements for term deposits if their allowed maximum outstanding balance and compensation reached a significant level. This may explain that the macroeconomic oriented literature resorts to retail deposits as point of comparison. Contemplating CBDCs as direct substitutes of term deposits would emphasize a role for them in the channeling of savings as opposed to a role as facilitator of payments.

CBDC effective substitutability with deposits is strongly design dependent. Its scope and intensity is shaped by an interlinked mix of financial and service related attributes. Service related considerations are a function of the use cases contemplated in the design of a CBDC, and the universality of their scope. Meanwhile, the key financial attribute is the remuneration rate attached to the CBDC, a feature that may impact significantly the speed of bank disintermediation.

The degree of service-related substitutability of CBDC and deposits may be very diverse. It may stretch from the extreme case of seamless and unconstrained integration with deposit accounts to one where the presence of frictions put sand in the interoperability of flows between CBDCs and bank deposits. The disintermediation risks experienced by a bank are obviously greater in the former case.

A bank account that is nominally interoperable with the CBDC could still be subject to frictions due to uncooperative practices (e.g. fees on money movements) as a defensive bank strategy against disintermediation. Such moral hazard risks might be limited by design, through a mechanism that combines a CBDC holding cap and a procedure to drain overflows, so that flows larger than the CBDC limit can be processed by drawing on the bank account or, alternatively, by depositing the excess of funds (this is envisaged for the digital euro, see section 5.1). The joint operation of a cap and a waterfall can preserve both the storage value and the transactional purpose of deposits outside the constrained range of operation of the CBDC.

Instead, a CBDC that incorporates structural frictions may be less attractive and less risky. (Li et al., 2024) demonstrate this phenomenon by analyzing the hedonic evaluations of CBDC demand in various distribution settings, such as CBDCs distributed through Canadian postal offices or bank branches. A subtle friction that may limit competition is the

operation of bundling effects in the provision of financial services by banks across a range of complementary products (mortgages and checking accounts, for instance)

A fundamental friction that might isolate CBDCs and bank deposits is imperfect convertibility, a sort of endogenous exchange fee between money forms. Although lifting the assurance of convertibility by design entails breaking with the singleness of money, the financial stability concerns caused by disintermediation potential of CBDCs have prompted academic proposals to relax convertibility. An extreme form of convertibility-based differentiation between CBDCs and bank demand deposits is the one proposed by (Kumhof, and Noone, 2018) who advocate an arbitrage-based model of money that hinges on fluctuating exchange rates between the two, not unlike the relationship of the market of value stablecoins with the value of actual money. Relaxation of CBDC convertibility by design thus breaks with some of the fundamental tenets of efficiency and risk profile of the money ecosystem.

Financial and service-related features could exhibit certain coupling in order to safeguard some minimum demand of CBDC and limit the risk of adoption failure. Namely, some component of CBDC remuneration could potentially be a function of the CBDC convenience relative to bank deposits. Some CBDC features, like a perception of differential privacy between deposits and CBDCs, may never be amenable to compensation with a remuneration differential.

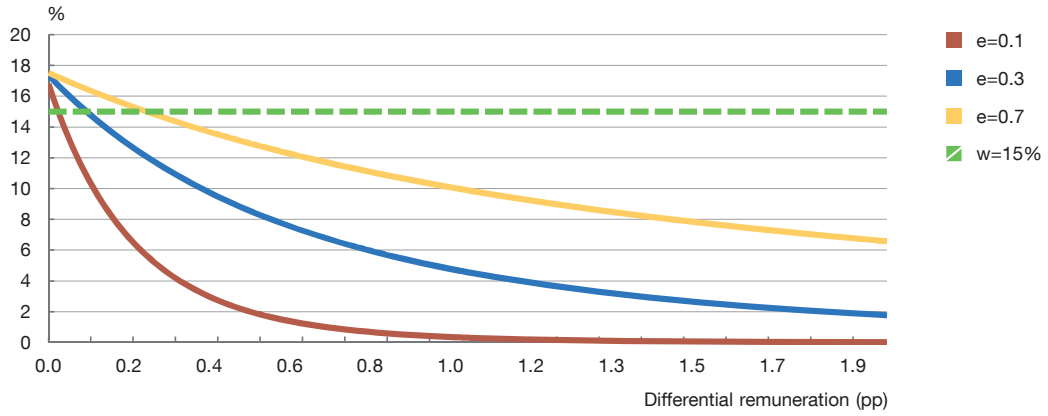
The academic literature has relied commonly on parsimonious models based on the utility provided by different baskets of money to represent different scenarios of substitutability. The drawbacks of this strategy relate to implicit assumption on the scale of the flow of liquidity services and of CBDC demand (Bindseil, and Senner, 2024). But bearing in mind this limitation it can be at least informative of the role of interest remuneration on substitution effects. In particular, the use of a CES (Constant Elasticity of Substitution) aggregator for the liquidity sources that feed the agents' utility of liquid financial holdings is particularly handy. A split of this overall balance L between demand deposits (D) and CBDCs (C) and a parameter of substitution (e) can represent situations where they are perfect complements (e = 0) and perfect substitutes (e = 1) as well as intermediate ones. Formally,

$$L = [(1 - w)^{e} D^{1-e} + w^{e} C^{1-e}]^{1/(1-e)}$$

where w represents the benchmark preference attributed to each of the liquidity sources. (Cirelli, and Nyffenegger, 2023) recollect some of the assumptions on the liquidity substitution made in the literature to characterize substitution between CBDCs and bank deposits. The range identified for the parameter e [0.125-0.7] provides the basis for a sensitivity analysis of the demand for each of these two forms of money. In this theoretical setting (Cirelli, and Nyffenegger, 2023), it is also possible to define a partial equilibrium condition for the relation between demand for deposits (D) and CBDCs (C) that captures both preferences and differential remuneration effects. Namely,

Chart 1

Demand of CBDC relative to the one of deposits for a range of remuneration differentials (a)



SOURCE: Own elaboration.

a The chart represents the relative demand of CBDCs when their weight in the utility of liquidity services is 15% (green discontinuous line).

$$C = \frac{w}{1-w} \times \left(\frac{r - r^d}{r - r^c} \right)^{\frac{1}{e}} D$$

where r, r^d and r^c and stand for the remuneration rates of the safe asset, of deposits and of CBDCs, respectively.

In addition to the substitution of bank deposits with CBDCs, the possibility of banknotes being replaced should also be considered. The strength of substitution between banknotes and CBDCs is uncertain considering how the demand of banknotes has withstood the substitution pressure from already existing digital payment instruments because of their complementary use cases.

Another important driver of uncertainty as regards the true scope for disintermediation is the actual preference w for different liquidity sources. This uncertainty renders the problem of disintermediation dynamic. The supplied share of liquidity services w* may be different of the demanded one when holding limits constrain the uptake of CBDC. A preferred share of CBDCs in excess of the supplied share w* would leave an unsatisfied level of demand that would not manifest itself immediately, but would lead to further disintermediation of deposits in the future, i.e. when the cap is eventually lifted. The issue has a direct bearing on the policy of limits discussed in 4.2.1.3.

Making a right choice on the remuneration differential between demand deposits and CBDCs seems to be critical to achieve a working ecosystem of money when including the latter. Chart 1 depicts relative demand of CBDC for various scenarios of the parameter e driving elasticity of substitution and for range of differential remuneration values. High substitution (low value of e) implies that the remuneration differential between CBDCs and demand deposits must be narrow for coexistence to take place.

Another potential driver of uncertainty regarding the scope for disintermediation is the actual policy guidance followed by authorities for CBDC remuneration. The diversity of responses on this issue tends to parallel the range of goals under consideration. In the macroeconomic literature, financial stability considerations have been largely shadowed by policy choices where CBDC remuneration is exploited as a tool that that expands the macroeconomic stabilization toolkit. (Bindseil, and Senner, 2024) undertake a critical review of heterogeneous modelling assumptions on CBDC design and launch conditions which have led to misconceptions relative to the one of the announced CBDCs. In particular, modelling assumptions in the academic literature reviewed tend to determine that the remuneration of CBDCs does not entail significant substitution effects with deposits whilst these very same risks have led central banks to curtail the pre-announced remuneration of CBDCs to the one of physical banknotes.

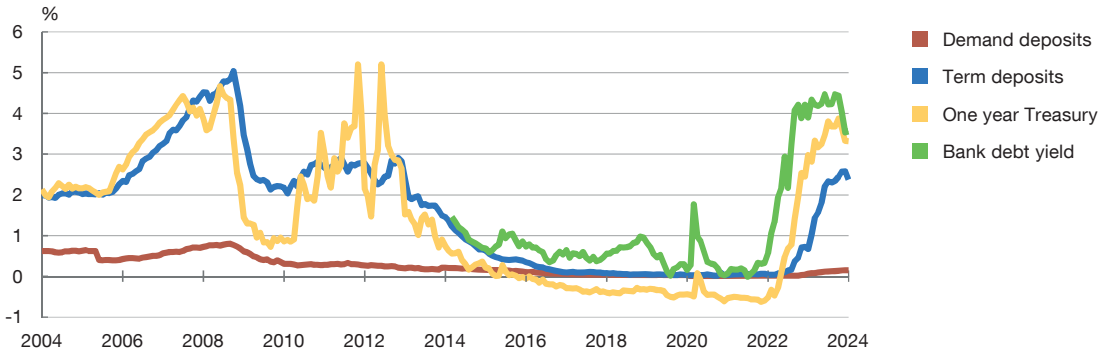
Public finance goals are sometimes perceived as influencing potential CBDC remuneration choices beyond the intent of existing plans. (Bacchetta, and Perazzi, 2021) analyze the optimal remuneration that would balance the opportunity costs of holding a CBDC and its impact on central bank seigniorage. A higher remuneration of CBDCs would induce outflows of deposits and households could then capture the rents that would flow just to bank's shareholders if deposits were not disintermediated. Interestingly, however the authors highlight the relative irrelevance of such public finance mechanism in significantly modulating CBDC remuneration rate if the general opportunity costs of holding money are low, as it has happened after the global financial crisis.

The adoption of a micro-economic goal tends to place CBDC remuneration within a narrow range. The enhancement of the efficiency of money mobilization with CBDCs must reconcile a sufficiently high remuneration level that incentivizes holding liquid balances with the containment of deposit disintermediation effects. Chart 1 has highlighted that this range gets tighter as the propensity for substitution is larger. The close to zero rate of demand deposits (see Chart 2) places CBDC remuneration within the interval $[0, r_d + \Delta]$ where Δ reflects the willingness to pay (implicit fees) to hold transactional balances in a commercial bank as a reflection of bundled services. The higher the stickiness of demand deposits the larger the magnitude of Δ. Certainly, a CBDC subject to a holding limits might theoretically be remunerated at higher rates than indicated by the given range, albeit at the risk of creating "latent financial pressure" to substitute deposits once limits are revised down the road.

Decisions on CBDC remuneration across time further adds an uncertainty layer and may lead to potential disintermediation fears. A direct need of adjustments results from the varying mix of opportunity costs of CBDC demand as financial conditions evolve. Chart 2 displays for the Spanish market the dynamism of benchmark rates relevant to determine the relative demand of CBDCs. But CBDC remuneration adjustment may entail political economy costs for central banks with an uncertain net effect on the materialization of disintermediation risks. Against this backdrop, (Paul et al., 2024) highlight the importance of calibrating CBDC remuneration as a spread relative to a relevant exogenous (market or policy) rate.

Chart 2

Demand deposit rates and other bank debt funding costs (a)



SOURCES: Author and Banco de España.

a The chart highlights the sticky dynamics of demand deposits and the (loose) link of other bank funding rates to the safe asset rate.

All in all, the multiple trade-offs influencing optimal CBDC remuneration have led practitioners to prefer a static remuneration at 0% or a value close to that value. As a compromise solution, the merits of a such a choice are not obvious. It may deter from CBDC adoption due to the limited width of the remuneration range where CBDCs could compete with deposits. But it limits disintermediation risks and looks like a particularly stable standard, because it is conceptually underpinned by uncontroversial rules on the remuneration of money like setting it so that cost of holding money equals the (zero) marginal social cost of satisfying its demand (Friedman rule) or the one that asserts that intermediate goods serving payment purposes should not be taxed (Guidotti, and Végh, 1993). The fact that these rules are unrelated in substance with the problem of CBDC remuneration tends not to be weighed in.

4.1.2 Adoption and governance-related risks

the lack of widespread adoption of a universal CBDC would mean that the original concerns motivating its consideration remain unaddressed, potentially leading to continued exposure to significant risks in the future. In particular, the threats over the singleness of money from "stablecoin" based payments, the improvement of retail payments or monetary sovereignty could be compromised.

CBDCs adoption success entails overcoming the network effects of existing instruments and arrangements. The provision of both basic and value-added payment services in the increasingly digital world is a primary ingredient for a CBDC to compete in the market. (León et al., 2024) show with the help of agent-based modelling techniques that introducing a CBDC without attractive design options and stimuli could result in low and slow adoption. They calibrate a CBDC to Spain's retail payment ecosystem to conclude that features like waterfall arrangements (envisaged for the digital euro) and positive remuneration spread are effective to foster adoption.

Social conventions can also be a hurdle for adoption, with systemic consequences. Social preferences on privacy and on public-private cooperation are two outstanding issues that may shape social acceptance of a universal CBDC. The information content of CBDCs may touch on social values on the privacy content of money that have proved to be very important for the demand of physical banknotes. The minimal information carried by banknotes on anything other than their value stands behind the significant widespread demand for large banknote denominations (Shy, 2023).

The presumption of privacy for CBDCs is less credible than for banknotes due to their digital implementation and, in any case, a trustworthy implementation of privacy may require costly data engineering.[7] Society's apprehensions regarding the examination of transactions completed through deposits are often mitigated by the safety provided by the incentives of intermediating banks to protect their customers. CBDCs lack a similar form of mitigation. Their demand could thus be very sensitive to the perception of privacy.

The solution implemented to handle the privacy problem posed by universal CBDCs tends to tighten the links between central banks and commercial banks. A consistent standard for setting up the CBDC privacy profile, designed to promote widespread acceptance and reduce potential drawbacks, involves treating it in the same manner as physical banknotes and bank deposits within similar usage scenarios. But such a symmetric benchmark reinforces the natural complementarity between central banks and commercial banks in the distribution of CBDCs.

Privacy concerns compel to envisage within the standard the delegation to banks of the handling of any privately sensitive information throughout the life-cycle of CBDCs. On-boarding,[8] screening and servicing CBDC holders are information sensitives phases where banks need to step in beyond inter-operability needs. Information handling binds thus binds particularly closely central banks and commercial banks in the co-opetition process of CBDC distribution.

A universal CBDC strengthens the dependence of central banks on the distribution services provided by commercial banks. The distribution of banknotes also entails close ties but interoperability requirements with bank deposits present in CBDCs reinforce the bonds between institutions. The realignment of incentives associated with CBDCs represents a transition from cooperation to "coopetition". Coopetition refers to situations where competing agents also must cooperate to achieve a common goal or get ahead. The value creation proposition of CBDCs entails co-opetition when the new technology of money achieves the pretended advantages while preserving the stability of the system.

The risk of moral hazard under co-opetition stresses the importance of its effective governance. The governance requires compatible incentives as well as regulatory initiatives.

---

7 The recourse to encryption protocols that use zero-knowledge proofs provides privacy during transactions but the required computations may slow down throughput.

8 Onboarding refers here to the process of assimilating new customers and gathering relevant information about them.

From a design perspective, the dictum "we need to be successful [..with the launch of a CBDC…] but not too much" (Bindseil et al., 2021) highlights, for example, the importance of limiting the downside for banks through a proper calibration. A consistent business model that remunerates banks for their participation and a disciplining toolkit that drives them towards the public policy goal stand out as core elements in an ideal CBDC governance model.

A proper regulatory and supervisory toolkit is an essential component for the working of CBDCs. In the context of a CBDC project, the need for stabilization measures arises from a diversity factors like disagreements on fees to be applied, on the technical features of the instruments themselves and shirking. Admittedly, regulatory and supervisory layers create governance and management challenges of their own. (Auer, and Böhme, 2021) highlight the novel trade-off for central banks that emerges in the supervision of privacy-enhanced CBDCs. Namely, a complex technical/supervisory infrastructure is required to overcome the impediments posed to simultaneously ensure privacy while enforcing performance and integrity on an account basis. Similarly, the regulatory toolkit to eliminate moral hazard and preserve innovation expands the traditional set of duties of central banks.

4.2 Financial stability outcomes, risk mitigants and the need of constrains

This section addresses financial stability outcomes understood as deposit disintermediation effects (medium-term or "slow" fragility, in section 4.2.1 and short-term or "fast" fragility in section 4.2.2) emerging after accounting for mitigants and/or amplification factors. The bottom line is that there is a need of explicit constraints over CBDC holdings in order to ensure stability by managing uncertainty on disintermediation.

Furthermore, this section also underscores the importance of an appropriate calibration of constraints. The meaning of appropriate encompasses two dimensions. The first one relates to the adoption of a framework free of possibly unwarranted assumptions that could otherwise predetermine the results and prejudge financial stability effects. For instance, the macroeconomic literature reviewed tends to attribute a mitigating effect on disintermediation to the improvement of bank competition, something that shapes its conclusions.

The second dimension of a sound calibration relates to the type of fragility to limit. In the discussion below on the role of competition factors, it will be clear that the slow disintermediation effects unleashed by CBDCs are not unanimously interpreted as potentially damaging in the literature. Under this view, the calibration of CBDC limits should focus just in containing fast-moving disintermediation taking place as a result of bank runs and panics (Bidder et al., 2024). This paper rather argues that medium-term and short-term fragility are not uncoupled.

Bank runs can be facilitated by deteriorated fundamentals, something that compels to keep at bay not only fast-moving but also slow-moving disintermediation. The liquidity constraints faced by banks as deposits outflow pay an important role in slow evolving fragility. This plays a critical role in developing a methodology to ensure an effective control of fragilities. Section 5.2 highlights with a practical case the logic of the methodology required.

4.2.1 Medium-term fragility and the role of mitigants

Banks face medium-term fragility when they are unable to generate sufficient capital on an ongoing basis. All else being equal, CBDCs could lead to banking system fragility if the impact of more intense competition in terms of higher funding costs worsens solvency, credit and/or confidence. The routes for a potential impairment of credit will be seen to be multiple and their estimation is qualitatively more uncertain than the impact on bank funding. Universal CBDCs could potentially entail financial stability risks due to ongoing fragility if a system-wide operation of negative effects ends up impairing basic functions of the financial sector like the allocation of savings (Kashyap et al., 2002), liquidity risks sharing (Piazzesi, and Schneider, 2020) and economic growth (Böser, and Gersbach, 2020).

But the potentially negative effects of CBDCs over financial stability are not automatic or inevitable. For that to be the case not only should the strength of the substitution effects of deposits or amplification factors be sufficiently large, but the contribution of risk mitigating factors should also be small. Much of the dispute regarding the effects of CBDCs on financial stability results from broad-based uncertainty on the role of mitigating factors. The potential transformations unleashed by CBDCs in the structure of the market for bank deposits or in the market for credit may be uncertain both in magnitude and sign and is often subject of dispute.

For example, much of the macroeconomic literature assumes that the new environment with CBDCs entails more competition for bank deposits and advantageous effects on overall risks and credit (see 4.2.1.1). But the potential amplification of risks cannot be discarded when the ability of banks to mitigate deposit outflows affects credit if alternative funding (wholesale funds or central bank funding) is not available (see 4.2.1.2). These elements of uncertainty and the potential of further endogenous transformations underscores the importance of exogenous mitigants. Namely, a proper calibration of holding limits can securely mitigate against the impact of slow disintermediation (see 4.2.1.3).

4.2.1.1 CBDCs, competition in the banking sector and credit

Competition in the banking sector turns out to be an important microeconomic consideration in the analysis of CBDCs in most of the macro-economic oriented literature. It tends to shape decisively the power of transformation of the financial system due to CBDCs. But the range of positions covers a wide spectrum.

According to a radical camp, CBDCs could play a profound role in addressing competition issues in the market for bank deposits. Under this view, CBDCs would reduce the “privileged” access of banks to central bank reserves and their singular role in the provision of payment services, two essential factors driving their power in the deposit market. In the long term, the transformation unleashed could pave the way towards narrow banking, i.e. full reserve banking (Mayer, 2023). The architecture of money and credit would thus get rid of intrinsic bank fragilities and public protections so pervasive nowadays. However, (Niepelt, 2023) examines the contribution of a CBDC-based transformation to improve efficiency

in liquidity supply to find that the direct costs of existing frictions (competition and fiscal support) do not justify abandoning a two-tiered arrangement.

A moderate camp identifies also in competition the sort of market failure whose correction with a CBDC would enhance welfare. The disintermediation and repricing of deposits prompted by CBDCs would activate competition among banks and potentially reverse their initial negative impact. The concrete mechanism at play is largely model dependent. The literature attains a diversity of results on the ultimate effect based on different assumptions on the market failure at stake.

(Andolfatto, 2018) envisions a situation of a bank monopoly where a sufficiently remunerated CBDC sets a floor to bank deposit remuneration, something that reverses initial outflows and ultimately increases bank deposits and lending. Similarly, (Cirelli, and Nyffenegger, 2023) argue in a model of monopolistic competition that the launch of public money as a close substitute of deposits elevates the effective elasticity of deposits, reduces bank spreads and raises saving. In both models, a crucial condition for these reversal effects to emerge is a simultaneous reaction of both saving and transaction balances to the reduction of spreads. A model with separate effects for demand and term deposits would more realistically represent the aggregate impact of an adjustment touching partially demand deposits.

A polar case to the previous ones is the one of a competitive banking market examined by (Keister, and Monnet, 2022; Keister, and Sanches, 2023). The impact of a CBDC then depends on it having a cash-like or their deposit-like profile. When the latter prevails, banks need to keep up with the higher CBDC remuneration by increasing deposit rates while still accepting lower levels of intermediation.

The impact of CBDCs on credit encompasses a heterogeneous set of channels whose individual magnitudes may be uncertain but that jointly shape the breadth of the scenarios where CBDCs may have real effects. The issuance of CBDCs expands the role of central banks in the channeling of credit and may also affect the ability of banks to grant credit.

A first channel results from the mechanical need to recycle as central bank investments the deposit outflows placed in CBDCs. The range of transformations in central bank credit policies may be too diverse when the variety of their political economy drivers is left unconstrained. But as a general principle a discretionary public allocation of credit to the private sector is well known to entail political economy and misallocation risks. Alternatively, a credit neutral overhaul of central bank credit policies could compensate banks for the disintermediation effects that they experience although at the cost of raising moral hazard, as further discussed in (4.2.1.2) below.

A second channel relates to the revisions of bank lending policies caused by the quantitative crowding-out of deposits and by the ensuing activation of bank frictions. The reduction of equity as a result of lower bank profitability and the activation of liquidity

constraints counts as significant frictions for credit. This paper assigns to this channel a primary role in the identification of effects from CBDCs, as further elaborated under section 5.2 below. In the same vein, (Gersbach, and Zelner, 2024) caution about permanent distortions caused by CBDCs to the flexible operation of fractional reserve banking due to an activation of new frictions. But there are no obvious candidates for these hypothetical frictions. Not even the higher funding of float[9] needed to settle instantaneously CBDCs (higher than the one required for current retail payment systems) counts as a potential significant restriction.

The estimation of the impact of a quantitative tightening effect (i.e. no compensatory funds available instantly) may be overestimated if the dynamics of its coverage is not considered. For example, a static estimate based on the magnitude of loan-to-deposit bank ratios would not take into account that the lost funds could indeed be sourced , although at a higher cost. (Bellia, and Calès, 2023) exploit a data panel of European banks containing information on profitability and deposit intensity ratios to guess the impact of a CBDC along a quantitative tightening logic. In any case, the relevant deposit metric to consider is the amount of demand deposits and not the amount of total retail deposits.

A third channel proposed in the literature works in a reverse direction, i.e. from credit to fragility. A sizeable CBDC could displace bank credit from loans to sovereign debt as a result of more intense collateral needs in the view of (Burlon et al., 2022). They study how this mechanism and the funding shock caused by deposit outflows plays out in a Dynamic Stochastic General Equilibrium (DSGE) model where CBDCs also can perform a macroeconomic stabilization function. The resulting balance between disintermediation and stabilization effects turns out to motivate a non-monotonous response of welfare to the size of CBDCs outstanding and, indeed, the authors conclude that the optimal amount of CBDCs is a significant one (between 15% and 45% of quarterly GDP). In any case, the risk of financial amplification of shocks is also assessed to be well under check.

A fourth channel relates to the potentially higher cost of credit. But the operation of a credit supply channel, through the impact of deposit competition on credit policies sounds as too speculative. In fact, the empirical literature on the impact of bank competition on credit is largely inconclusive (De Nicolo et al., 2006). A more reasonable outcome is that demand for credit reacts to CBDCs based on the pass-through of the higher funding costs and the elasticity of demand. Section 5 shows for the Spanish banking market case that the magnitude of this mechanism can be small in normal times.

A fifth channel links banks credit policies with the transformation that CBDCs may have on the information set under which they manage their operations. Information handling can be a sensitive are for CBDC design. Visibility of the payment flows of customers has positive effects on bank credit. A veil on the flow of customer payments channeled with

9 Float refers typically to interim money recorded both in the account of the payer and in the account of payee. This happens typically due to the slow transaction processing speed involving that sum of money. An instantaneously settled CBDC does not entail float but the finality of the settlement requires funding previously for it.

CBDCs would thus be negative. But the prevalence of the symmetry principle on privacy highlighted in section 4.1.2 neutralizes this mechanism. In fact, the transformation of payment processes prompted by CBDCs may enable banks to exploit conditional payments and data-related business more generally.

4.2.1.2 CBDCs and compensation of deposit outflows

The ability to compensate the funds lost by banks can be crucial to dampen the bank fragility concerns raised by CBDCs. (Whited et al., 2022) find that access to compensating wholesale funding limits the pass-through of CBDC competition to lending. In their calibration they identify a 25% passthrough in lending from a drop in deposits. The automatic compensation at the risk free rate of deposits lost assumed in the model of (Bacchetta, and Perazzi, 2021) also leads to split effects of CBDCs on funding and credit markets.

The ability to compensate outflows determines that CBDC impact depends on market and institutional settings. The ability to source funds from other banks through various funding instruments makes of disintermediation a non-binary and idiosyncratic outcome. It may be accommodated by funding rates and the reduced profitability varies across banks and market settings. Chart 2 displays the dynamics of bank long term funding rates and deposit rates for Spanish banks as an illustration of the market-based analysis done in section 5.2.

The influence of institutional settings on the ability to compensate outflows results from two endogenous and complementary mechanisms. First, central banks may facilitate the compensation of outflows. In particular, they may adapt their bank refinancing and CBDC recycling policies to pro-actively respond to the challenges posed by disintermediation. The macroeconomic literature on CBDCs examined early on the importance of compensating measures provided by the central banks in the study of the equivalence between public and private money (Brunnermeier, and Niepelt, 2019). But it has also highlighted that their feasibility may be compromised by frictions like collateral availability or political economy considerations (Fernández-Villaverde et al., 2021).

A concrete dilemma that may be faced by central banks when deciding on compensation policies is whether to be neutral or stimulate the adoption of CBDCs. The deployment of a dedicated refinancing facility could enable supporting banks that intermediate CBDCs and increase holding limits. The mix of tools to contain financial stability risks might thus be rebalanced somewhat. But CBDCs do not fundamentally differ from banknotes as regards refinancing requirements and the stimulus policy applied would prove to be overly distortive.

An entirely different type of situation may emerge when central bank refinancing policy is adjusted not to stimulate CBDC adoption but as a result of the impact of CBDC on aggregate liquidity conditions. For example, (Abad et al., 2024) study the potential normalization of excess liquidity conditions and the resulting overhaul of monetary policy implementation framework. A floor system may have to transit to a corridor one if the drawdown of deposits to CBDCs is sufficiently large.

A second mechanism that could influence the ability to compensate for the lost funds is the endogenous overhaul of the composition of banks' balance sheet. CBDC issuance entails competition between banks and commercial banks for the safe asset. (Williamson, S., 2022) argues that this mechanism can lead to positive disintermediation effects even in the absence of a monopoly. A more difficult access to the safe asset entails that banks face the disciplining effect of a more limited ability to hedge their demand deposits with safe assets and hence the need to extend the term of its liabilities a result of the launch of CBDCs (Williamson, S. D., 2022).

4.2.1.3 CBDC limits and their calibration

The fact that universal CBDCs are substitute of demand deposits has been argued to require an adjusted separation principle for money. A straightforward idea to contain the disruptions of bank deposits due to CBDC is the imposition of caps on holdings. But the implementation of limits faces relevant challenges like the choice of limit modality, the methodology to calibrate static limits and their dynamics of adjustment.

The type of limits on CBDC holdings proposed in the literature and by practitioners result from the combinations of three different attributes to the constraint: (i) static versus dynamic, (ii) aggregated versus disaggregated, and (iii) institutional-based restrictions to hold CBDCs. Table 2 outlines the main guiding principles considered in the selection of the various configurations of limits. In general, they result from the application of a principle that they ensure financial stability in a preferred use case. For example, a preference to closely emulate banknotes with CBDCs and to retain a storage of value function with them suggests the adoption of dynamic limits. Dynamic limits just set restrictions on the size of deposit outflows from banks over specified intervals of time to keep at check the size disintermediation (Dudley et al., 2023).

Conversely, the widespread choice of establishing explicit and granular boundaries on the stock of CBDC holding underscores mainly a transactional rationale for the CBDC that preserves stability on an ongoing basis.[10] In turn, restrictions along some institutional perimeter limit the categories of agents who can hold CBDCs. For example, access to CBDC can be restricted in a manner that preserves the circulation cycle of transactional money for some agents. For instance, when only individuals may maintain CBDCs the activity with money of non-financial corporations are required cannot entail a disintermediation risk. They have to hold all their cash in bank accounts.

A fundamental methodological choice when calibrating limits to contain disintermediation is the election of the metric to target. The major alternatives are a measure of the erosion of recurrent bank earnings or some metric of fast drawdowns of deposits under stress. In fact, the choice collapses into just a single metric aimed at of containing outflows under stress when slow disintermediation yields positive transformations because

10 See (Genc, and Takagi, 2024) for a survey of design models.

Table 2

Notional types of limits on the balance of CBDCs outstanding: control variable, perimeter of control and goals

		Control	
		On a stock variable	On a flow variable
Perimeter of the limit	Aggregate	Macroeconomic-Transactional-No inclusion	Macroeconomic-Store of Value-No inclusion
	Sectorial	Microeconomic-Transactional-No inclusion	Microeconomic-Store of Value-No inclusion
	Granular	Microeconomic-Transactional-Inclusion	Microeconomic-Store of Value-Inclusion

SOURCE: Own elaboration.
NOTE: The table attempts to reflect the broad economic logic of diffirent configuration of limits on CBDC balances aimed at ensuring stability. The formulation of limits on a stock or a flow variable places the focus on a transactional or a storage of value functionality. The perimeter on which the control is applied tends to determine that allocation of CBDCs follow a macro- or a microeconomic allocation logic. In particular, granular limits may pursue inclusion goals more easily than other kind of checks on holdings. The categories represented in the table are just notional types of limits. Real limits may be a mixture of some of the categories identified because some of them are compatible. This is the case for example with sectoral and granular limits. As discussed in the text, the different configurations are not equivalent from an stabilization perspective.

of improvements in bank competition. For example, in their calibration (Bidder et al., 2024) weigh the improvements of a CBDC in payments and the risk of fast disintermediation. The reduction in leverage and the increase in competition associated with slow disintermediation takes it out of the optimization.

But the uncertainty on the mitigants and amplification factors of the impact of CBDCs on bank fragility suggests keeping under control the magnitude of slow disintermediation. Another advantage of this approach is the indirect limit placed on fundamentals based fast disintermediation (see 4.2.2)

The unfolding of uncertainty across time imparts calibration with dynamic structure. Calibration of holding caps entails both a medium and a long-term perspective. From a medium-term perspective, financial stability concerns call for setting holding caps at a level below the size of deposit outflows that determine the onset of disruptions because of the presence of frictions.

In an ideal scenario, calibrated holding limits would hit exactly the latent demand for CBDCs, i.e. the one that would prevail without restrictions. But it looks more prudent to accommodate that demand from below, i.e. to ramp up supply of CBDCs in a controlled way through gradually laxer caps. The disparity between the initial references for holding limits provided by some central banks like the Bank of England and the ECB may be more indicative of different perceptions on the pace of increase of CBDC supply after launch than on the ultimate target for CBDC balances outstanding, as hinted by (Panetta, 2023). In any case, the ultimate target and the path of the limit adjustment process may be path-dependent as a reflection of the influence of the transformations of bank competition and credit.

The practical element of an exercise of limits calibration is its operationalization. (Meller, and Soons, 2023) present a simulation methodology to identify the point at which various liquidity buffers of banks are exhausted as deposits outflows get larger. The presence of liquidity frictions in banks gauges the difficulties faced banks to adjust their operations

to the changes caused by CBDCs, mainly on bank profitability, liquidity and prudential metrics. The magnitude of the caps on quantities gets smaller as the frictions grow, i.e. as the buffers held by banks to absorb the impact of CBDCs get smaller. Section 5 undertakes an illustrative application of it to examine the effects of limits in a potential digital euro in the Spanish market, whilst the annex describes the balance sheet optimization program underlying the management of liquidity which is applied to this analysis.

4.2.2 Short-term fragility: the risk of bank runs and panics

CBDCs may not inherently act as a destabilizing factor for banks but could potentially facilitate the probability of bank stress. The ability to immediately call demand deposits and the potential contribution of CBDCs to facilitate runs has led to natural concerns regarding the potential for fast disintermediation. The problem may be particularly pressing when CBDC-driven slow disintermediation exacerbate strategic complementarities among depositors who may bid up bank deposit rates (Ahnert, and Martinez-Miera, 2021), further deteriorate fundamentals and ultimately trigger a bank run.

A differential contribution of CBDC as (potential) facilitator of bank stress lies in the combination of their safety and efficiency in money mobilization. Exogenous stress can spread wider with limited frictions on the back of a seamless channeling of funds. In fact, the feasibility to mobilize deposits without major frictions as a result of technology developments is also a major reason for volatile deposit flows (Bindseil et al., 2023). The onset of individual bank runs and/or panics in such a volatile environment has spurred initiatives to expand sovereign support aimed at neutralizing fragility without killing the (potential) disciplining effects of (fundamentals-driven) bank runs.[11] But CBDCs can effectively operate as a countermeasure to that program. They offer a safe and very efficient public exit option to depositors (a public "safety valve"), something that contradictorily mines the support program.

Indeed, the working of a CBDCs as a "safety valve" during a crisis context tends to be worse the better is its functional design for normal times. The working of a mechanical valve requires a resistance mechanism that limits the escape of liquids. Following this analogy, an unrestricted highly interoperable CBDC might end up functioning as a leaking pipe: a high interoperability with deposits may eliminate entirely the correlate of the transaction costs eventually braking the conversion of deposits into banknotes even in a crisis. The subpar performance of universal CBDCs as safe valve thus should be expected to show up during crisis times in terms of quickly evolving inconsistencies.

The potential role of CBDCs as "safety valve" exposes a fundamental financial stability dilemma that is absent in the case of physical banknotes (see 3.2). Namely, either (1) CBDC enhance the overall feeling of safety among depositors and thereby stabilize the market, not unlike the classical contribution of the elastic provision of banknotes. Or, (2)

11 The ability offered by digital technology to facilitate and to swiftly coordinate decisions across agents, as evidenced recently in SVB crisis, further raises the financial stability concerns of CBDCs under stress.

CBDCs offer a route to escape from the internal contradictions prevailing in the financial system in crisis times, and, thereby, further spur financial instability. Overcoming the dilemma of CBDC in crisis times then requires targeted policies to issues (1) and (2). More specifically, (1) may be literally infeasible, but a regime of co-existence between banknotes and CBDCs may restore a "safety valve" in crisis times. In turn, (2) calls for a calibration of CBDC limits aimed at keeping at check not only medium-term fragility but also fast disintermediation.

The calibration of holding limits specifically aimed at containing fast disintermediation should ideally be related with the caps to deal with medium-term fragility, but operate independently. But the specification entails some challenges. It raises the confusing issue of a dual set of limits, one for slow and one for fast disintermediation. The duality also questions implicitly convertibility between CBDCs and bank deposits if the cap for stress time is smaller than the one for normal times (based on slow disintermediation).

The sensitivity of the composition of the optimal demand of liquid balances to remuneration differentials has been envisaged as a mechanism to address run risks. (Bindseil, 2020) sketches a mechanism based on the tiered remuneration of CBDCs that theoretically could disincentive outflows away from bank deposits into CBDCs. The application of sizeable negative rates would discourage further outflows in extreme cases. But the efficacy of the mechanism can suffer from robustness issues due to the complex and dynamic action-reaction interactions required for them to work.

In addition to the need of a cap on holdings, financial stress underscores also the importance of a coexistence regime between physical banknotes and CBDC. The elastic issuance of money is instrumental to gain time and deal with the crisis but, whilst CBDCs can be pro-cyclical and accelerate contagion, banknotes can support the new transactional and storage needs without those hindrances. This same mechanism could also distort perceptions on the soundness of individual banks exposed to the turmoil and increase the potential for contagion. The "safety valve" gap of CBDCs during stress thus highlight the importance of a coexistence regime between banknotes and CBDCs. In fact, a similar conclusion results when comparing the robustness of physical banknotes and CBDCs across types of crisis (see Table 3). Banknotes not only can operate as "safety valves" during most financial crisis but remain operational in crisis the technology of the money. CBDCs and banknotes are definitively complementary forms of public money.

However, ultimately a monetary "safety valve" does not guarantee success in dealing with a situation of stress. Crisis management goes beyond the scope of this paper. But eventually convertibility suspensions are needed to reset the overall set of economic consistency conditions that ensure the singleness of money. (Rösl, and Seitz, 2022) recount this process in the context of the Greek banking crisis. Similarly, a large sovereign crisis may unavoidably trigger the onset of inconsistent scenarios highlighted like the ones highlighted by (Fernández-Villaverde et al., 2021) and finally require shutting down existing "valves". Physical banknotes and CBDCs would not be too dissimilar at a reset point.

Table 3

Crisis types and comparative adavantage of banknotes and CBDCs

	Banknotes		CBDC
	Transactional	Storage of value	Transactional
Monetary	↔	↓↓	↔
Political	↑	↑↑	↔
Financial	↑	↑↑	↔
Cyber	↑↑	↑↑	↓↓
Natural	↑↑	↑	↓↓

SOURCES: Own elaboration and Rösl (2022).
NOTE: The table attempts to represent the performance of banknotes and transactional CBDCs functionalities in different types of crisis. The focus on transactional CBDCs excludes an analysis of the performance of the storage of value. The meaning of the symbols is as follows. ↔ represents a broadly neutral response while ↑ means an increase in demand or the opposite when the arrow heading down. The balance of strengths and weak points of banknotes and CBDCs highlight the complementairty between CBDCs and banknotes, especially under cyber shocks.

But in the way to a reset point, CBDCs can be useful to handle run risks through controlled convertibility suspensions. (Panetta, 2023) assesses positively the potential contribution of CBDCs its potential role as circuit breaker in the hands of public authorities to deal with contagion risks. Certainly, the argument may work ex-post, i.e. as a crisis management tool. The formulation ex-ante of such a role for CBDCs might lead to more problems than solutions if it erodes credibility ion the system. In any case, a convertibility suspensions should still satisfy other requirements to improve welfare, such as leading to an increase the signal to noise ratio in the banking system under stress (Gorton, 1985).

A proposal to end with bank runs and convertibility suspension is to breaking away with convertibility guarantees altogether (Kumhof, and Noone, 2018). This view implies that exchange at par between CBDCs and deposits is not assured at all and that this part of the money ecosystem would be driven by arbitrage. The price to pay for financial stability seems to be too high and too uncertain to be acceptable.

5 Digital euro and the financial stability impact on the Spanish banking system

5.1 The digital euro

The purpose of this section is to complement the general discussion on the role of stability considerations on CBDCs with some specific highlights for the digital euro project, a prototype of a universal CBDC. It is outside the scope of this paper to describe exhaustively the project itself, already very well documented in other publications.[12] The purpose of this section is rather to illustrate with a concrete case some of the ideas discussed previously.

After completing a two-year investigation phase, the digital euro project has transitioned to a preparatory phase to lay the foundations for a (still) potential issuance decision. The conclusions gathered in the investigation phase and the orientation of the project can be examined in (European Central Bank, 2023a) as well as in the interim text setting its legal basis and the opinion expressed by the ECB about it (European Central Bank, 2023b).

The objective of the digital euro is to provide to the general public a digital payment instrument issued by the central bank as legal tender. The most salient goals pursued with it are the provision of a state-of-the-art and cost-efficient digital retail payment instrument, the enhancement of the strategic autonomy of Europe and the achievement of financial inclusion goals. Additionally, the digital euro legal text and the associated ECB opinion emphasize repeatedly the commitment not to impair financial stability.

The digital euro is profiled as a public monetary infrastructure[13] to underpin the euro as unit of account and medium of exchange in the context of an intense digitalization. The regulatory framework for the digital euro seeks to ensure that individuals can use basic digital euro services free of charge for basic purposes. The infrastructure leverages strongly on existing intermediaries for the distribution of those services on a mandatory basis.

Financial intermediaries are planned to be fully responsible for the management of the on-boarding and the direct relationship with clients and no contractual relationship is envisaged between the Eurosystem and digital euro users. The interoperability of digital euros with demand deposits is also a central feature of the arrangement.

The digital euro makes compatible a cap on individual holdings of digital euros with a frictionless payment experience through a system of so called “waterfalls”, i.e. mechanisms to drain overflows of payment orders, so that those that would exceed the CBDC limit can still be processed by drawing on the bank account or, alternatively, by depositing the excess of funds. In other words, incoming or outgoing payments whose size overflows the wallet limit can still be processed through the automatic operation of transfers between the operational digital euro account and the sight deposit account of the client.

12 See digital euro web page at the dedicated ECB web for the project.

13 See section 2 for the rationale and nature of digital public infrastructure.

The scope of the digital euro is further shaped by its focus on improving payments. Its design restricts the digital euro as an instrument to store economic vale by envisaging limits on holdings along two important dimensions. First, the digital euro can be held just by individuals. Merchants are not foreseen to hold digital euros overnight. Inter-operability with bank deposit accounts should lead to a mechanical transformation of their digital euro balances into demand deposits. This limit restricts the quantitative scope of outflows from bank deposits to individuals. Second, individuals who can be net holders cannot exceed a cap whose value will be calibrated bearing in mind the risks of disintermediation.

Another key consequence on the focus on payment processes is the fact that the digital euro is not planned in the initial draft legal text to be remunerated, but the ECB cannot exclude future scenarios where remuneration of the digital euro might be warranted. The digital euro project attempts to provide a public payment infrastructure without compromising monetary policy transmission or financial stability.

The digital euro openly highlights its intent to improve the European strategic autonomy in the retail payments scape against the backdrop of a dominant position of non-European card companies. The argument of inertia as catalyst for public intervention in technological development seems to apply. For example, (Meyers, 2023) reviews the multiple initiatives adopted by EU institutions in the past to deepen the working of cross-border retail payments against the backdrop of an oligopolistic market for credit card services. But commercial banks have faced difficulties to coordinate in the effective transformation of European retail payments due to the multiplicity of roles.

Anonymity of the digital euro has proved to be an important concern for both users and authorities. But the digital euro will not offer complete anonymity due to legal requirements regarding anti-money laundering and combating the financing of terrorism. Holders of digital euros will have to identify themselves with their payment system provider when they are “on-boarded”, although access to data on transactions will emulate for low denomination cases the protections enjoyed by banknotes.

The bottom line is the fact that the digital euro is conceived as a universal sort of CBDC, based on the range of use cases and strong interoperability with bank deposits contemplated. The potential financial stability risks are planned to be addressed with a cap on holdings by individuals and possibly with zero remuneration.

5.2 Impact study for the Spanish banking system

This section examines the potential impact for Spanish credit institutions of the introduction of the digital euro. The analysis of this section can only be tentative. The digital euro project is still undergoing a preparatory phase and a full-fledged assessment of its risks can only take place with a broader information set, which would not be expected to be available until a date closer to the potential launch. The main goal of the analysis is to examine in an

applied context the calibration issues put forward in a general context in section 4. More specifically, this section examines the ability of Spanish banks to accommodate holding limits for the digital euro of various magnitudes.

The analysis done shocks demand deposits of Spanish households held in a sample of 65 deposit institutions comprising both significant (SI) and less significant (LSI) ones[14] in order to gauge the magnitude of problematic scenarios of digital euro take-up. The shock scenarios will be formulated as a proportion of the base of demand deposits of households in each bank. That fraction is assumed to be uniform for different banks and with increasing intensity as the severity of the outflows grows. Ideally, the shocks should reflect the heterogeneity of banks' customers of banks and their latent demand of digital euros as modelled by (Lambert et al., 2024). In the absence of the required information, the framework to interpret the meaning of the scenarios is the one contained in (Adalid et al., 2022) who estimate that an instrument serving a payment function in the euro zone is estimated to require a take-up of EUR 1,500 per capita whilst a large demand would amount to EUR 14,000. A benchmark figure for a capped take-up that matches the set of functional goals is EUR 3,000 for every individual eligible to hold digital euros.

Importantly, the simulation exercise does not shock deposits which are not close substitutes of a potential digital euro. Term deposits held by households and demand deposits held by NFCs are assumed not to react initially to the launch of a digital euro. The first assumption might have to be relaxed to examine second round effects in conditions where a reshuffling of payment balance may induce changes in the allocations of savings in bank deposits. But the planned remuneration policy for a digital euro does not anticipate that to be necessary. The second assumption follows from the envisaged institutional restriction to hold digital euro accounts to any entity other than individuals. The deposit balances shocked are dated as of end 2022.

The simulation date is not immaterial for the risks captured by this exercise. Demand deposit balances tend to be sensitive to interest rate conditions. The opportunity cost of term deposit rates falls (increases) relative to the convenience yield (due to immediate liquidity) of demand deposits when interest rates are lower (higher). Demand deposits can thus cover liquidity and (residual) purposes.

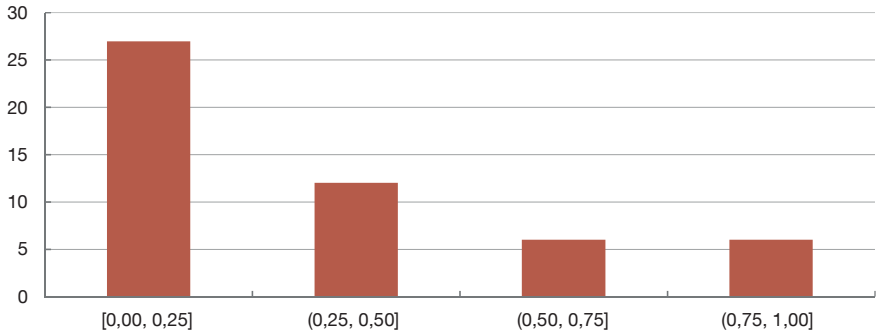
At end 2022, aggregate liquidity in the Eurozone was still abundant and term deposit rates quite low despite the ongoing tightening process. The split between demand and term deposits in Spain had traditionally followed the pattern 40/60, although the rule broke down when banks revised their liquidity strategies in the context of QE policies. At end 2022, the deposit composition of Spanish credit institutions had reached 80/20, as the spread between demand and term deposit rates had compressed. The elevated weight of demand

14 SI and LSI credit institutions are categories envisaged in the SSM to differentiate between larger and smaller ones and organize supervision accordingly. Sis are supervised by the ECB and LSIs by national competent authorities. The data sources employed are a range of regulatory filings to the Spanish competent authority. Namely, statistical reporting of assets, liabilities and P&L relating to their business in Spain as well as reporting of LCR and NSFR metrics.

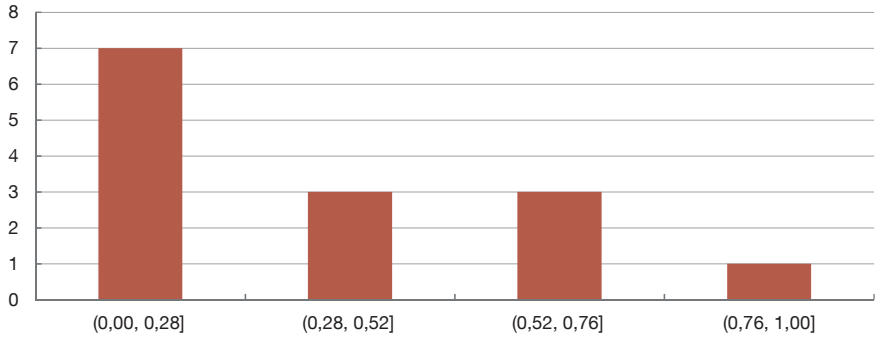
Chart 3

Coverage of demand deposits with reserves by type of credit institution (a)

3.a Coverage ratio for Less Significant Institutions



3.b Coverage ratio for Significant Institutions



SOURCES: Banco de España and own elaboration.

a The charts display the count-based histogram of the coverage of demand deposits with liquidity held in the central bank by LSI and SI Spanish credit institutions as of 2022 end.

deposits at the considered period justifies that the magnitude of the exposure to the risk of (demand deposit) outflows cannot be considered as biased to the downside.

A more relevant exposure metric to the liquidity risks posed by deposit outflows is the balance of deposits net of liquidity held at the central bank. Chart 3 displays the magnitude of deposit outflows that banks would be able to accommodate drawing on their excess reserves at the date of the analysis. The raw analysis (deprived of any consideration of limitations to draw reserves) differentiates between SIs and LSIs. The chart conveys a clear sense that the preparedness as at end 2022 was heterogeneous.

The ability to individually cover shocks with reserves does not convey a realistic picture of resiliency. Leaving aside the fact that a 100% outflow is an extreme assumption to make, a hypothesis of self-insurance against shocks leaves outside of the radar the potential contribution of market mechanisms to address the consequences of shocks. The operation of frictions to accommodate the outflows determine the transition in the dimension of the problem caused by outflows as they get larger until the onset of risks for financial stability. Namely, demand deposits of households are shocked parametrically in increments of 5 pp.

from 5% until 40% and banks optimize their response within their limits. The onset of financial stability risks can ultimately be gauged by a significant permanent impact on their earnings generation capacity.

Banks optimize the re-composition of their funding base to accommodate deposit outflows much as in (Meller, and Soons, 2023). The annex provides a simplified account of the analytics and discusses the realism of the assumptions of this optimization model. Under this framework, banks can fund outflows with excess reserves, medium term secured debt, unsecured interbank debt, central bank funding and long-term funding. The number and type of markets considered might be wider though. An optimal response by each individual bank is characterized by the choice of a certain composition of funding instruments that minimizes the cost of restoring the funding equilibrium of the bank balance sheet while still fulfilling any applicable prudential and market access constraints. More specifically, the relevant constraints considered are liquidity prudential constraints (LSR and NSFR) as well as counterparty limits and collateral needed to access markets.[15]

Altogether, an equi-proportional outflow from demand deposits of the sample of considered banks entails a response that is captured by a set of 65 independent linear programs. A key element to make useful this set of independent linear programs is the imposition of counterparty restrictions that limit individually their access to the interbank market as a proportion of their equity or constraints the volume of lent out funds proportionally to the size of each bank. The operation of this realistic constraint broadens the expression of internal liquidity frictions in terms of new funding instruments required. A qualitatively different route to limit the contribution of interbank markets and to activate these instruments would be to incorporate “market closure” conditions, i.e. the clearing of the market for each of the instruments. But the outcome would not be realistic to the extent that the binding constraint in practice tend to be counterparty limits.

Chart 4 depicts the successive expansion of the palette of funding instruments used by LSIs and SIs as the outflows get larger. The exhaustion of cheaper funding instruments like reserves paves the way to more expensive ones up to the limits allowed by their relevant constraints. Collateralized interbank borrowing can be resorted up to the inventory of freely available collateral. In turn, uncollateralized borrowing is resorted to up to the point where LCR and NSFR are impaired and reach a binding constraint.

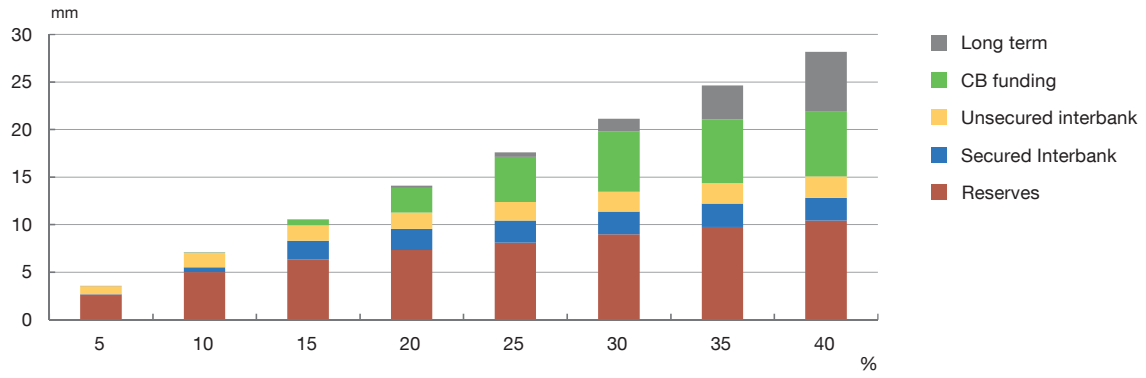
The simulation of chart 4 assumes that banks optimize their funding sources while allowing some deterioration in the prudential liquidity ratios. More specifically, the simulation assumes that bank wish to maintain these ratios above the minimum requirement, but they are ready to let them decrease (in this case, half the way to the minimum requirement). Chart 4 highlights graphically that the funding mix must evolve towards more expensive sources to compensate increasing amounts of deposits drawdown.

15 The simplified version of this model resorts on liquid collateral instead of the broader set of instruments eligible in ECB operations for tractability reasons.

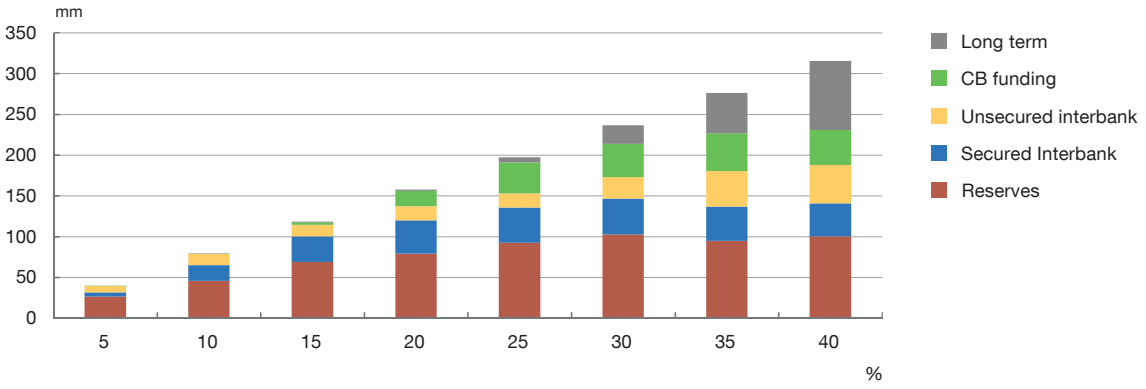
Chart 4

Optimal accomodation of deposit outflows (a)

4.a Less Significant Institutions



4.b Significant Institutions



SOURCE: Banco de España and author own calculation.

a The charts display the recourse to different funding instruments as the size of outflows increases from 5% to 40% and banks (LSIs and SIs) have to reoptimize their funding mix with market and balance sheet data as of 2022 end. The presence of balance sheet frictions grants special relevance to the availability of refinancing facilities and, in any case, to long-term finance as the funding source that ultimately accomodates accomodates funding gaps.

Chart 5 displays how the net interest margin of SIs gets affected as outflows get larger and costlier funding must be sourced.[16] Revenues from reserves held at central bank lost as a result of the outflows contribute to the reduction of margin. The magnitude of the impact is significant for levels of uptake above 10% and, in any case, the effect is heterogeneous, as highlighted by the box plots in the same chart. Some banks under pressure already in the domestic business exhibit a significant drop in earnings when they have to refund outgoing deposits. But they are low net interest income banks to start with.

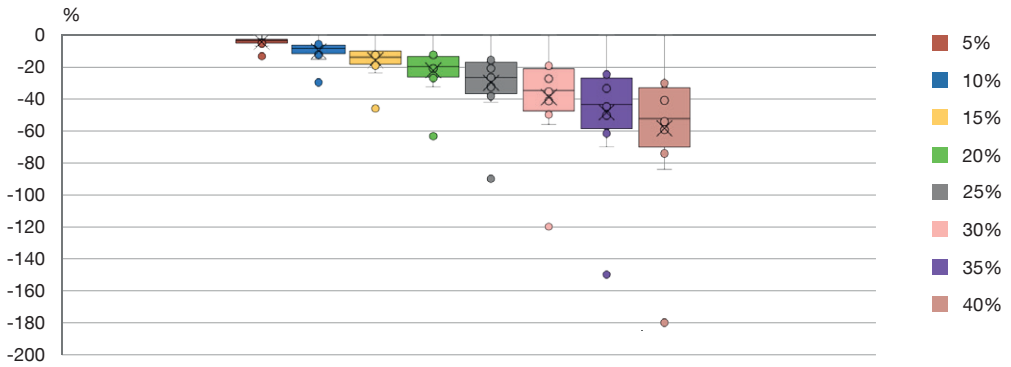
The presence of heterogeneity in the impact of outflows may extend beyond what can be captured in the described simulations. The ability to compensate in the markets the funds lost may not be just costlier, but also volatile and uncertain. Smaller banks may be

16 The estimates of NI impact are determined by the net interest income at the period of reference and the impact of outflows and optimization on costs. These are calculated on the basis of prevailing rates at the simulation date. Namely, 2% for the central bank deposit facility rate, 2.2% for the unsecured interest rate, 2.5% for the secured interest rate, 2.5% for central bank funding rate and 4.2% for the bank long term funding rate. The estimate do not account for the pass-through to credit due to the funding shock.

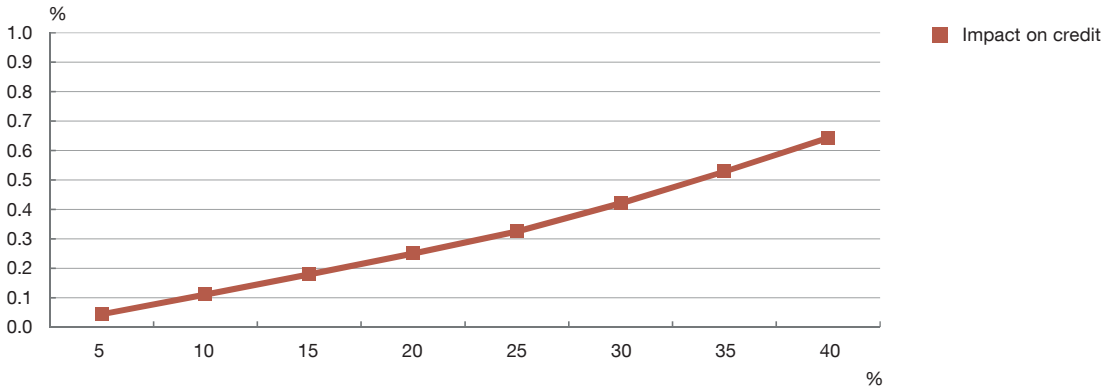
Chart 5

Impact of scenarios of deposit outflows on profitability and credit (a)

5.a Change in net interest margin (b)



5.b Impact on credit (c)



SOURCES: Banco de España and author calculation.

a The charts display tentative estimates of the impact of the different scenarios of deposit outflows on net interest margin and on credit of the funding shocks faced under parametric scenarios of outflow. The methodology and its limitations are described in section 5.2.
b The chart represents the distribution of impact on net interest margin in quartiles, also highlighting the median and outliers.
c The chart represents the impact on credit of the funding shocks associated with the different scenarios.

particularly affected by market access issues. In this context, the idea of adapting central bank refinancing facilities to contribute to the mitigation of the risk of funding shortfalls from drawdown surprises deserves consideration.

The results from the simulation also bear on the limited impact of the digital euro on lending. A precise estimation of the impact on lending should be ascertained based on the assessment of the different channels highlighted in 4. But in a regime of low drawdowns, the most significant channel impacting credit should be expected to be the pass-through of higher funding costs to borrowers. A full translation of higher funding costs (inclusive of lower revenues from reserves) to borrowers would lead to an adjustment of aggregate credit proportional to its semi-elasticity to borrowing costs. (Altavilla et al., 2022) have estimated that the semi-elasticity of credit demand for the euro zone lies between 1.5 and 2. Based on a central value for this figure, Chart 5.b reflects the average impact of different scenarios of outflows on credit.

A note of caution on the interpretation of the simulation results is warranted. The methodological and tentative purpose of the exercise derives mainly from the informational gaps faced. Shocks should be ideally customized to the customer base of banks considered. A complete analysis would also require incorporating all the relevant players in the euro interbank market, and not only Spanish ones. Furthermore, a realistic analysis of liquidity redistribution also requires considering the impact of the non-observable counterparty limits that may lead to an earlier onset of frictions and of a sooner recourse to central bank facilities. In fact, the significance of funding compensation instruments highlights the importance of an accurate modelling of incentives to refinance drawdowns in central bank refinancing facilities. A final note of realism that should be included in a more complete practical application of the methodology refers to the sensitivity of funding rates to the magnitude of flows to be funded. In this paper, this sensitivity has been assumed to be zero, that is, a linear assumption has been applied. In the same vein, the magnitude of the impact on credit could also reflect not just the pass-through of higher funding costs but potentially also non-linear effects from system wide deleveraging under sufficiently big shocks.

6 Conclusions

CBDCs are a fundamental expansion to the existing ecosystem of money and credit. Firstly, CBDCs complement banknotes in the context of transformations prompted by digitization. Universal CBDCs deliver this goal by additionally ensuring seamless interoperability with private forms of money like demand deposits. Hence, the inclusion of universal CBDCs in the existing ecosystem, in the absence of proper design safeguards, can be expected to entail strong substitution effects with bank deposits. The combination of a brittle form of money (demand deposits) with a public safer one (CBDC) thus elevates the importance of the stability of the overall arrangement to the core features of any universal CBDC project.

This paper uncovers the connections between universal CBDCs and three fundamental stability related goals. The quest for stability of the money and credit system is multi-dimensional, but two of them, its internal consistency, and its resiliency to shocks, turn out to be instrumental in every respect. Universal CBDCs might compromise both of them if designed and operated carelessly. But they may be an unavoidable option to improve the money ecosystem when microeconomic inertia (excess of stability) detracts the system from adaptability to technologic advance.

The paper addresses and reviews in a model-free setting the stability-related trade-offs congenital with universal CBDCs and their solution. A universal CBDC need to be a specially constrained form money. Constraints are not something new. The presence of money constraints like transactional costs and non-remuneration for banknotes, or credibility weakness in the case of bank deposits, underlies the complexity of the existing ecosystem of money. The specialty in the case of CBDCs is the fact that the fundamental limits on their quantity and remuneration are not technological but have to be engineered to preserve the short-term and long-term stability of the entire ecosystem of money and credit.

The paper does not attempt to assess the welfare benefits of CBDCs. It rather tries to gain robust insights on fundamental design and mitigating features necessary to contain any propensity to instability. The paper assesses both the contribution of quantity limits and the subtle role of CBDC remuneration limits in terms of their capacity to contain banking fragility and stress.

The discussion ends up emphasizing the importance of calibrating limits within a framework that recognizes the special role played by financial and political economy frictions in reinforcing stability issues through liquidity and credit channels. This contrasts with much of the macroeconomic literature on CBDCs, where unconstrained CBDCs can play out beneficially for the economy as a whole on the basis of assumptions regarding their contribution to a new competition regime.

The operation of constraints as a contribution to short- and medium-term stability raises also long-term trade-offs. An open ended policy on the balance of CBDC outstanding may recurrently raise at the time of update of limits the issue of the contribution of CBDCs to stability.

And the need of crisis management activation under major stress may expose a fundamental difference of CBDCs with banknotes as regards their ability to provide a safety valve.

The paper also performs a tentative quantitative assessment of financial stability risks in the Spanish banking system due to the introduction of a digital euro. The analysis cannot be considered as the full-fledged assessment of risks that will be undertaken by the ECB ahead of a potential launch with a richer set of information. Still, this early analysis is useful, and redundant examination of financial stability risks of the digital euro is advised given its central importance for the money and credit systems. This simulation analysis indicates that uptakes of the digital euro within the cap levels tentatively envisaged as of now would not entail significant destabilization risks or impact on credit However, the complexity and novelty of this instrument merits further analysis in the future.

References

Abad, Jorge, Galo Nuño and Carlos Thomas. (2024). "CBDC and the operational framework of monetary policy". Documento de Trabajo, 2404, Banco de España. https://doi.org/10.53479/35997

Adalid, Ramón, Álvaro Álvarez-Blázquez, Katrin Assenmacher, Lorenzo Burlon, Maria Dimou, Carolina López-Quiles, Natalia Martín Fuentes, Barbara Meller, Manuel Muñoz and Petya Radulova. (2022). "Central bank digital currency and bank intermediation". Occasional Paper, 293, ECB. https://dx.doi.org/10.2139/ssrn.4108346

Ahnert, Toni, and David Martinez-Miera. (2021). "Bank runs, bank competition and opacity". Staff Working Paper, 30, Bank of Canada. https://doi.org/10.34989/swp-2021-30

Altavilla, Carlo, Miguel Boucinha and Paul Bouscasse. (2022). "Supply or demand: What drives fluctuations in the bank loan market?". Working Paper, 2646, ECB. https://dx.doi.org/10.2139/ssrn.4037835

Andolfatto, David. (2018). "Assessing the Impact of Central Bank Digital Currency on Private Banks". Working Paper, 25, FRB St Louis. https://dx.doi.org/10.20955/wp.2018.026

Andreessen, Marc. (2019). *From the Internet's Past to the Future of Crypto* [Podcast]. The a16z Podcast, 31 August 2019. https://a16z.com/podcast/a16z-podcast-from-the-internets-past-to-the-future-of-crypto

Auer, Raphael, and Rainer Böhme. (2021). "Central bank digital currency: the quest for minimally invasive technology". Working Paper, 948, Bank for International Settlements. https://www.bis.org/publ/work948.htm

Bacchetta, Philippe, and Perazzi, Elena (2021). "CBDC as imperfect substitute for bank deposits: A macroeconomic perspective". Research Paper, 81, Swiss Finance Institute. https://dx.doi.org/10.2139/ssrn.3976994

Baumol, William. (1952). "The transactions demand for cash: An inventory theoretic approach". The Quarterly Journal of Economics, 66, 4, pp. 545-556. https://doi.org/10.2307/1882104

Bellia, Mario, and Ludovic Calès. (2023). "Bank profitability and central bank digital currency". Working Papers in Economics and Finance, 6, Joint Research Center. https://dx.doi.org/10.2139/ssrn.4493875

Bidder, Rhys M, Timothy P. Jackson and Matthias Rottner. (2024). "CBDC and banks: Disintermediating fast and slow". Discussion Paper, 15, Bundesbank. https://dx.doi.org/10.2139/ssrn.4838345

Bindseil, Ulrich. (2020). "Tiered CBDC and the financial system". Working paper, 2351, European Central Bank. https://dx.doi.org/10.2139/ssrn.3513422

Bindseil, Ulrich, Fabio Panetta and Ignacio Terol. (2021). "Central Bank Digital Currency: functional scope, pricing and controls". Occasional Paper, 286, European Central Bank. https://dx.doi.org/10.2139/ssrn.3975939

Bindseil, Ulrich, and Richard Senner. (2024). "Macroeconomic Modelling of CBDC: A Critical Review". Working Paper, 2978, https://dx.doi.org/10.2139/ssrn.4782993

Bindseil, Ulrich, Richard Senner and SUERF Policy Note. (2023). "Technological change and the destabilisation of bank deposits: Assessment and policy implications". Policy Note, 321, SUERF. https://www.suerf.org/wp-content/uploads/2023/11/

Brunnermeier, Markus K., and Dirk Niepelt. (2019). "On the equivalence of private and public money". *Journal of Monetary Economics,* 106(October), pp. 27-41. https://doi.org/10.1016/j.jmoneco.2019.07.004

Böser, Florian, and Hans Gersbach (2020). "Monetary policy with a central bank digital currency: The short and the long term". Discussion Paper, 15322, CEPR. https://papers.ssrn.com/abstract=3723511

Burlon, Lorenzo, Carlos Montes-Galdón, Manuel A. Muñoz and Frank Smets. (2022). "The optimal quantity of CBDC in a bank-based economy". Working Paper, 2689, European Central Bank. https://dx.doi.org/10.2139/ssrn.4175853

Carstens, Agustín, and Nandan Nilekani. (2024). "The rise of the Finternet". Project Syndicate. https://www.project-syndicate.org/commentary/finternet-redesign-global-financial-architecture-blockchain-innovation-by-agustin-carstens-and-nandan-nilekani-2024-05

Champ, Bruce, Bruce D. Smith and Stephen D. Williamson. (1996). "Currency elasticity and banking panics: Theory and evidence". *Canadian Journal of Economics,* 29(Nov.), pp. 828-864. https://doi.org/10.2307/136217

Cirelli, Fernando, and Remo Nyffenegger. (2023). "CBDC and Bank Lending: The Role of Financial Frictions". Working Paper, Columbia University. https://dx.doi.org/10.2139/ssrn.4678281

Committee on Payments and Market Infrastructures - International Organization of Securities Commission. (2012). *Principles for financial market infrastructures,* Bank of International Settlements, April. https://www.bis.org/cpmi/publ/d101.htm

Diamond, Douglas, and Philip Dybvig. (1983). "Bank runs, deposit insurance, and liquidity". *Journal of Political Economy,* 91(Jun.), 3, pp. 401-419. https://doi.org/10.1086/261155

Dudley, William, Athony Elson and Natalya Thakur. (2023). "Central Bank Digital Currencies: Design and Implementation in the Evolution of Sovereign Money". Digital Finance Project, 8, The Bretton Woods Committee. https://www.brettonwoods.org/sites/default/files/documents/BWC-DFPT-CenBank-Dig-Currencies_FNL-web.pdf

Dwyer Jr., Gerald P. (1996). "Wildcat Banking, Banking Panics, and Free Banking in the United States". *Economic Review,* 81, FRB Atlanta. https://www.atlantafed.org/research/publications/economic-review/1996/no3-6/vol81nos3-6_wildcat-banking.aspx

De Nicolo, Gianni, John Boyd and Abu Jalal. (2006). "Bank risk-taking and competition revisited: New theory and new evidence". Working Paper, 297, IMF. https://doi.org/10.5089/9781451865578.001

Eaves, David, Mariana Mazzucatto and Beatriz Vasconcellos. (2024). "Digital public infrastructure and public value: What is 'public' about DPI?". IIPP Working Paper, 05, UCL. https://www.ucl.ac.uk/bartlett/public-purpose/publications/2024/mar/digital-public-infrastructure-and-public-value-what-public-about-dpi

European Central Bank. (2023a). "A stocktake of the digital euro. Summary report on the investigation phase and outlook on the next phase". https://www.ecb.europa.eu/euro/digital_euro/timeline/profuse/shared/pdf/ecb.dedocs231018.en.pdf&ved=2ahUKEwjXqsbcl52JAxVBRvEDHSPyJ4cQFnoECBQQAQ&usg=AOvVaw2k6dOq6JgNufOp0UFFLOHy

European Central Bank. (2023b). "Opinion of the European Central Bank on the digital euro". https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/%3Furi%3DCELEX:52023AB0034&ved=2ahUKEwjtvvuUl52JAxVMRaQEHXEeFgoQFnoECBQQAQ&usg=AOvVaw1i1e7Rp_4ulqrZ8dDwRu6X

European Commission Staff. (2013). "Impact assessment 52013SC0288". European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/%3Furi%3Dcelex%253A52013SC0288&ved=2ahUKEwjH94vDmJ2JAxVxUaQEHaH-CtgQFnoECBQQAQ&usg=AOvVaw2_HtUCxZgh-2TWgVAS0vbB

European Commission Staff. (2022). "Impact assessment 52022SC0546". European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/%3Furi%3DSWD:2022:546:FIN&ved=2ahUKEwid5_eRmZ2JAxX2RKQEHdLsJ-sQFnoECBMQAQ&usg=AOvVaw1YJo2uGtu8RvaboGRcKjhD

European Commission Staff. (2023). "Second impact assessment 52023SC0231". European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/%3Furi%3DCELEX%253A52023SC0231&ved=2ahUKEwj53ZDSmZ2JAxVnAtsEHScABOEQFnoECBcQAQ&usg=AOvVaw3OauDugfmd0Fk9u839iE4S

Fernández-Villaverde, Jesús, Daniel Sánchez, Linda Schilling and Harald Uhlig. (2021). "Central bank digital currency: Central banking for all?". *Review of Economic Dynamics,* 41, pp. 225-242. https://doi.org/10.1016/j.red.2020.12.004

Fernández-Villaverde, Jesús, Linda Schilling, and Harald Uhlig. (2024). "Central bank digital currency: When price and bank stability collide". *Journal of Monetary Economics,* 145 (July), 103554, pp. 125-159. https://doi.org/10.1016/j.jmoneco.2024.01.007

Genc, Huseyin Oguz, and Soichiro Takagi. (2024). "A literature review on the design and implementation of central bank digital currencies". *International Journal of Economic Policy Studies,* 18(1)(Feb.), pp. 197-225. OriginalPaper. https://doi.org/10.1007/s42495-023-00125-9

Gersbach, Hans, and Sebastian Zelner. (2024). "Why Bank Money Creation?". Discussion Paper, 17753, CEPR. https://cepr.org/publications/dp17753

Goodhart, Charles. (1988). *The evolution of central banks.* MIT press. https://mitpress.mit.edu/9780262570732/the-evolution-of-central-banks/

Gorton, Gary. (1985). "Bank suspension of convertibility". *Journal of Monetary Economics,* 15(2), pp. 177-193. https://doi.org/10.1016/0304-3932(85)90063-7

Guidotti, Pablo E., and Carlos A. Végh. (1993). "The optimal inflation tax when money reduces transactions costs: A reconsideration". *Journal of Monetary Economics,* 31(2), pp. 189-205. https://doi.org/10.1016/0304-3932(93)90044-G

Humphrey, David, Lawrence Pulley and Jukka Vesala. (2000). "The Check's in the Mail: Why the United States Lags in the Adoption of Cost-Saving Electronic Payments". *Journal of Financial Services Research,* 17(1), pp. 17-39. https://doi.org/10.1023/A:1008163308353

Kashyap, Anil K., Raghuram Rajan and Jeremy C. Stein. (2002). "Banks as liquidity providers: An explanation for the coexistence of lending and deposit-taking". *The Journal of Finance,* 57(1), pp. 33-73. https://dx.doi.org/10.2139/ssrn.156748

Keister, Todd, and Cyril Monnet. (2022). "Central bank digital currency: Stability and information". *Journal of Economic Dynamics and Control,* 142(September), 104501. https://doi.org/10.1016/j.jedc.2022.104501

Keister, Todd, and Daniel Sanches. (2023). "Should Central Banks Issue Digital Currency?". Working Paper, 1, FRB Philadelphia. https://dx.doi.org/10.21799/frbp.wp.2019.26

Kocherlakota, Narayana R. (1998). "Money is memory". *Journal of Economic Theory,* 81(2), pp. 232-251. https://doi.org/10.1006/jeth.1997.2357

Kumhof, Michael, and Clare Noone. (2018). "Central Bank Digital Currencies - Design Principles and Balance Sheet Implications". Working Paper, 725, Bank of England. https://dx.doi.org/10.2139/ssrn.3180713

Lambert, Claudia, Barbara Meller, Cosimo Pancaro, Antonella Pellicani, Petya Radulova, Oscar Soons and Anton van der Kraaij. (2024). "Digital euro safeguards - Protecting financial stability and liquidity in the banking sector". Occasional Paper, 345, European Central Bank. https://dx.doi.org/10.2139/ssrn.4800259

Leibbrandt, Johan Gottfried. (2004). *Payment systems and network effects* [Thesis]. University of Maastricht. https://cris.maastrichtuniversity.nl/files/612143/guid-dcaa651e-4d40-4aa0-8226-ae95f3b7b04c-ASSET1.0.pdf&ved=2ahUKEwilzN7QrpiJAxVqcvEDHaOCKCUQFnoECBUQAQ&usg=AOvVaw0H0qwwHRL419iaHqxnJj-B

León, Carlos, José Moreno and Kimmo Soramaki. (2023). "Simulating the adoption of a retail CBDC". Discussion Paper, 018, TILEC. https://dx.doi.org/10.2139/ssrn.4528315

Li, Jiaqi, Andrew Usher and Yu Zhu. (2024). "Central bank digital currency and banking choices". Working Paper, Bank of Canada. https://dx.doi.org/10.2139/ssrn.4705512

Mayer, Thomas. (2023). "The digital euro: An opportunity likely to be missed". Flossbach von Storch Research Institute. https://www.flossbachvonstorch-researchinstitute.com/en/studies/the-digital-euro-an-opportunity-likely-to-be-missed/

McKinsey. (2023). "On the cusp of the next payments era: Future opportunities for banks". In *Global Payments Report,* McKinsey. https://www.mckinsey.com/industries/financial-services/our-insights/the-2023-mckinsey-global-payments-report

Meller, Barbara, and Oscar Soons. (2023). "Know your (holding) limits: CBDC, financial stability and central bank reliance". Occasional Paper, 326, European Central Bank. https://dx.doi.org/10.2139/ssrn.4543369

Meyers, Zach. (2023). "Does Europe's payments strategy add up?". In *Insight,* Center for European Reform. https://www.cer.eu/insights/does-europes-payments-strategy-add

Nalebuf, Barry, and Adam Branderburger. (1997). "Co-opetition: Competitive and cooperative business strategies for the digital economy". *Strategy & Leadership,* 25(6), pp. 28-33. https://doi.org/10.1108/eb054655

Niepelt, Dirk. (2023). "Retail central bank digital currency and the social costs of liquidity provision". *Vox Eu Column,* September 27. https://cepr.org/voxeu/columns/retail-central-bank-digital-currency-and-social-costs-liquidity-provision

Padoa-Schioppa, Tommaso. (2004). "Shaping the payment system: a central bank's role". European Central Bank. https://www.ecb.europa.eu/press/key/date/2004/html/sp040513_1.en.html

Panetta, Fabio. (2023). *The cost of not issuing a digital euro.* ECB-CEPR "The macroeconomic implications of central bank digital currencies", Frankfurt am Main, December 6. https://www.bis.org/review/r231127i.htm

Paul, Pascal, Mauricio Ulate and Jing Cynthia Wu. (2024). "A Macroeconomic Model of Central Bank Digital Currency". 11, FRB San Francisco. https://doi.org/10.24148/wp2024-11

Piazzesi, Monika, and Martin Schneider. (2022). "Credit lines, bank deposits or CBDC? Competition and efficiency in modern payment systems", Working Paper, University of Standford. https://web.stanford.edu/~piazzesi/CBDC.pdf

Rösl, Gerhard, and Franz Seitz. (2022). "On the stabilizing role of cash for societies". Working Paper, IMFS. https://mpra.ub.uni-muenchen.de/113784/

Shy, Oz. (2023). "Cash is alive: How economists explain holding and use of cash". *Journal of Economic Literature,* 61(December), pp. 1465-1520. https://doi.org/10.1257/jel.20221632

Townsend, Robert M. (1980). "Models of money with spatially separated agents". Working Paper, 130, FRB Minneapolis. https://researchdatabase.minneapolisfed.org/concern/publications/rf55z7713?locale=en

Williamson, Stephen. (2022). "Central bank digital currency: Welfare and policy implications". *Journal of Political Economy,* 130(11), pp. 2829-2861. https://dx.doi.org/10.2139/ssrn.4792946

Whited, Toni M., Yufeng Wu and Kairong Xiao. (2022). "Will Central Bank Digital Currency Disintermediate Banks?". Working Paper, University of Michigan. https://dx.doi.org/10.2139/ssrn.4112644

Annex

This annex sketches a simplified version of the liquidity management model used by banks in the simulation of the impact of deposit outflows on earnings and prudential ratios. For a richer version readers are referred to (*Meller*, and Soons, 2023) who consider different tenors for each funding market. This simplified version illustrates the nature of the methodology to calibrate holding limits in a way that the accommodation of the frictions is economically and regulatory feasible. Moreover, the annex helps also to highlight a number of important issues that can condition the realism and relevance of simulations in practical applications of the methodology.

The optimization is as follows. Each bank in the sample considered independently seeks new funding sources to respond to deposit outflows ΔD. The re-composition of the bank balance sheet takes place on the basis of a linear program used to maximize the change in earnings $\Delta E = \Delta I - \Delta C$ that results from the adjustment in reserves , borrowings ΔBx or lending ΔLx at their corresponding opportunity costs, as per equations. G_1 to G_3.

$$\Delta E = \Delta I - \Delta C \tag{G_1}$$

$$\Delta C = r_u \times \Delta Bu + r_c \times \Delta Bc + r_{cb} \times \Delta Bcb + r_{LT} \times \Delta Blt \tag{G_2}$$

$$\Delta I = -r_R \times \Delta R + r_c \times \Delta Lc + r_u \times \Delta Lu \tag{G_3}$$

Each individual program is subject to multiple constraints that reflect individual frictions reflected as represented in eqns. RI_1 to RI_9 below. Namely, they represent the need to source sufficient funding to deal with outflows (RI_1), to keep the reserves account in the central bank at a positive level (RI_2), to have sufficient collateral for the provision of collateral in funding transactions (RI_3), to have sufficient collateral for sourcing central bank funding (RI_4), to maintain liquidity prudential levels above the statutory limits as adjusted with voluntary buffers (RI_5 and RI_6, as per the definitions for the prudential ratios RI_7 and RI_8 and their impact on changes of liquid assets and available or required stable funding, i.e. ΔASF_t and ΔARF_i*)*.

$$\Delta D = \Delta R_D + \Delta Bu + \Delta Bc + \Delta Bcb + \Delta Blt \tag{RI_1}$$

$$R_0 + \Delta R \geq 0 \tag{RI_2}$$

$$\Delta R = \Delta R_D + \Delta R_{lending} \tag{RI_3}$$

$$\Delta Bc \leq \frac{col}{1 + haircut} \tag{RI_4}$$

$$\Delta Bcb \leq \frac{col}{1 + haircut} - \Delta Bc \tag{RI_5}$$

$$\Delta LCR_i \geq 100 + buffer_i \tag{RI_6}$$

$$\Delta NSFR_i \geq 100 + buffer_i \tag{RI_7}$$

with

$$LCR_i = \frac{HQLA_i + \Delta HQLA_i}{E\,[outflow]_i + \Delta E\,[outflow]_i} \quad \text{(RI\_8)}$$

$$NSFR_i = \frac{ASF_i + \Delta ASF_i}{RSF_i + \Delta RSF_i} \quad \text{(RI\_9)}$$

and eqns for $\Delta E[outflow]_i$, $\Delta HQLA_i$, ΔASF_i, ΔRSF_i, reflecting the new balance sheet and regulatory definitions in terms of corresponding runoff rates and funding rates.

The closure of the optimization program at an aggregate level also requires an aggregate restriction for each funding market (i.e., funding sources where banks can either borrow or lend based on their level of excess reserves available for lending $\Delta R_{lending}$). These restrictions nominally should look as follows $\sum_i \Delta Lu_i = \sum_i \Delta SBu_i$. However, they have not been incorporated in the set of restrictions actually used in the simulation because of realism considerations.

The fact is that realistic simulations may not be feasible as regards a representation of aggregate equilibrium of funding markets due to two fundamental reasons. First, partial information on the set of players in the funding markets limit the rationale of a (necessarily partial) balancing of these markets. Second, the operation of non-observable counterparty limits, both for borrowing and lending operations, also limits the meaning of aggregate balancing conditions. This paper has opted for including additional individual restrictions that reflect counterparty limits for borrowing and lending transactions proportional to equity and total assets, respectively. A final note of realism that should be included in a practical application of the methodology refers to the sensitivity of funding rates to the magnitude of flows to be funded. In this paper, this sensitivity has been assumed to be zero.

These notes of caution and realism do not detract usefulness of the linear programming technique applied to calibration. The advantage of the methodology lies in the ability to amend and adapt the model based on available information as opposed to other methodologies that may rely on closed solutions.

BANCO DE ESPAÑA PUBLICATIONS

OCCASIONAL PAPERS

2320 BANCO DE ESPAÑA: In-person access to banking services in Spain: 2023 Monitoring Report. (There is a Spanish version of this edition with the same number).

2321 EDUARDO AGUILAR GARCÍA, MARIO ALLOZA FRUTOS, TAMARA DE LA MATA, ENRIQUE MORAL-BENITO, IÑIGO PORTILLO PAMPIN and DAVID SARASA FLORES: Una primera caracterización de las empresas receptoras de fondos NGEU en España.

2401 ALEJANDRO MORALES, MANUEL ORTEGA, JOAQUÍN RIVERO and SUSANA SALA: How to identify all companies worldwide. Experience with the legal entity identifier (LEI). (There is a Spanish version of this edition with the same number).

2402 XAVIER SERRA and SONSOLES GALLEGO: An initial stocktake of the IMF's resilience and sustainability trust as a channel for using special drawing rights. (There is a Spanish version of this edition with the same number).

2403 PABLO HERNÁNDEZ DE COS: The role of macroprudential policy in the stabilisation of macro-financial fluctuations. Conference on Financial Stability/Banco de Portugal, Lisbon (Portugal), 2 October 2023. (There is a Spanish version of this edition with the same number).

2404 MORTEZA GHOMI, SAMUEL HURTADO and JOSÉ MANUEL MONTERO: Analysis of recent inflation dynamics in Spain. An approach based on the Blanchard and Bernanke (2023) model. (There is a Spanish version of this edition with the same number).

2405 PILUCA ALVARGONZÁLEZ, MARINA ASENSIO, CRISTINA BARCELÓ, OLYMPIA BOVER, LUCÍA COBREROS, LAURA CRESPO, NAJIBA EL AMRANI, SANDRA GARCÍA-URIBE, CARLOS GENTO, MARINA GÓMEZ, PALOMA URCELAY, ERNESTO VILLANUEVA and ELENA VOZMEDIANO: The Spanish Survey of Household Finances (EFF): description and methods of the 2020 wave.

2406 ANA GÓMEZ LOSCOS, MIGUEL ÁNGEL GONZÁLEZ SIMÓN and MATÍAS JOSÉ PACCE: Short-term real-time forecasting model for Spanish GDP (Spain-STING): new specification and reassessment of its predictive power. (There is a Spanish version of this edition with the same number).

2407 OLYMPIA BOVER, LAURA CRESPO, SANDRA GARCÍA-URIBE, MARINA GÓMEZ-GARCÍA, PALOMA URCELAY and PILAR VELILLA: Micro and macro data on household wealth, income and expenditure: comparing the Spanish Survey of Household Finances (EFF) to other statistical sources.

2408 ÁNGEL ESTRADA and CARLOS PÉREZ MONTES: Un análisis de la evolución de la actividad bancaria en España tras el establecimiento del gravamen temporal de la ley 38/2022.

2409 PABLO A. AGUILAR, MARIO ALLOZA, JAMES COSTAIN, SAMUEL HURTADO and JAIME MARTÍNEZ-MARTÍN: The effect of the European Central Bank's asset purchase programmes on Spain's public finances. (There is a Spanish version of this edition with the same number).

2410 RICARDO BARAHONA and MARÍA RODRÍGUEZ-MORENO: Estimating the OIS term premium with analyst expectation surveys.

2411 JOSÉ MANUEL CARBÓ, HOSSEIN JAHANSHAHLOO and JOSÉ CARLOS PIQUERAS: Análisis de fuentes de datos para seguir la evolución de *Bitcoin.*

2412 IVÁN KATARYNIUK, RAQUEL LORENZO ALONSO, ENRIQUE MARTÍNEZ CASILLAS and JACOPO TIMINI: An extended Debt Sustainability Analysis framework for Latin American economies.

2413 Survey of Household Finances (EFF) 2022: methods, results and changes since 2020. (There is a Spanish version of this edition with the same number).

2414 ÁNGEL ESTRADA, CARLOS PÉREZ MONTES, JORGE ABAD, CARMEN BROTO, ESTHER CÁCERES, ALEJANDRO FERRER, JORGE GALÁN, GERGELY GANICS, JAVIER GARCÍA VILLASUR, SAMUEL HURTADO, NADIA LAVÍN, JOËL MARBET, ENRIC MARTORELL, DAVID MARTÍNEZ-MIERA, ANA MOLINA, IRENE PABLOS and GABRIEL PÉREZ-QUIRÓS: Analysis of cyclical systemic risks in spain and of their mitigation through countercyclical bank capital requirements. (There is a Spanish version of this edition with the same number).

2415 CONCEPCIÓN FERNÁNDEZ ZAMANILLO and LUNA AZAHARA ROMO GONZÁLEZ: Facilitadores de la innovación 2.0: impulsando la innovación financiera en la era *fintech*.

2416 JAMES COSTAIN and ANTON NAKOV: Models of price setting and inflation dynamics.

2417 ARTURO PABLO MACÍAS FERNÁNDEZ and IGNACIO DE LA PEÑA LEAL: Sensibilidad a los tipos de interés soberanos de la cartera de colateral elegible para los préstamos de política monetaria.

2418 ANTONIO F. AMORES, HENRIQUE BASSO, JOHANNES SIMEON BISCHL, PAOLA DE AGOSTINI, SILVIA DE POLI, EMANUELE DICARLO, MARIA FLEVOTOMOU, MAXIMILIAN FREIER, SOFIA MAIER, ESTEBAN GARCÍA-MIRALLES, MYROSLAV PIDKUYKO, MATTIA RICCI and SARA RISCADO: Inflation, fiscal policy and inequality. The distributional impact of fiscal measures to compensate for consumer inflation.

2419 LUIS ÁNGEL MAZA: Una reflexión sobre los umbrales cuantitativos en los modelos de depósito de las cuentas anuales y su posible impacto en el tamaño empresarial en España.

2420 MARIO ALLOZA, JORGE MARTÍNEZ, JUAN ROJAS and IACOPO VAROTTO: Public debt dynamics: a stochastic approach applied to Spain. (There is a Spanish version of this edition with the same number).

2421 NOEMÍ LÓPEZ CHAMORRO: El camino hacia la supremacía cuántica: oportunidades y desafíos en el ámbito financiero, la nueva generación de criptografía resiliente.

2422 SOFÍA BALLADARES and ESTEBAN GARCÍA-MIRALLES: Fiscal drag: the heterogeneous impact of inflation on personal income tax revenue. (There is a Spanish version of this edition with the same number).

2423 JULIO ORTEGA CARRILLO and ROBERTO RAMOS: Parametric estimates of the spanish personal income tax in 2019. (There is a Spanish version of this edition with the same number).

2424 PILAR L'HOTELLERIE-FALLOIS, MARTA MANRIQUE and DANILO BIANCO: EU policies for the green transition, 2019-2024. (There is a Spanish version of this edition with the same number).

2425 CATERINA CARVALHO-MACHADO, SABINA DE LA CAL, LAURA HOSPIDO, SARA IZQUIERDO, MARGARITA MACHELETT, MYROSLAV PIDKUYKO y ERNESTO VILLANUEVA: The Survey of Financial Competences: description and methods of the 2021 wave.

2426 MARINA DIAKONOVA, CORINNA GHIRELLI and JUAN QUIÑÓNEZ: Economic Policy Uncertainty in Central America and the Dominican Republic.

2427 CONCEPCIÓN FERNÁNDEZ ZAMANILLO and CAROLINA TOLOBA GÓMEZ: *Sandbox* regulatorio español: impacto en los promotores de los proyectos monitorizados por el Banco de España.

2428 ANDRES ALONSO-ROBISCO, JOSE MANUEL CARBO, EMILY KORMANYOS and ELENA TRIEBSKORN: Houston, we have a problem: can satellite information bridge the climate-related data gap?

2429 ALEJANDRO FERNÁNDEZ CEREZO, BORJA FERNÁNDEZ-ROSILLO SAN ISIDRO and NATIVIDAD PÉREZ MARTÍN: The Banco de España's Central Balance sheet data office database: a regional perspective. (There is a Spanish version of this edition with the same number).

2430 JOSE GONZÁLEZ MÍNGUEZ: The Letta report: a set of proposals for revitalising the European economy. (There is a Spanish version of this edition with the same number).

2431 MARIYA MELNYCHUK and JAVIER MENCÍA: A taxonomy of macro-financial risks and policies to address them.

2432 DMITRY KHAMETSHIN, DAVID LÓPEZ RODRÍGUEZ and LUIS PÉREZ GARCÍA: El mercado del alquiler de vivienda residencial en españa: evolución reciente, determinantes e indicadores de esfuerzo.

2433 ANDRÉS LAJER BARON, DAVID LÓPEZ RODRÍGUEZ and LUCIO SAN JUAN: El mercado de la vivienda residencial en España: evolución reciente y comparación internacional.

2434 CARLOS GONZÁLEZ PEDRAZ, ADRIAN VAN RIXTEL and ROBERTO PASCUAL GONZÁLEZ: Navigating the boom and bust of global SPACs.

2435 PATROCINIO TELLO-CASAS: El papel de China como acreedor financiero internacional.

2436 JOSÉ RAMÓN MARTÍNEZ RESANO: CBDCs, banknotes and bank deposits: the financial stability nexus.