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Central Bank Digital Currency and Monetary Architecture

Dirk Niepelt

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Schanzeneckstrasse 1
CH-3012 Bern, Switzerland
http://www.vwi.unibe.ch

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Dirk Niepelt*

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Abstract

We review the macroeconomic literature on retail central bank digital currency (CBDC), organizing the discussion around a CBDC-irrelevance result. We identify both fundamental and policy-related sources of relevance, or departures from neutrality. Bank disintermediation—the crowding out of deposits—does not, by itself, constitute such a source. We argue that the literature has primarily focused on policy-related sources of non-neutrality, often without making this focus explicit. From a macroeconomic perspective, CBDC is, at its core, a matter of monetary architecture, and political economy considerations are central to understanding CBDC policy design.

JEL codes: E42, E51, G21, G28

Keywords: Monetary architecture, central bank digital currency, public money, private money, neutrality, lender of last resort.

*University of Bern & CEPR, dirk.niepelt@unibe.ch, www.niepelt.ch. For comments and discussions, we are grateful to Tobias Berg, Martín Gonzalez-Eiras, My Hedlin, Yuliyan Mitkov, Cyril Monnet, Mariana Rojas Breu, Oscar Soons, Remo Taudien, and conference or seminar participants at Bank of England, Central Bank of Ireland, Goethe University/SAFE, Qatar Centre for Global Banking & Finance, Swiss National Bank/CIF Conference. For help with the data and research assistance, we thank Luca Benati and Jonathan Häberli, respectively. Financial support of the Swiss National Fund (Grant Nr. 100018_219835) is gratefully acknowledged.

1 Introduction

The financial architecture is undergoing a profound transformation. On one front, real and financial assets are increasingly being tokenized—that is, represented on shared digital ledgers. This shift is altering the nature of financial intermediation, reshaping market structures, and challenging the business models of incumbents. On another front, new forms of money are making inroads into payment systems that have long relied on public-private partnerships between monetary authorities and commercial banks. Among these new forms of money, retail central bank digital currency (CBDC)—or "Reserves for All"—stands out as particularly significant, as it is issued directly by the central bank, unlike bank deposits or deposit-based payment instruments. If adopted at scale, CBDC could displace bank deposits, decouple payment services from traditional bank intermediation, and place established banking models under pressure.

What macroeconomic consequences might follow from the introduction of CBDC? While policymakers have acknowledged potential benefits—discussed below—they have also voiced concerns about the implications of deposit displacement. By offering a safe public alternative, they argue, the introduction of CBDC could disrupt credit provision and endanger financial stability. Others—often speaking after leaving office—have conversely emphasized CBDC's stabilizing potential, arguing that CBDC could address structural vulnerabilities in a financial system built on fractional reserve banking. As the Bank of England's outgoing chief economist put it in 2021:[1]

> "On financial stability, a widely-used digital currency could change the topology of banking fundamentally. It could result in something akin to narrow banking, with safe, payments-based activities segregated from banks' riskier credit-provision activities. In other words, the traditional model of banking familiar for over 800 years could be disrupted. While the focus of debate so far has been on the costs of this disruption, largely in the form of disintermediation of existing agents, there are significant potential benefits to be had too.
>
> ...This radically different topology, while not costless, would reduce at source the fragilities in the banking model that have been causing financial crises for over 800 years. Given the costs of those crises—large and rising—this is a benefit that needs to be weighed."

Paralleling the policy debate, a rapidly growing literature has, over the past decade, explored how CBDC-induced changes in the monetary architecture can affect macroeconomic outcomes. The findings are mixed and at times seem to contradict each other, offering little in the way of clear policy guidance and underscoring the need for greater conceptual clarity. This paper seeks to meet that need by developing a unified perspective on the macroeconomic CBDC literature—identifying common themes, bringing to light critical assumptions that often remain implicit yet shape key conclusions, and highlighting structural factors that drive policy trade-offs.

[1] Speech by Andy Haldane: https://www.bankofengland.co.uk/speech/2021/june/andy-haldane-speech-at-the-institute-for-government-on-the-changes-in-monetary-policy.

We set the stage in Section 2 by providing background context on the monetary architecture, drawing on long-run illustrative data, earlier theoretical debates, and recent policy discussions. Section 3 then introduces a general framework to clarify the macroeconomic consequences of a regime change, specifically the introduction of CBDC coupled with the displacement of deposits. Designed to structure the subsequent literature review, this framework is built around a neutrality result that establishes sufficient conditions for the change not to alter equilibrium outcomes (beyond a few balance sheet positions), even when deposits are a cheap source of bank funding, bank lending is critical for economic activity, and the economy faces financial and other frictions. Intuitively, if the introduction of CBDC were accompanied by the displacement of cash rather than deposits, macroeconomic outcomes would remain unaffected, provided that CBDC pays no interest and that nonbanks are indifferent between using CBDC and cash for transactions. We show that, under our sufficient conditions, the same result holds when CBDC replaces bank deposits.

In Section 4, we apply the neutrality conditions to three core domains impacted by CBDC: The nonbank sector, where households and firms convert deposits into CBDC; the banking sector, where banks lose a cheap source of funding; and the system as a whole where general equilibrium implications cannot be directly attributed to individual agents. For each domain, we review the literature's assumptions and assess whether they satisfy or violate the neutrality conditions. In the latter case, we distinguish between fundamental sources of non-neutrality, rooted in economic factors, and policy-related sources, which could, in principle, be modified to restore neutrality.

We find that the literature mostly focuses on policy-related sources of non-neutrality, often without clearly acknowledging this. In other words, many conclusions regarding the relevance of CBDC rely on assumptions about policy which, if modified, imply that CBDC is largely irrelevant. Fundamental sources of non-neutrality exist as well. Many models include one such source—a particular type of non-substitutability of CBDC and deposit liquidity services—whose empirical relevance appears unclear. Other fundamental sources that may be more empirically relevant—such as unequal resource costs, network effects, or externalities in the system domain—have received less attention.

In Section 5, we broaden the discussion to include heterogeneity, information frictions faced by policymakers, bank fragility and runs, taxation, and other frictions. We also review work on transmission mechanisms (when the neutrality conditions are violated), as well as DSGE analyses. The conclusion that CBDC's macroeconomic relevance strongly depends on policy choices—and, on a deeper level, political economy aspects, which we also consider—remains intact. Rather than fundamental economic factors, political constraints and objectives may ultimately determine CBDC's allocative and distributive significance.

The concluding Section 6 summarizes our findings and discusses policy implications. One straightforward implication is that, when the conditions for neutrality are satisfied, the introduction of CBDC can often be made Pareto improving through modest adjustments in accompanying policy. Another one is that policy makers have far greater control over the macroeconomic consequences of CBDC than over those of private payment innovations such as cryptocurrencies, whose issuers pursue independent objectives.

A further takeaway concerns the framing of the CBDC policy debate. The introduction of CBDC should not be cast narrowly as a technical innovation in the payments system with potential effects on intermediation and financial stability. Fundamentally, it represents a shift in the topology of banking and a transformation of the broader monetary architecture. As such, it raises deeply political questions that reach beyond the mandate of technocratic institutions such as central banks. A particularly important direction for future research, therefore, lies in examining the distributive implications of alternative monetary architectures—and how CBDC may reshape these distributions in politico-economic equilibrium.

As interest in CBDC continues to grow, so does the number of literature reviews and surveys on the topic (Ahnert, Assenmacher, Hoffmann, Leonello, Monnet and Porcellacchia, 2024; Auer et al., 2022; Bindseil and Senner, 2024; Chapman et al., 2023; Infante et al., 2022, 2023; Niepelt, 2021). What distinguishes our paper is its general equilibrium perspective and its focus on CBDC as a structural change in the monetary architecture.[2] Another distinctive feature is our systematic use of a neutrality result—extending Brunnermeier and Niepelt (2019)—to organize the literature. As with classical neutrality results (Modigliani and Miller, 1958; Barro, 1974; Wallace, 1981; Bryant, 1983; Chamley and Polemarchakis, 1984),[3] its value lies in identifying which adjustments can leave economic outcomes unchanged. Whereas classical results emphasize how private sector responses can neutralize policy changes, our result highlights how the effects of introducing CBDC can be offset through appropriate accompanying policy choices. A key conclusion of our analysis thus is that the macroeconomic impact of CBDC hinges less on its introduction per se, and more on how it is implemented and what policies accompany it.

2 Monetary Architecture

2.1 Public and Private Money

The monetary architecture of modern economies exhibits a two-tier structure. At the base layer, nonbanks transact using bank deposits, claims on deposits, or cash—a liability of the central bank. At the top layer, banks settle payments using reserves, another central bank liability, but in digital rather than physical form. We refer to cash and reserves—payment instruments issued by the central bank—as "public money," and to deposits and other instruments issued by commercial banks as "private money."

When issuing private money, banks are not obliged to back it with public money. In fact, banks create most deposits not in exchange for deposited cash or reserves, but in the act of making loans (e.g. McLeay et al., 2014).[4] As a consequence, the stocks of public

[2] Faure and Gersbach (2018) also analyze monetary architectures. Allen and Walther (2024) study the implications of financial innovation for money creation and stability in an environment with bank and nonbank financial firms.

[3] For a textbook treatment of neutrality results, see Sargent (1987, 5.4).

[4] Traditional money multiplier analysis (Phillips, 1920) describes the limits of this money creation process.

and private money need not track each other. Historically, the latter has exceeded the former, and their ratio—the money multiplier—has varied over time.

Figure 1 shows the historical evolution of public and private money components denominated in Swiss francs and U.S. dollars (see Appendix A for data sources). Swiss franc M1 and U.S. dollar M2 expanded at broadly similar average rates over the past century. The Swiss franc M1 money multiplier remained relatively stable until the 1980s, then more than tripled before collapsing during the global financial crisis. The U.S. dollar M2 money multiplier fell sharply during the 1930s, then rose steadily until the mid-1980s, declined again through 2006, and then experienced a similarly sharp collapse in the late 2000s.

The expansions of the monetary base during and after the financial crisis were accompanied by a sharp rise in their reserve components, reflecting lender-of-last-resort interventions followed by quantitative easing (QE) and exchange rate stabilization policies (Pattipeilohy, 2016). At their peak, reserves accounted for nearly 90% of the Swiss franc monetary base and close to 70% of the U.S. dollar base. Bazot et al. (2025) report similar magnitudes for many other currency areas, with cash shares in central bank liabilities typically starting to decline already before the turn of the century. While the use of cash as a means of payment has declined in recent years, it widely continues to serve as a store of value (Bayeh et al., 2024; Bech et al., 2018; Jiang and Shao, 2020; Khiaonarong and Humphrey, 2022; Zamora-Pérez, 2021).

Views on the merits of private versus public money creation vary widely. While central banks regard both their position at the center of the monetary system and the uniformity of money as essential to fulfilling their mandate,[5] they are considerably less concerned with the delegation of money creation to the private sector (BIS, 2003). Academic work grounded in banking models in the tradition of Diamond and Dybvig (1983) often portrays banks as creators and managers of scarce liquidity. In contrast, research that adopts a more macroeconomic perspective, exemplified by Friedman (1969), treats liquidity as socially costless to produce, thus offering no obvious rationale for assigning its creation to private intermediaries.[6]

Indeed, a long-standing tradition, dating back at least to the Chicago plan of the 1930s, holds that 100% reserve banking—with a strict separation between bank lending and money creation—is preferable to the inherently unstable system of fractional reserve banking (Knight et al., 1933; Fisher, 1935, 1936; Benes and Kumhof, 2012).[7] A related

[5]The objective of monetary uniformity relates to money's role as a unit of account, a public good (Ricardo, 1816; Issing, 1999). When central bank and commercial bank money trade at par, controlling the terms on which banks access reserves allows the central bank to influence monetary conditions.

[6]Monnet (2006) analyzes the optimality of private versus public money issuance in a framework where the key trade-off involves the opportunity cost of foregone goods production. Grodecka-Messi and Zhang (2023), Xu and Yang (2022) as well as Ögren (2022) and Grodecka-Messi and Zhang (2025) examine the co-existence of public and private money in historical contexts—specifically, the establishment of the Bank of Canada in 1935, the U.S. National Banking Act of 1864, and the introduction of the Riksbank's note issuance monopoly in 1897, respectively.

[7]Similar to the Chicago plan, the Swiss constitutional "Vollgeld" initiative of 2018 proposed a ban on private money creation (https://www.vollgeld-initiative.ch/english/). See Friedman and Schwartz (1963) and Bernanke (1983) on the "money" vs. "credit" views of the great depression.

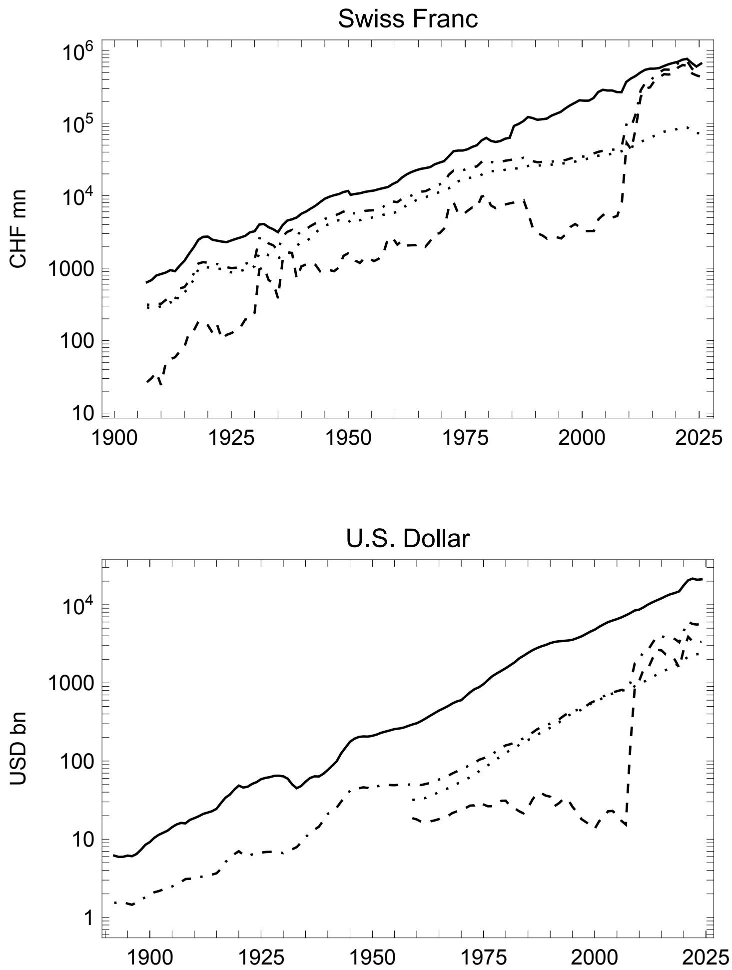

Figure 1: Public and private money components, Swiss franc and U.S. dollar. The solid lines indicate M1 (Swiss franc) or M2 (U.S. dollar); the dot-dashed lines the monetary base; the dotted lines cash in circulation; and the dashed lines reserves held by commercial banks at the central bank.

line of argument maintains that even when the social net benefit of private money creation becomes negative, the private benefits to banks may remain positive, resulting in excessive issuance of bank money (Chari and Phelan, 2014). Concerns like these have motivated a range of reform proposals aimed at limiting the scope of banks' maturity and liquidity "transformation."[8]

Money creation accounts for a substantial share of banks' revenues. Figure 2, taken from Niepelt (2024a), shows bounds for the annual U.S. deposit-to-GDP ratio multiplied by the annual deposit spread. This quantity represents the interest income depositors forego by holding deposits rather than a risk-free but illiquid asset or, equivalently, the revenue banks generate from borrowing at deposit interest rates and investing in safe, illiquid assets. When interest rates are low—such as during the 2010s or the Covid

[8]See, e.g., Kay (2009), Kotlikoff (2010), McMillan (2014), and King (2016). Sargent (2011) offers a historical perspective on the evolution of economic thought surrounding bank regulation.

pandemic—deposit spreads also tend to be low, as the effective lower bound limits the extent to which banks can reduce deposit rates. This, in turn, compresses the revenue generated from deposit-taking. Conversely, when rates are high, deposit spreads are typically wider, possibly due to limited competition in the deposit market (Drechsler et al., 2017), and the associated revenue increases.

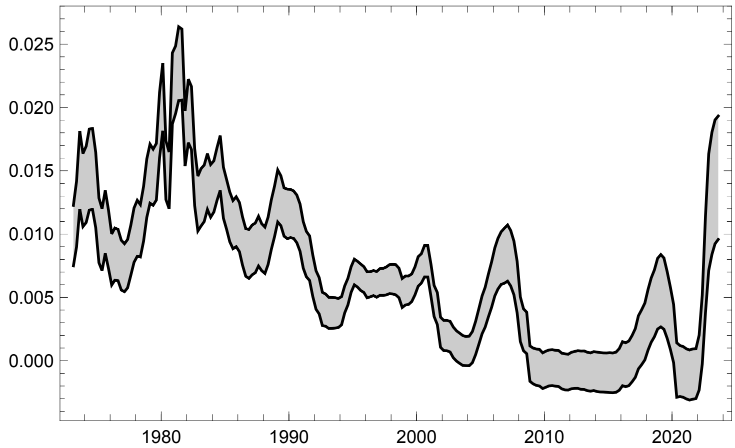

Figure 2: Bounds for U.S. deposit-to-GDP ratio times deposit spread.

2.2 Retail Central Bank Digital Currency

This paper is concerned with retail central bank digital currency—CBDC for short—defined as digital, universally (or at least widely) accessible, central bank money. Unlike deposits, CBDC is issued by the central bank. Unlike cash, it is a digital payment instrument, permitting online use. Unlike reserves, nonbanks—not only financial institutions—may hold it and use it for payments. In other words, CBDC is Reserves for All. Unlike the Chicago plan, CBDC proposals do not envision explicit constraints on the business model of banks or their ability to create money, but they aim at introducing a substitute for the private monies that nonbanks use in contemporary monetary architecture.[9]

The concept of Reserves for All is not new, if one sets aside the online functionality aspect. Practically, historical precedents exist: "In the early days of central banking, it was fairly common to offer accounts not just to banks but also to non-banks . . . [until] starting in the 20th century, central banks have tended to progressively restrict access by non-banks" (BIS, 2018, p. 3).[10] Theoretically, the modern discussion dates back to

[9]See also the "money flower" taxonomy of monetary instruments in Bech and Garratt (2017) and BIS (2018).

[10]See also, e.g., Bindseil (2019), Fernández-Villaverde et al. (2021), and Jorge-Sotelo (2024). Degorce and Monnet (2024) describe how, starting in the late 19th century, savings banks—including postal savings systems—competed with commercial banks to attract customer deposits. Unlike commercial banks, savings banks were strictly regulated and benefited from explicit or implicit state guarantees, making their liabilities similar to those of a narrow bank or to what Adrian and Mancini-Griffoli (2019) call "synthetic CBDC." In recent years, some central banks have begun expanding access to their balance sheets or payment systems again for select nonbank financial institutions, including fintechs and e-money

Tobin (1985) who emphasizes the benefits for society of having access to electronic means of payment circulating in a robust payment system. Tobin argues that institutional features that promote robustness, especially deposit insurance, require regulatory limits on competition, creating a tradeoff between providing safe, convenient money and preserving competitive efficiency and sound incentives in the financial system. Against this background he proposes that

> "*Deposited currency*—100%-reserve deposits—payable in notes or coin on demand, transferable by order to third parties, secure against loss or theft, would be a perfect store of value in the unit of account" (p. 25).

Similarly, Tobin (1987, pp. 172–173) suggests that

> "government should make available to the public a medium with the convenience of deposits and the safety of currency, essentially currency on deposit ... The Federal Reserve banks themselves could offer such deposits, a species of 'Federal Funds.' ... Transactions ... would be cleared through the Federal Reserve ... Computer capabilities should soon make it possible to withdraw conventional currency at any office or agency, and even to order payments to third parties by card or telephone. Interest at a rate sufficiently below the rates on Treasury securities to cover costs could be paid ... [Or b]anks and other depository institutions could offer the same type of account, or indeed be required to do so. The deposited funds would be segregated ... and invested entirely in ... Federal Funds or Treasury obligations of no more than three months maturity."

It took thirty years for Tobin's vision to gain traction—though largely for reasons unrelated to his original motivation. A new wave of suggestions, such as the "Fedcoin" proposal of a U.S.-dollar-based central bank cryptocurrency by Koning (2014), drew inspiration from innovations emerging within the cryptosphere and the technological advancements that enabled them.[11] These developments, in turn, reflected the push into—or reinvention of—monetary economics by software engineers, alongside a growing distrust of traditional financial institutions in the wake of the global financial crisis and the Occupy Wall Street movement (Berentsen and Schär, 2018). Raskin and Yermack (2016), Bordo and Levin (2017), and Bordo (2021) place CBDC and private virtual currencies in broader historical context, relating them to earlier shifts in monetary history and the history of economic thought. They portray CBDC as a natural progression in the history of transformations in monetary systems.[12]

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providers.

[11] See also Groff (2013), Kaminska (2014), Motamedi (2014), and Andolfatto (2015). In contrast, Niepelt (2015) focuses on the reserves-for-all aspect of CBDC. Raskin and Yermack (2016) consider dollarization-type challenges for central banks posed by private cryptocurrencies, and they discuss how remunerated CBDC could change banking and monetary policy. Kahn et al. (2019) discuss the linkages between technological advances and the tradeoffs involved in offering universal access to digital central bank money. They argue that the case for tokenized electronic cash is not self evident.

[12] See also Bordo and Roberds (2023). Raskin and Yermack (2016) note that Friedman anticipated and welcomed in the late twentieth century, how an internet-based digital currency could constrain monetary policy discretion.

Some central banks engaged early.[13] Auer et al. (2022) describe CBDC projects in the 2010s that were motivated by the desire to keep up with technological developments (blockchain and crytpocurrencies); the will to accommodate the accelerated adoption of digital payment instruments during the Covid-19 pandemic; and concerns about the rise of private stablecoins as well as big tech firms that monetize synergies between payments and data collection.

The latter concerns became more acute with the Libra (later Diem) initiative to establish a global payment system integrated with Facebook's social network and supported by a payment instrument backed by reserve assets denominated in a basket of currencies.[14] In response, the mood at many more central banks shifted from bemusement or outright dismissal of innovation to a more serious engagement—and a clearer understanding of the differences between cryptocurrencies and CBDCs (see, e.g., the stance of speeches delivered by central bank representatives reported by Auer et al. (2020)). Surveys suggest that there could be multiple CBDCs publicly circulating in 2030 (Boar and Wehrli, 2021; Kosse and Mattei, 2023; Di Iorio et al., 2024; Illes et al., 2025).[15]

Not all rationales of CBDC proposals are entirely convincing. Engert and Fung (2017) identify six main motivations in early policy discussions, of which they endorse only two and a half.[16] They reject a first motivation, to help curb criminal activity, on the grounds that there is no clear economic rationale linking CBDC to the prevention of crime, even if its introduction were to reduce cash usage. They also reject the motivation of eliminating the effective lower bound on interest rates or supporting unconventional "helicopter drop" policies, because eliminating the lower bound would require increased cost of holding cash, rather than introducing CBDC (we return to this point in Section 5),[17] and because CBDC is not a prerequisite for helicopter drops even if it could be used to facilitate them. On the third goal of promoting financial inclusion, the authors view the introduction of CBDC neither as the only nor necessarily the most effective tool to achieve it. The experience of mobile payments in Africa or the successful introduction of Brazil's instant payment platform Pix—supported by the central bank but not based on CBDC—corroborates this perspective.[18]

In contrast, Engert and Fung (2017) endorse the mitigation of financial stability risks arising from a leveraged banking system and enhanced competition in the payments sphere as plausible motivations for the introduction of CBDC. Both arguments do not only

[13] In 2017–2018, Banco Central del Uruguay tested an "e-Peso" for consumers which allowed for one-to-one conversion between cash and the digital payment instrument.

[14] See Niepelt (2019).

[15] See also https://www.atlanticcouncil.org/cbdctracker/. Auer et al. (2020) construct a CBDC project index tracking the development of CBDC projects across countries and correlate it with factors such as digital infrastructure, the size of the informal economy, financial development, and income. They report that CBDC designs vary widely, but generally involve a direct claim on the central bank and retain a role for private intermediaries. All are intended to complement, rather than replace, cash.

[16] See also Mancini-Griffoli et al. (2018).

[17] In fact, the introduction of non-remunerated CBDC could raise the effective lower bound from slightly negative to essentially zero.

[18] See Infante et al. (2022, 2.2) and Board of Governors (2022) for a discussion of financial inclusion aspects and the cost of remittance payments.

resonate with Tobin (1985, 1987) as well as large literatures on financial instability and market power in banking and payments, but they have also been taken up in the CBDC literature, so we will return to them later.[19] On the last motivation—preserving central bank seignorage and ensuring continued access to central bank money for the public, even if cash use declines—Engert and Fung (2017) dismiss seignorage preservation as a compelling rationale, particularly in the context of advanced economies, while giving credence to the accessibility motivation.[20]

The accessibility argument is noteworthy for several reasons. First, the decline in the use of cash for payments stands in contrast to the continued strong demand for cash as a store of value, as discussed earlier. Second, this decline has partly been driven by central banks and governments themselves—by delegating the creation of money to commercial banks, shifting a greater share of cash management costs to the private sector, and imposing limits on cash transactions to combat tax evasion and informal economic activity. In this sense, the decline is partly self-inflicted and reflects the somewhat paradoxical stance of governments to discourage use of state money, the only widely accessible form of legal tender. Finally, a common argument for the desirability of access, namely that accessibility underpins public trust in money, remains to be formally incorporated into economic models.

More recently, concerns over monetary—and even national—sovereignty have gained prominence among CBDC motivations. Proponents argue that a domestic CBDC could help reduce rents captured by foreign payment service providers; defend the role of the national unit of account against the potential appeal of foreign currency-denominated stablecoins; and promote the national currency internationally, thereby generating seignorage or supporting other policy objectives.[21] For example, Board of Governors (2022, p. 15) states that[22]

> "[t]he dollar's international role benefits the United States by, among other things, lowering transaction and borrowing costs . . . [It] also allows the United States to influence standards for the global monetary system. Today, the dollar is widely used . . . because of the depth and liquidity of U.S. financial markets, the size and openness of the U.S. economy, and international trust in U.S. institutions and rule of law. . . . Some have suggested that, [if in the future, foreign] CBDCs were more attractive than existing forms of the U.S.

[19] Lack of competition may be a consequence of high compliance related fixed costs, resulting in turn from concerns about the safety of payment and saving instruments and the stability of the financial system, as articulated by Tobin (1985, 1987).

[20] See Sveriges Riksbank (2017, 2018) on the objective to secure access of the general public to central bank money.

[21] See also Brunnermeier and Landau (2022). Brunnermeier et al. (2019, pp. 2–3) predict that new privately issued digital currencies "will emerge as the central lynchpins of large, systemically important social and economic platforms that transcend national borders," unbundling the functions of money, contributing to the establishment of "digital currency areas" and fostering competition between private and public money, eventually leading countries to offer CBDC "in order to retain monetary independence."

[22] On the role of the U.S. dollar in international finance and payments see, e.g., the chapters in the Handbook of International Economics (2022). Chorzempa and Spielberger (2025) discuss China's growing role in international payments.

dollar, global use of the dollar could decrease—and a U.S. CBDC might help preserve the international role of the dollar."

More recently, Lane (2025) argues that

> "Europe's reliance on foreign payment providers has reached striking levels. International card schemes ... process sixty-five per cent of euro area card payments. ... In addition, mobile app payments, dominated by non-European tech firms ... now account for nearly a tenth of retail transactions and are showing double-digit annual growth. This dependence exposes Europe to risks of economic pressure and coercion and has implications for our strategic autonomy, limiting our ability to control critical aspects of our financial infrastructure. ... [T]hese risks could be further compounded by the growing dominance of foreign technology companies and a potential increase in the holdings of foreign-currency stablecoins. ... The digital euro is a promising solution to counter these risks and ensure the euro area retains control over its financial future. ... From a strategic perspective, the digital euro would curtail the risk that domestic-currency stablecoins might gain a significant market share in the domestic payments system, which would be highly disruptive for the banking system and credit intermediation. Likewise, the availability of the digital euro would also limit the likelihood of foreign-currency stablecoins gaining a foothold as a medium of exchange in the euro area."

Another frequently cited motivation for introducing CBDC is to enhance user autonomy in response to widespread privacy intrusions by private digital service providers—intrusions often enabled by users' own behavior, giving rise to the so-called "privacy paradox" (Norberg et al., 2007).[23] However, despite this potential, much of the public views CBDC as a vehicle for state surveillance rather than a safeguard of privacy, an impression reinforced by the limited adoption of privacy-preserving technologies in current CBDC proposals (van Oordt, 2025). As a result, concerns about official monitoring, data misuse, or even restriction of payments remain widespread (European Central Bank, 2021).[24] Many potential users appear more willing to share sensitive information with private service providers than to engage with a central bank-run payment system, even though governments have legal means of accessing data held by private providers.

The degree of privacy a CBDC provides ultimately depends on its regulatory framework, technological design, and system architecture (Auer and Böhme, 2021; Board of Governors, 2022; Murphy et al., 2024).[25] Beyond these structural factors, broader societal attitudes toward government and institutional trust influence the perceived privacy

[23]Borrowing-constrained users of a digital payment platform may willingly forgo privacy in order to commit to debt repayments, turning future transactions into "digital collateral." A privacy-preserving CBDC could undermine this mechanism by weakening enforcement (Brunnermeier and Payne, 2025).

[24]Nevertheless, Patel and Ortlieb (2020, p. 19) argue that in many jurisdictions, "central banks are preferred digital currency issuers."

[25]In a "one-tier" model, the central bank interacts directly with end users and acts as the main collector and repository of identity and transaction data. Most central banks exploring CBDCs have ruled out this model. In contrast, a "two-tier" model delegates the customer interface to private payment service providers, restricting the central bank's access to only aggregated or anonymized data. Chaum et al.

differences between publicly and privately issued payment instruments.[26] Reflecting these concerns, central banks have explicitly linked CBDC development to legislative commitments ensuring robust privacy protections, alongside exploration of technical solutions designed to give users meaningful control over their data (Torres Vives et al., 2024).

Since many of the previously discussed motivations do not point to a clearly identifiable market failure that would justify CBDC as the natural policy response, critics have argued that CBDC is a "solution in search of a problem" (e.g., Economic Affairs Committee, 2022) and they have voiced doubts about any substantial demand for CBDC.[27] In stark contrast, central banks tend to be more concerned about excessive CBDC adoption. Their primary worry is the risk of bank disintermediation—large-scale deposit outflows into CBDC, especially during times of financial stress—a worry that often reflects partial equilibrium reasoning, as we discuss below.[28]

In response to this concern, some central banks exploring the introduction of CBDC consider to promote its use primarily as a means of payment, seeking to preserve bank balance sheets while offering an alternative to existing—often foreign-owned—payment providers. Key policy instruments in that context include caps on individual CBDC holdings and the absence of remuneration; their effective use would separate the store-of-value function of money from its role as a means of payment.[29] Evidence presented in Berg et al. (2024) suggests that such a model could materially reshape the payments landscape. The authors find that stock prices of U.S. payment firms decline in response to positive announcements about the digital euro, while stock prices of European payment firms increase. Berg et al. (2024) find no significant stock price reaction for banks.[30] But as we will discuss below, caps on CBDC holdings have their problems, related to

(2021) propose a CBDC model that uses cryptographic techniques to combine transaction privacy with regulatory compliance.

[26]See also the evidence discussed in Bidder et al. (2024).

[27]Bofinger and Haas (2020) argue that, from the perspective of allocative efficiency, there is no compelling case for central banks to issue digital cash substitutes. They identify a market failure in global payment networks stemming from monopolistic or oligopolistic market structures, and contend that addressing this failure would require a supranational policy response.

[28]Concerns about either 'too low' or 'too high' CBDC uptake have motivated numerous efforts to forecast potential adoption levels. An expanding body of literature seeks to estimate how extensively CBDC might be used as a store of value or means of payment, with predictions varying widely depending on underlying assumptions about design choices. See, e.g., Bijlsma et al. (2024), Bidder et al. (2024), Gross and Letizia (2023), Huynh et al. (2020), Lambert et al. (2024), Li (2023), Nocciola and Zamora-Pérez (2024), or Whited et al. (2023).

[29]According to Bindseil and Senner (2024), the European Central Bank envisions a holding limit of EUR 3,000; the Bank of England proposes GBP 10,000–20,000; and the People's Bank of China, CNY 10,000. None of the three central banks plans to offer remuneration. Furthermore, "the ECB plans to only allow natural persons who are permanent residents of the euro area (or possibly of the EU), and temporary residents (e.g., travelers) to be able to hold digital euro within the limits" (p. 2). The European Central Bank's proposed "waterfall" model would automatically transfer any digital euro holdings above the cap into a user's linked bank account, while the "reverse waterfall" would draw funds from that account to complete a payment if the CBDC balance is insufficient (Bindseil et al., 2024).

[30]Burlon et al. (2024) find that euro area banks more reliant on deposit funding experience negative stock price reactions to news related to the digital euro. These effects dissipate following announcements about planned holding limits.

adoption, market segmentation, and the risk to miss out on some of the opportunities CBDC affords.

The following analysis and discussion centers on the implications of CBDC for banks, financial markets, and the broader macroeconomy. Following Tobin, it emphasizes the public issuer nature of CBDC—Reserves for All—rather than the technical infrastructure underlying the payment system.[31] This approach aligns with much of the macroeconomic and banking literature, which prioritizes the balance sheet and market structure effects of CBDC over its technological implementation. Instead of delving into technical specifics, the literature typically assumes rather than models the liquidity and convenience features of CBDC, even though they fundamentally depend on payment system technology.[32]

The discussion also deliberately sets aside wholesale central bank digital currency; that is, reserves held by financial institutions (as in the contemporary monetary system) but implemented on a different technological platform. Wholesale central bank digital currency projects aim at enhancing interoperability, connecting infrastructures for atomic (instant and risk-free) payment and settlement without the need for costly reconciliation processes.[33] This exclusion does not imply that wholesale central bank digital currency is unimportant or unlikely to be adopted, on the contrary. Since wholesale central bank digital currency promises efficiency gains without requiring major structural change or having large redistributive impact among market participants, it can be seen as a technological upgrade and, arguably, a straightforward policy choice. This stands in sharp contrast to the CBDC at the center of this review—Reserves for All—which raises deeper questions about monetary architecture and financial intermediation.

3 Conceptual Framework

In this section, we establish conditions for neutral regime change—specifically, the neutral introduction of CBDC. Subsequently, we will use these conditions to identify sources of non-neutrality. We derive the conditions in an abstract setting rather than a specific, fully specified model. The idea is to dispense with unnecessary auxiliary assumptions and noncentral elements that would narrow applicability and obscure the general insights. To accommodate this level of generality, we base the analysis on agents' choice sets and aggregate consistency requirements. The logic is that, if the regime change does not alter

[31] For system design considerations, see, e.g., Group of Central Banks (2024b). We also abstract from legal issues; see Group of Central Banks (2024a). In 2021, the majority of central banks lacked legal authority to issue CBDC (Boar and Wehrli, 2021).

[32] On operational architectures and technology, see for example Auer and Böhme (2020) and Auer et al. (2022). The Federal Reserve has argued that a "potential U.S. CBDC, if one were created, would best serve the needs of the United States by being privacy-protected, intermediated [accounts or digital wallets to facilitate the management of CBDC holdings and payments offered by the private sector], widely transferable, and identity-verified" (Board of Governors, 2022, p. 13). Almost all current CBDC designs envision such an intermediated model.

[33] Many BIS Innovation Hub projects focus on wholesale central bank digital currency; see, e.g., Di Iorio et al. (2024). For estimates of reconciliation costs in today's financial architecture, see Mainelli and Milne (2016).

agents' opportunities nor violate aggregate constraints, then equilibrium outcomes must remain unchanged as well.

Ricardian equivalence (Barro, 1974) offers an illustration. One way to prove it is to show in a given model that changing the timing of tax collections does not alter key equilibrium outcomes. A more general and transparent strategy is to establish that the change leaves agents' choice sets unaffected regardless of specific modeling assumptions—and to infer neutrality in a broad class of models. Our analysis follows the latter approach. Since we consider an abstract setting, the neutrality conditions we derive are sufficient but not necessary in every specific model. We keep the discussion informal and defer details to Appendix B.

3.1 Economy

We consider a dynamic economy comprising private sector agents and a government. The private sector includes potentially heterogeneous households, firms, and banks, some of which may reside abroad. The consolidated government consists of a central bank and a fiscal authority. Time is discrete. Preferences, technologies, and other primitives may be subject to exogenous shocks, with histories of these shocks up to a node of the event tree at time t indexed by ϵ^t. We allow for an arbitrary set of assets and do not restrict the sources of liquidity demand.[34] Bank operations may be costly.

Private sector agents and the government make *choices*. For example, agents in the private sector may choose current and future consumption, production or portfolios, and agents with market power may set prices. The government's choices or *policy* may include paths for public consumption, central bank or treasury balance sheet positions, or tax functions. Competitive prices are also treated as government choices.

Private sector agents face *constraints* such as dynamic budget constraints, no-Ponzi game conditions, or technological and regulatory constraints. The constraints depend on factors beyond the agent's control, which we refer to as the agent's *state*. For example, the state of a competitive agent includes current and expected future market prices, among other factors, and the state of a monopolist includes the demand function the firm faces. The *choice set* of a private sector agent then is given by the set of feasible choices conditional on the agent's constraints and state. Each private sector agent has an *objective*, which depends on the agent's choices and state. Typical objectives are a household's utility or a firm's profit.

The economy also is subject to *aggregate constraints* representing, e.g., market clearing conditions, the government budget constraint, or linkages between productivity levels of firms due to spillover effects. The aggregate constraints depend on the economy's exogenous state. They imply the *aggregate choice set*, namely the set of private sector and government choices that are feasible conditional on the aggregate constraints and state.

[34] For example, liquidity demand may derive from "money in the utility function" (Sidrauski, 1967), "cash-in-advance" constraints (Clower, 1967), or cost functions and resource requirements as in Baumol (1952), Tobin (1956) or Niepelt (2023, 2024b).

In history ϵ^t, the economy is characterized by the aggregate state, the aggregate choice set, and the collection of private sector choice sets and objectives conditional on the aggregate state. An *equilibrium* in history ϵ^t is a policy and a collection of private sector choices and states such that policy and private sector choices are feasible in the aggregate, private sector choices are individually feasible and optimal, and states determining private sector constraints are consistent with outcomes on and off the equilibrium path.[35]

3.2 Regime Change

Starting from some "initial" equilibrium, we consider a *regime change* that prescribes a policy change and a proposed change of private sector choices—a *proposal*. Since policy and agent choices constrain the choices of others, the regime change may also imply new states including altered off-equilibrium outcomes.[36]

The specific regime change we consider pairs the introduction of CBDC with a small set of accompanying policy actions and proposed changes of private sector choices. In particular, we restrict the policy change to include (at most) altered reserve and CBDC issuance by the central bank, changed central bank lending to banks, and lump-sum transfers. As we will see, not all of these elements may be needed. Similarly, we restrict the proposed changes of private sector choices to (at most) changes in deposits (issued by banks and held by nonbanks), the banks' reserve holdings and borrowing from the central bank, and nonbanks' CBDC holdings. All other elements of policy or private sector choices in the initial equilibrium, such as prices, returns, consumption, labor supply, capital accumulation, or bank loans, are unaffected by the regime changes we consider.

Our focus on deposits in addition to the other balance sheet positions is guided by what we view as the most likely and relevant scenario for the introduction of CBDC, namely a scenario in which nonbanks gain the option to convert deposits into CBDC balances. If they exercise this option, banks might still manage CBDC balances on behalf of their customers, but the deposit-CBDC swap converts customer claims against the bank into claims against the central bank. Simultaneously, it deprives banks of an important source of funding, a fact that has triggered concerns about the potential implications for financial stability and bank lending.

In several dimensions, this baseline scenario resembles the withdrawal of cash by a nonbank at the ATM. In either case, the nonbank swaps deposits against central bank liabilities, either physical bank notes or digital ledger entries or tokens. Moreover, in either case the bank loses deposit funding, which by double-entry bookkeeping must be accompanied by (an)other balance sheet change(s). In the ATM example, the bank's cash holdings fall, so the bank's balance sheet shortens. In the CBDC scenario, the deposit outflow similarly drains the bank's reserves, as with a regular deposit-based interbank

[35]For the last equilibrium requirement, consider for example a monopolist. The state of this firm includes the demand function it perceives to face, and consistency requires the perceived function to correspond with the one that would actually result if the monopolist deviated from its optimal (price or quantity) choice and the firms' customers changed their demands accordingly. The exact off-equilibrium refinement is not important as long as we maintain it across the environments we compare.

[36]For example, if the state of a monopolist includes a perceived demand curve and the proposal is for the firm's customers to change their demand, then this proposal implies a new perceived demand curve.

payment, or the bank balance sheet maintains its length as the deposit outflow is compensated by new funding from the central bank or a third party.

An alternative scenario for the introduction of CBDC is one in which nonbanks and the central bank directly interact, swapping CBDC against cash. Such a change of assets by the nonbank accompanied by a change of liabilities of the central bank has no direct effect on bank balance sheets. As a consequence, the immediate repercussions are much more limited, and the macroeconomic implications, if any, would likely derive from differential "convenience" of the two means of payment (e.g., related to liquidity or privacy) or from unequal costs of using the payment instruments for transactions. These potential implications are also present in the baseline scenario and will be addressed later. Then, we will also discuss yet other scenarios for the introduction of CBDC, such as CBDC issuance in exchange for government bonds rather than cash, or by helicopter drop (transfer).

The introduction of CBDC may also be associated with no change in balance sheet positions at all and still be relevant, for instance because it increases competitive pressure on payment service providers without being adopted. Our framing of regime change allows for this possibility and we will consider it.

Without loss of generality, we focus on a regime change in history ϵ^t and its immediate successor histories, $\{\epsilon^{t+1|t}\}$. The extension to changes in multiple histories is immediate. For now, we also assume that the regime change affects only one bank, denoted by b, in addition to the government, g, as well as a nonbank, i. Below, we consider the extension to multiple, heterogeneous banks or nonbanks.

Formally, letting τ denote transfers and n, r, m, ℓ deposit, reserve, CBDC, and central-bank-loan balance sheet positions, respectively, the policy change we consider is given by

$$\begin{aligned}
&\Delta m^g, \Delta r^g, \Delta \ell^g, \\
&\Delta \tau^j, \{\Delta \tau^j_+\},\ j = i, b, \\
&\Delta \tau^g, \{\Delta \tau^g_+\}.
\end{aligned}$$

The first line represents the modified CBDC and reserve issuance in history ϵ^t as well as the central bank loan to the bank, respectively. These policy changes in history ϵ^t are reversed in each of the immediate successor histories. That is, when the government issues additional CBDC in history ϵ^t, $\Delta m^g > 0$, then it retires the same amount in the following period, such that the stock of CBDC at the end of period $t + 1$ is the same as in the initial equilibrium. A parallel logic applies to negative changes, $\Delta m^g < 0$, or to changes in reserves and the central bank loan.

The first term in the second line represents changes in lump-sum transfers to the nonbank or the bank in history ϵ^t, and the second term represents such transfer changes in the successor histories. (To simplify the notation, we write τ^j_+ for $\tau^j(\epsilon^{t+1|t})$ and similarly for other variables in period $t+1$.) The last line represents changes in lump-sum transfers to the government.

The proposed balance sheet adjustments in the private sector are

$$\begin{aligned}
&\Delta n^i, \Delta m^i, \\
&\Delta n^b, \Delta \ell^b, \Delta r^b,
\end{aligned}$$

where the first line represents the increase in the nonbank's exposure to deposits and CBDC, and the second line represents changes in the bank's deposit and central bank loan liabilities as well as reserve holdings, respectively. Again, these changes occur in history ϵ^t and are reversed in the immediate successor histories.

We impose from the outset that the regime change satisfies asset market clearing (encoded in the aggregate constraints). That is, the change in the bank's deposit liabilities equals the change in the nonbank's deposit holdings, $\Delta n^b = \Delta n^i$; ditto for CBDC, $\Delta m^g = \Delta m^i$; and reserve as well as loan changes in the balance sheet of the bank and the central bank match, $\Delta r^g = \Delta r^b$ and $\Delta \ell^g = \Delta \ell^b$. Moreover, transfer changes must sum to zero in each history. We assume that the regime change is sufficiently small not to interfere with nonnegativity constraints on balance sheet positions.

Finally, we assume that at the initial equilibrium prices, CBDC is a redundant asset whose introduction does not change the asset span.[37]

3.3 Neutrality

We are interested in sufficient conditions under which the regime change is consistent with a "new" equilibrium that is identical to the initial equilibrium except for the policy change and the proposed changes in private sector choices and implied states. In other words, we are interested in sufficient conditions for a *neutral* regime change.

The first condition for neutral change is that the new policy and proposed private sector choices are feasible:

Condition 1. Proposed private sector choices are individually feasible given the new states, and the new policy and proposed private sector choices are feasible in the aggregate.

The first part of Condition 1 stipulates that it is individually feasible for any private sector agent to follow the proposal conditional on the modified states. The second part asserts that this also holds true at the aggregate level. It would be violated, for example, if a regime change conflicted with market clearing conditions. While Condition 1 is necessary for the regime change to be implementable, it is not sufficient because it does not guarantee that private sector agents want to follow the proposal. We therefore impose a second, (sufficient) condition on choice sets and objectives:

Condition 2. The policy change and proposed change of private sector choices leave objective values unchanged. Moreover, if a private sector choice is individually feasible after the regime change, then the same choice, net of the proposed adjustment, is feasible prior to the regime change.

The first part of Condition 2 stipulates that starting from any individually feasible choice prior to the regime change, modifying that choice according to the proposal leaves

[37]See Geanakoplos (1990) for a discussion of market incompleteness and the effects of changes in the asset span. As discussed below, a neutral regime change also leaves liquidity or convenience premia unchanged. In some cases, we consider policy changes that set CBDC remuneration inconsistently with the state prices and convenience premia of the pre-CBDC equilibrium. Regime changes involving such policies are not neutral.

the values of agents' objectives after the regime change unchanged. The second part asserts that every individually feasible choice after the regime change is identical to an individually feasible choice before the regime change, modified by the proposed change. This ensures that the regime change does not enlarge the effective choice sets of agents. If Condition 2 is satisfied, the proposal is incentive compatible (see Appendix B).

In many applications of interest, Condition 2 can easily be verified. For example, if neither the proposal nor the change of state directly enter the objective function, or if the effects of the proposal and the changed state on the objective cancel, then it follows immediately that the first part of Condition 2 is satisfied. And if the proposal exactly compensates for the effect of the change of state on the agent's choice set, i.e., if

$$\text{(initial choice set)} = \text{(new set of feasible choices net of proposal)}, \tag{1}$$

then the second part of Condition 2 is satisfied. (Incidentally, the first part of Condition 1 is satisfied as well in this case.) Intuitively, Equality (1) guarantees that if it is feasible for an agent to make a choice after the regime change, then it is also feasible to make a very similar choice before the regime change—the latter augmented by the proposal being the same as the former. That is, following the proposal allows the agent to maintain all other elements of its choice.

We have thus established the following result (see Appendix B):

Theorem 1. Consider an initial equilibrium in history ϵ^t. A regime change satisfying Conditions 1–2 is neutral except for the policy change and the proposal and implied new states.

While the implications of Conditions 1 and 2 vary across models, the two conditions always require that the regime change respects budget and resource constraints. Focusing first on budgets, individual feasibility demands that the policy change and proposed change of balance sheet positions does not tighten budget constraints (at unchanged prices); otherwise, some other choices or some prices would have to change, undermining neutrality. At the same time, incentive compatibility demands that the policy change does not increase disposable wealth (defined below); otherwise, the nonbank or bank could spend more than in the initial equilibrium, and this would violate the second part of Condition 2, which requires that the regime change not enlarge the agent's effective choice set.

Formally, denoting equilibrium gross rates of return on a generic asset x by R_+^{x*}, Conditions 1 and 2 applied to the budget constraints entail

$$\sum_{x=n,m} \Delta x^i + \Delta\varphi^i = \Delta\tau^i, \tag{2}$$

$$\sum_{x=n,m} R_+^{x*} \Delta x^i = -\Delta\tau_+^i \quad \forall\epsilon^{t+1|t}, \tag{3}$$

$$\Delta r^b + \Delta\varphi^b = \sum_{x=\ell,n} \Delta x^b + \Delta\tau_t^b, \tag{4}$$

$$R_+^{r*} \Delta r^b = \sum_{x=\ell,n} R_+^{x*} \Delta x^b - \Delta\tau_+^b \quad \forall\epsilon^{t+1|t}. \tag{5}$$

Equation (2) states that the change in transfers to the nonbank in history ϵ^t equals the change in deposit and CBDC exposures, plus any increase in balance sheet costs, $\Delta\varphi^i$, which may depend on the affected balance sheet positions. We introduce balance sheet costs to account for any type of cost agents may incur from managing or administering balance sheet positions. For example, if swapping deposits for CBDC were to reduce fees, then $\Delta m^i > 0$, $\Delta n^i < 0$ would be associated with $\Delta\varphi^i < 0$. According to Equation (3), the financial payoff implications of the balance sheet changes in successor histories must also be offset by transfer changes. Otherwise, the nonbank would not be able to maintain its equilibrium choices in areas unaffected by the proposal, thereby undermining neutrality. For simplicity, we abstract from balance sheet costs in period $t+1$.

Equations (4) and (5) impose parallel restrictions on the bank's budget constraints. Equation (4) states that the bank's budget in history ϵ^t continues to balance after the regime change. Specifically, any increase in reserve exposure and balance sheet costs must be matched by higher obligations on deposits or central bank loans, along with increased transfer receipts. Equation (5) requires that, in each immediate successor history, the return on the changed reserves position matches the return on the adjusted deposit and loan positions, adjusted for a transfer change.

Let sdf^*_+ denote the equilibrium stochastic discount factor (SDF). Subtracting the SDF-weighted Equation (3) from Equation (2), and similarly Equation (5) from Equation (4), and taking expectations conditional on information in history ϵ^t yields

$$\sum_{x=n,m} \Delta x^i \sigma^{x*} + \Delta\varphi^i \quad = \quad \Delta\tau^i + \mathbb{E}[\mathrm{sdf}^*_+ \Delta\tau^i_+], \tag{6}$$

$$\Delta r^b \sigma^{r*} - \sum_{x=\ell,n} \Delta x^b \sigma^{x*} + \Delta\varphi^b \quad = \quad \Delta\tau^b + \mathbb{E}[\mathrm{sdf}^*_+ \Delta\tau^b_+], \tag{7}$$

where we denote the equilibrium spread on generic asset x by $\sigma^{x*} \equiv 1 - \mathbb{E}[\mathrm{sdf}^*_+ R^{x*}_+]$.[38] As with Conditions (2)–(5), the implied Equations (6) and (7) represent feasibility and incentive compatibility requirements. They state that the change in disposable wealth, i.e., market value of transfers net of balance sheet costs, is just sufficient to cover the change in expenditures for convenience or liquidity. Equations (6)–(7) generalize the result leading to Lemma 1 in Brunnermeier and Niepelt (2019), who abstract from balance sheet costs.

By construction, the regime change guarantees asset market clearing for the affected balance sheet positions (deposits, CBDC, reserves, central bank loans) and ensures that transfers sum to zero in each history. Equations (6)–(7) and the parallel condition for the government therefore imply the neutrality requirement

$$\Delta\varphi^g + \Delta\varphi^i + \Delta\varphi^b = 0, \tag{8}$$

[38] The spread differs from zero when the return satisfies $\mathbb{E}[\mathrm{sdf}^*_+ R^{x*}_+] \neq 1$, which is the case when the balance sheet position x enters an objective or a constraint other than the budget constraint. For example, a positive spread, corresponding to a subpar return in some history $\epsilon^{t+1|t}$, indicates that the asset holder is willing to sacrifice financial payoffs in exchange for another benefit of the asset, namely a positive direct effect on the objective or a relaxation of a binding constraint other than the budget constraint. The spread represents the unit cost of this convenience or liquidity benefit.

which states that the change in balance sheet costs borne by the government balances the combined changes borne by the private sector. Intuitively, when changes in balance sheet positions net out in aggregate and transfer changes similarly sum to zero, any aggregate change in balance sheet costs would violate some budget constraint. If balance sheet costs represent resource requirements, then aggregate resource restrictions and neutrality (the second part of Condition 1) also imply Condition (8), for each resource individually.

4 CBDC—Central Domains

The previous section established general conditions under which the introduction of CBDC is neutral. In this section, we add minimal structure and review the literature in light of the conditions. Our analysis focuses on three domains directly affected by CBDC: The nonbank, the bank, and the system as a whole, where general equilibrium effects cannot be directly attributed to individual agents.

For each domain, we offer illustrative examples of neutrality and identify features on which it rests. We show how neutrality can break down, either due to structural characteristics of the economic environment or because of policy choices, referring to these two types of sources of non-neutrality as "fundamentals" and "policy," respectively. In Section 5, we discuss extensions and generalizations.

4.1 Nonbank

We start with an example of a household. It demonstrates that neutral regime change is possible even if convenience or liquidity benefits of deposits and CBDC differ.

Example 1 (Household)**.** Household i has "money in the utility function" preferences (Sidrauski, 1967). The liquidity services of deposits and CBDC are a weighted sum of the two balance sheet positions, $n^i + \lambda m^i, \lambda > 0$. In equilibrium, deposits and CBDC therefore carry a liquidity premium and the premium of CBDC relative to deposits equals λ, which may differ from one.[39] The regime change does not alter the household's balance sheet costs, $\Delta\varphi^i = 0$.

The regime change tightens the household's budget constraint in history ϵ^t by $\Delta n^i + \Delta m^i - \Delta\tau^i$ and relaxes it in history $\epsilon^{t+1|t}$ by $R_+^{n*}\Delta n^i + R_+^{m*}\Delta m^i + \Delta\tau_+^i$. Individual feasibility and unchanged wealth net of balance sheet costs demand that both these effects equal zero. Moreover, incentive compatibility requires the asset swap to have no effect on the objective function, i.e., we must have $\Delta n^i + \lambda\Delta m^i = 0$. Taken together, neutrality thus requires $(1-\lambda^{-1})\Delta n^i = \Delta\tau^i$ and $(R_+^{m*}/\lambda - R_+^{n*})\Delta n^i = \Delta\tau_+^i$. This also implies that the regime change is wealth neutral for the household.[40]

[39] The household's Euler equations imply $\lambda(1 - \mathbb{E}[\text{sdf}_+^* R_+^{n*}]) = 1 - \mathbb{E}[\text{sdf}_+^* R^{m*}]$.

[40] $\Delta\tau^i + \mathbb{E}[\text{sdf}_+^* \Delta\tau_+^i] = \Delta n^i\{(1-\lambda^{-1}) + \mathbb{E}[\text{sdf}_+^*(R_+^{m*}/\lambda - R_+^{n*})]\} = 0$, where the last equality follows from the equilibrium relationship between R_+^{m*} and R_+^{n*}.

We conclude that the restrictions

$$\left.\begin{aligned} &\Delta m^i = -\lambda^{-1}\Delta n^i,\ R_+^{m*} \text{ satisfies condition in fn. 39} \\ &\Delta \tau^i = (1-\lambda^{-1})\Delta n^i \\ &\Delta \tau_+^i = (R_+^{m*}/\lambda - R_+^{n*})\Delta n^i \quad \forall \epsilon^{t+1|t} \end{aligned}\right\} \tag{9}$$

guarantee that the regime change satisfies the first part of Condition 1 as well as the first part of Condition 2 for the household. It also satisfies the second part of Condition 2 because Equation (1) applies: Conditional on the modified transfers, the proposed swap of balance sheet positions puts the household exactly in the same position as before the regime change, letting the household choose from the exact same menu of options. The household therefore is indifferent about the regime change and neutrality prevails as far as the household is concerned.

Fundamentals. Clearly, the "money in the utility function" assumption in Example 1 is not important for the neutrality result. The same restrictions would follow if the household faced a binding cash-in-advance constraint as in Lucas (1982), a shopping time constraint as in Saving (1971), or some other type of constraint that depends on a linear combination of n^i and m^i. What matters for neutrality is not the source of liquidity or convenience benefits, but how these benefits can be substituted across payment instruments.

In particular, as emphasized by Brunnermeier and Niepelt (2019), the marginal rate of substitution between deposit and CBDC liquidity or convenience benefits must be constant; otherwise, Condition 1 is violated. A non-constant rate of substitution undermines neutrality because, for given spreads and expenditures, substituting one means of payment by the other reduces total liquidity or convenience benefits. Viewed differently, a portfolio adjustment that changes the marginal rate of substitution is inconsistent with equilibrium unless the relative spreads of the assets change correspondingly, rendering the regime change non-neutral.

Many papers in the literature assume that nonlinear aggregates of deposits and CBDC (and possibly other means of payment) offer convenience (Abad et al., 2025; Burlon et al., 2024; Kumhof et al., 2023), relax a cash-in-advance constraint (Assenmacher et al., 2024), provide liquidity services that reduce transaction costs (Barrdear and Kumhof, 2022; Bidder et al., 2024), or enter the budget constraint (Paul et al., 2025). This implies non-neutrality as we just saw, although the empirical relevance of the nonlinearity assumption appears questionable.[41] Abad et al. (2025) and Burlon et al. (2024) calibrate the elasticity of substitution between payment instruments to be roughly four, while Bidder et al. (2024) posit an elasticity above six. These assumptions translate into commensurate effects on spreads resulting from a regime change. Bacchetta and Perazzi (2022) analyze how the relative convenience of CBDC and deposits as well as their degree of substitutability shape money demand and seignorage revenues.

[41] Paying the first installment of one's rent or mortgage with deposits and the second with CBDC, or paying both installments with either one, should not make much of a difference for a household that is indifferent at the margin. This suggests that substantial rebalancing of the payment portfolio could be undertaken before confronting nonconstant rates of substitution. Assenmacher et al. (2023) and Gross and Schiller (2021) present DSGE models with a constant marginal rate of substitution.

In Assenmacher et al. (2021), substitutability between deposits and CBDC is limited for technological reasons. The authors assume that certain factors of production can only be purchased using deposits, while others require CBDC as the means of payment, with a finite elasticity of factor substitution. Lamersdorf et al. (2024) similarly assume that CBDC is an essential means of payment—thereby ruling out neutrality by design. Their framework links the demands for CBDC and reserves by modeling banks as intermediaries that purchase CBDC on behalf of their clients, settling the purchases with reserves. This creates a reserve management challenge analogous to that described by Poole (1968): Banks must weigh the costs and benefits of acquiring reserves in the interbank market prior to the realization of shocks versus relying on central bank deposit and lending facilities afterward.

Brunnermeier and Niepelt (2019) identify another source of potential non-neutrality that is present when a payment instrument portfolio enters multiple constraints. They illustrate the issue in the context of a cash-in-advance constraint framework, contrasting the timing assumptions of Lucas (1982) and Svensson (1985). Under the Lucas (1982) assumption, the nonbank acquires money balances just before spending them, after observing an exogenous shock. With linearly substitutable payment instruments, neutrality imposes a single restriction, and the analysis in Example 1 applies.

In contrast, the Svensson (1985) assumption dictates that the nonbank acquires money balances before the shock occurs, leading to contingent cash-in-advance constraints, one for each possible realization of the shock. If these constraints vary across contingencies—for instance, due to differences in velocity—the effects of portfolio reallocation depend on the specific shock realization, and neutrality typically breaks down. A similar issue arises when CBDC and deposits provide convenience in multiple dimensions (e.g., privacy and transaction speed), meaning there is no single, uniform marginal rate of substitution.[42]

The parameter λ in Example 1 may capture various non-financial benefits of a payment instrument. One such benefit is the privacy it affords, along with related aspects such as censorship resistance. Kahn et al. (2005) and Acquisti et al. (2016) discuss economic and non-economic dimensions of privacy (see also Section 2). Moreover, λ may reflect the payment instrument choice of other agents, for instance because usefulness of a means of payment increases with broader adoption, giving rise to network effects, or as a consequence of privacy externalities. We discuss both issues below.

Finally, differences in transaction costs across payment instruments also challenge neutrality. In Example 1, we abstract from such costs by setting $\Delta\varphi^i = 0$. But the challenge is surmountable: When transaction costs associated with the use of deposits and CBDC differ at the margin, neutrality can still be preserved, provided that transfers are adjusted to maintain indifference; Example 2 below establishes this in the bank context. In contrast, fixed transaction costs generally break indifference across instruments before the introduction of CBDC, but of course cease to matter afterwards.

Policy. Example 1 clarifies another general point: When $\lambda \neq 1$, neutrality requires transfers between the household and the government, $\Delta\tau^i \neq 0$. This is an implication of

[42]See Agur et al. (2022) for a model in which CBDC has multiple convenience dimensions.

the budget constraint in history ϵ^t and the fact that unchanged convenience or liquidity under $\lambda \neq 1$ requires a change in the portfolio value $m^i + n^i$. For the same reason, transfers are needed in the successor histories $\epsilon^{t+1|t}$. When returns are deterministic, the required transfer at time $t+1$ equals the negative of the time-t transfer, multiplied by the risk-free gross interest rate;[43] with stochastic returns, the time-$(t+1)$ transfer generally must be stochastic as well.

If the government lacks transfer instruments, neutrality in a weaker sense—conditional on changes in additional balance sheet positions beyond those considered so far—may still prevail. Consider Example 1 with $\lambda \neq 1$ and suppose that the household's deposit-CBDC swap is accompanied by another portfolio change, namely changed exposure to some third asset k without convenience or liquidity benefits. Rather than receiving transfer $(1 - \lambda^{-1})\Delta n^i$ in history ϵ^t, the household reduces its exposure to k by that same amount. If the gross return on k happens to equal $(R_+^{m*}/\lambda - R_+^{n*})/(\lambda^{-1} - 1)$, then the modified exposure to k fully replicates the effects of transfers on household budget constraints. As far as the household is concerned, the regime change accompanied by modified exposure to k therefore is neutral, and the transfer changes described in Example 1 can be dispensed with.

This result extends to general equilibrium if the household's reduced exposure to k mirrors increased exposure by the government, i.e., if the household sells $(1 - \lambda^{-1})\Delta n^i$ worth of asset k to the government.[44] Moreover, even if k does not have the specific return characteristics to match the contingent transfers $\Delta\tau_+^i$, the latter may still not be needed. To see this, note that the consequence of mis-matched return characteristics is to induce contingent redistribution. In the context of Example 1, any difference between the gross return on k on the one hand and $(R_+^{m*}/\lambda - R_+^{n*})/(\lambda^{-1} - 1)$ on the other implies that along some continuation history, financial wealth of one party is higher than in the initial equilibrium, while it is lower for the counter party. This undermines neutrality when the altered financial wealth distribution affects the equilibrium allocation—but not otherwise. Because of Ricardian equivalence (Barro, 1974), neutrality prevails in spite of mis-matched return characteristics when the nonbank is the taxpayer, or is owned by the taxpayer, such that a change of financial wealth distribution is offset by altered future tax and transfer payments. The key point is that ownership linkages can substitute for contingent transfers.[45]

Neutrality may be compromised for another reason, namely, inappropriate CBDC remuneration. If the interest rate on a newly introduced CBDC fails to satisfy the condition given in Footnote 39, nonbanks will not be indifferent at the margin. In particular, when the CBDC interest rate is set too low, nonbanks have no incentive to adopt CBDC, and this renders the regime change not implementable. However, different types of regime change may still be possible, in particular those that involve swaps of unremunerated

[43]The transfer per unit of Δn^i equals $R_+^{m*}/\lambda - R_+^{n*} = (1-\lambda)/\lambda/\mathbb{E}[\text{sdf}_+^*]$.

[44]Wallace (1981) stresses the complementarity of open market operations and contingent transfers: A nonbank acquires government liabilities in exchange for capital, but the allocation remains unchanged when lump-sum taxes are adjusted correspondingly. In Wallace (1981), there is no bank and the liability does not serve as payment instrument.

[45]For a related discussion, see Brunnermeier and Niepelt (2019, p. 35).

CBDC against cash.

4.2 Bank

Turning to the second domain, we consider the implications of a regime change for a bank. We start again with an example. It demonstrates that market power and nonlinear constraints on balance sheet positions need not undermine neutrality.

Example 2 (Bank)**.** Bank b finances its reserve holdings and lending to third parties through deposits and, following a regime change, also through a central bank loan. (While the bank may have access to additional funding sources and may invest in other assets, these play no role for the analysis.) In the presence of market power in the deposit market, the bank faces an inelastic deposit supply schedule. In the initial equilibrium, this schedule is given by $R_+^{n*}(n^b)$, implying that deposit funding of size n^b results in gross interest payments of $h_+(n^b) \equiv n^b \cdot R_+^{n*}(n^b)$ in the following period. Deposit-related operations—such as processing payments for customers—incur costs denoted by $\varphi^b = \alpha(\zeta)n^b$, where α may decrease in the reserves-to-deposits ratio $\zeta \equiv r^b/n^b$, for instance because liquidity transformation entails operational and stability risks, which increase as the reserve buffer shrinks.[46]

At equilibrium prices, incentive compatibility requires $\Delta\zeta = 0$ or $\Delta r^b = \zeta^*\Delta n^b$, such that the regime change does not affect unit operating costs. Accordingly, the bank's budget constraint in history ϵ^t tightens by $\Delta r^b + (\alpha(\zeta^*) - 1)\Delta n^b - \Delta\ell^b - \Delta\tau^b$ or $(\zeta^* + \alpha(\zeta^*) - 1)\Delta n^b - \Delta\ell^b - \Delta\tau^b$. How the regime change affects the budget constraint in history $\epsilon^{t+1|t}$ depends on the terms of the central bank loan. To preserve the choice set of the bank, the central bank must post a loan funding schedule that replicates the deposit funding schedule before the regime change, effectively insulating the bank from the change in deposit funding and preserving its perceived market power.

To achieve this, the total gross interest payments on bank liabilities (n^b, ℓ^b) must equal

$$h_+\left(n^b + \frac{\ell^b}{1-\zeta^*}\right) + \beta\ell^b,$$

where the constant β is yet to be determined. With this funding schedule, the gross interest rate on deposits depends on the quantity of deposits plus the scaled central bank loan, and the gross interest rate on the central bank loan satisfies $R_+^{\ell*} = R_+^{n*}/(1-\zeta^*) + \beta$. The appropriate choice of β renders the bank indifferent between deposits and the central bank loan. A unit of deposits generates net cash flow $1 - \alpha(\zeta^*) - \zeta^*$ in history ϵ^t, because of operating costs and increased reserves holdings; in history $\epsilon^{t+1|t}$, it generates net cash flow $\zeta^* R_+^{r*} - R_+^{n*} - (n^b + \ell^b/(1-\zeta^*))\partial R_+^{n*}/\partial n^b$. The alternative, raising $1-\zeta^*$ units of central bank loan funding, generates marginal cash flows $1-\zeta^*$ and $-R_+^{n*} - (1-\zeta^*)\beta - (n^b + \ell^b/(1-\zeta^*))\partial R_+^{n*}/\partial n^b$.[47] Indifference thus requires

$$(1-\zeta^*)\beta\mathbb{E}[\mathrm{sdf}_+^*] = \alpha(\zeta^*) - \zeta^*\mathbb{E}[\mathrm{sdf}_+^* R_+^{r*}].$$

[46] The bank chooses the optimal reserve ratio ζ by weighing the benefit of holding more reserves—lower operational cost—against the cost of a lower return: $\zeta^* = \arg\min_\zeta n^b\{\alpha(\zeta) + \zeta\mathbb{E}[\mathrm{sdf}_+^*(R_+^{b*} - R_+^{r*})]\}$ with R_+^{b*} denoting interest on loans.

[47] Note that $(1-\zeta^*)\partial R_+^{n*}/\partial\ell^b = \partial R_+^{n*}/\partial n^b$.

Intuitively, the value for β that ensures indifference compensates for the unit operating costs of deposits net of the discounted return on reserves that a share ζ^* of deposits generates.

From the budget constraints in histories ϵ^t and $\epsilon^{t+1|t}$, individual feasibility thus implies $\alpha(\zeta^*)\Delta n^b = \Delta\tau^b$ and $R_+^{r*}\Delta r^b - \beta\Delta\ell^b + \Delta\tau_+^b = 0$, which also ensures that the total market value of the transfer changes equals zero. We conclude that a regime change

$$\left.\begin{aligned}
&\Delta r^b = \zeta^*\Delta n^b \\
&\Delta\ell^b = -(1-\zeta^*)\Delta n^b,\ R_+^{\ell*} = R_+^{n*}/(1-\zeta^*) + \beta \\
&\Delta\tau^b = \alpha(\zeta^*)\Delta n^b \\
&\Delta\tau_+^b = -(R_+^{r*}\zeta^* + \beta(1-\zeta^*))\Delta n^b \quad \forall\epsilon^{t+1|t} \\
&\text{with}\ \ \beta = (\alpha(\zeta^*) - \zeta^*\mathbb{E}[\mathrm{sdf}_+^* R_+^{r*}])/((1-\zeta^*)\mathbb{E}[\mathrm{sdf}_+^*])
\end{aligned}\right\} \tag{10}$$

satisfies the first part of Condition 1 for the bank.[48] It also satisfies Condition 2 for the bank as long as the changes do not alter the value of the bank's objective function and the central bank loan is priced as discussed before. This follows, again, because Equation (1) applies: Conditional on the changed transfers and the central bank's loan supply schedule, the modified balance sheet positions in (10) enable the bank to choose from exactly the same menu of options as before the regime change. Changes in the composition of (n^b, ℓ^b) (subject to unchanged $n^b + \ell^b/(1-\zeta^*)$) do not alter the bank's funding net of reserve holdings, nor do they alter the bank's perceived market power. Since the regime change effectively preserves the bank's choice set, the bank is indifferent about it.

Example 2 emphasizes the role of the central bank loan in insulating banks from CBDC. When CBDC crowds out deposits, the central bank can channel newly sourced CBDC funds net of reserves back to banks. If it chooses to do so at appropriate terms, it transfers CBDC seignorage to banks and the bank's environment effectively remains unchanged.[49] Deposit-CBDC substitution in conjunction with refinancing of banks by the central bank transforms private into public money, turns the central bank into an intermediary between nonbanks and banks, and decouples bank funding from liquidity provision (Brunnermeier and Niepelt, 2019). This decoupling occurs rather mechanically: When deposits are transferred to the central bank (and the central bank accepts the incoming payment), it debits the bank's reserves account and/or acquires new claims against the bank. In Example 2, the former amounts to $\zeta^*\Delta n^i$ and the latter to $(1-\zeta^*)\Delta n^i$.

This perspective contrasts with frequently voiced concerns according to which CBDC issuance puts pressure on bank funding, with potentially detrimental effects on financial stability and bank lending. Those concerns reflect a focus on the link between CBDC issuance and deposit redemptions but disregard the link between central bank assets and liabilities. When the central bank issues CBDC, it acquires assets in exchange and provides funding for other market participants. Assessments of the consequences of CBDC issuance remain incomplete if they do not account for this funding.

[48]If R_+^{r*} is deterministic, the fourth condition reduces to $\Delta\tau_+^b = -\alpha(\zeta^*)\Delta n^b/\mathbb{E}[\mathrm{sdf}_+^*]$.

[49]Note that the central bank loan balances the fall in deposits net of reserve holdings; see also Kim and Kwon (2023).

Naturally, central bank loans to banks constitute just one type of central bank asset acquisitions. But even if the central bank acquires other assets, the deposit-CBDC substitution must result in some financial market participants obtaining claims against the banking sector; this is a consequence of double-entry bookkeeping. The question thus is not whether deposit outflows make way for alternative sources of bank funding, but what these sources are and under what terms the financing is extended. Below, we return to the question whether financial markets can substitute for central bank loans in general equilibrium and we also discuss CBDC injections by transfer.

Example 2 also shows how deposit market power affects the mechanism through which the central bank insulates banks. The restrictions in (10) must hold independently of market structure; they ensure that the regime change satisfies bank budget constraints and is wealth neutral and that the central bank loan is priced appropriately. Bank market power imposes additional, off-equilibrium restrictions on central bank lending. To effectively preserve the noncompetitive bank's choice set, the central bank loan must be supplied inelastically to mimic the deposit supply schedule the bank faces before the regime change.

Finally, Example 2 clarifies how balance sheet costs affect the neutrality requirements. If one source of funding (here, deposits) carries higher balance sheet costs than the other (the central bank loan), then the return on the latter must be correspondingly higher to render the bank indifferent. The expression for β shows this most clearly if one considers the case of $\zeta^* = 0$. Due to the lack of synchronicity between deposit balance sheet costs in history ϵ^t and central bank loan interest charges in the successor histories, transfers are needed to render a change of funding sources feasible. Under similar circumstances as those discussed in the context of Example 1, the transfers can be dispensed with.

Fundamentals. For the bank's choice set to remain unchanged, the central bank loan must fully replicate the role of deposits—not only as a source of funding, which generates costs, but also in any other dimension relevant to the bank's optimization problem. In other words, deposits must not be "special" in the sense of embodying features that are relevant to the bank but cannot be replicated by a central bank loan.

While the banking literature identifies several ways in which deposits may affect banks beyond their role as a funding source, such effects do not necessarily imply specialness. For example, demandable deposits may help banks mitigate agency conflicts in lending (Calomiris and Kahn, 1991; Diamond and Rajan, 2001), and accepting deposits from borrowers may improve banks' ability to monitor them (Mester et al., 2007).[50] The monitoring or disciplinary function that these theories attribute to deposits or depositors can, in principle, be performed by a central bank loan or the central bank. Indeed, given its superior information access and legal authority, the central bank is typically in a better position than individual depositors to discipline bank management. It could also share relevant transaction data from CBDC holders with the banks extending credit to them, thereby replicating the monitoring benefits associated with deposits. Moral hazard

[50] In contrast to Diamond and Rajan (2001), who argue that financial fragility is essential for liquidity creation, Günnewig and Mitkov (2024) find that fragility is instead detrimental to it. The optimal contract they propose also addresses the free-riding incentives highlighted by Calomiris and Kahn (1991).

frictions similarly need not undermine neutrality as long as they apply symmetrically to both deposits and a central bank loan (Gross and Schiller, 2021).

Kashyap et al. (2002) argue for a different form of complementarity—a synergy between deposit-taking and loan commitments. Their central point is that both deposit liabilities and loan commitments generate liquidity demands that banks must meet. Since these liquidity demands are imperfectly correlated, the combination allows banks to economize on the (assumedly costly) holdings of liquid assets such as cash or reserves.[51]

However, this complementarity does not imply specialness, provided the central bank can replicate the relevant liquidity management function through its refinancing operations. Moreover, banks make loans by creating deposits (McLeay et al., 2014), even when a credit line is drawn. Contrary to the framing in Kashyap et al. (2002), the relevant synergy arises not between deposit-taking and loan commitments per se, but between existing deposits and those newly created through the drawdown of a credit line. This synergy can be interpreted as shaping the cost function α in Example 2, whose presence, as we have seen, does not necessarily undermine neutrality.[52]

Piazzesi and Schneider (2022) emphasize the role of holding costs of bank assets. When it is expensive for banks to hold assets that back their liabilities, liquidity services are provided more efficiently when the financial sector minimizes balance sheet length. By creating money only when it is needed, as with credit lines, banks avoid the need to preemptively manage a balance sheet to support future transactions, thereby reducing the cost of asset holdings. Piazzesi and Schneider (2022) argue that, if commercial banks had an advantage over the central bank in offering credit lines, any CBDC induced crowding out of credit line creation by banks would increase total balance sheet costs and undermine neutrality.

Whited et al. (2023) estimate a dynamic banking model to quantify the effect of deposit-CBDC substitution on bank funding costs, profits, and lending.[53] They find that CBDC significantly reduces bank deposits. About one-quarter of that decline is passed through to lending, as banks partly offset lost deposits with wholesale funding. Smaller banks are more affected than larger ones, and when CBDC is intermediated through banks, which adds convenience, the effect is amplified. Importantly, Whited et al. (2023) analyze a partial equilibrium setup and exclude central bank pass-through funding. With such funding, deposit-CBDC substitution could be neutral as Example 2 shows.

Policy. While being able to sterilize the effect of CBDC issuance on banks' choice sets, the central bank may choose not to pursue this strategy, ultimately undermining neutrality. A case in point involves regulatory constraints that treat deposit and central

[51] See Hanson et al. (2015) for a related argument in the context of commercial vs. shadow banks.

[52] However, under alternative functional forms for α, neutrality may break down. For empirical assessments of synergies, see Pulley and Humphrey (1993), Egan et al. (2022), and Darst et al. (2025).

[53] In standard models with imperfect competition, banks choose the deposit rate by equating the marginal cost of funding across available sources and set the lending rate by balancing the marginal returns to investment opportunities (Klein, 1971; Monti, 1972). Because deposit-taking and lending decisions are separable in these models, shocks to the deposit market have no effect on bank lending. Whited et al. (2023) depart from this frictionless benchmark by introducing costly wholesale financing and capital regulations, which connect banks' deposit and loan policy choices.

bank funding asymmetrically.[54] If we interpret the function α in Example 2 as a liquidity regulation that requires banks to hold a fraction of their deposit funding in reserves, then neutrality in that example hinges on a specific form of symmetry, namely, that no minimum reserve requirement applies to the central bank loan.

This reflects the fact that the central bank loan does not replace deposit funding as such, but rather substitutes for the share of deposits that is not held as reserves but allocated to other bank assets. Since this investible share of deposits (the portion $1 - \zeta^*$ in Example 2) is not subject to a reserve requirement, maintaining neutrality implies that the corresponding central bank loan should receive equal treatment.

A related argument applies to collateral requirements. Since the bank does not post collateral for the share $1 - \zeta^*$ of its deposits, neutrality requires that no collateral be posted for the central bank loan either. At first glance, this appears to mark a significant departure from established practice, in which central banks typically demand collateral when providing funding to banks. However, this impression is misleading. Rather than introducing a novel arrangement, dispensing with collateral requirements on the substitute central bank loan mirrors the status quo, in which central banks provide implicit lender-of-last-resort guarantees for the share of deposits not backed by reserves without requiring collateral. A symmetric treatment under a CBDC regime replicates these unsecured guarantees in the form of unsecured central bank loans (Brunnermeier and Niepelt, 2019). Alternatively, symmetry could be achieved by introducing collateral requirements already in the pre-CBDC equilibrium. As proposed by King (2016), banks could be required to back deposits either with liquid assets or with pre-positioned collateral at the central bank.

Chen and Filippin (2025b) explicitly introduce a collateral constraint on central bank lending in a framework that otherwise satisfies neutrality.[55] They show that in order for such lending to maintain bank profitability, the loans must be offered at a lower interest rate to compensate banks for the cost of holding collateral. However, this collateral requirement alters the composition of bank assets and crowds out lending to firms.

An even more severe violation of the neutrality condition arises when the central bank does not refinance banks at all, or when it forces banks to raise the remuneration of deposits. Many papers in the literature make this assumption, sometimes implicitly. Keister and Sanches (2023) analyze the introduction of CBDC in a model that reflects key trade-offs highlighted by policymakers. In their framework, issuing CBDC at a competitive interest rate erodes the liquidity premium on deposits, compelling banks to raise lending rates and reducing the volume of investment. At the same time, CBDC increases the total supply of liquid assets in the economy, facilitating more efficient exchange.[56] The optimal CBDC amount balances these opposing effects, and the introduction of CBDC tends to enhance welfare when pre-CBDC investment is not too far below the first-best

[54] See, for example, Adalid et al. (2022) who argue that regulatory and collateral constraints limit the central bank's ability to shield bank intermediation from the impact of CBDC introduction.

[55] See also Böser and Gersbach (2020). Collateral requirements reflect concerns about central bank net worth and independence. We discuss politico-economic considerations below.

[56] Keister and Sanches (2023) distinguish between "cash-like" and "deposit-like" CBDC, with the latter being the more relevant case for their analysis.

level and demand for transaction services remains unsatiated.

Crucially, the analysis assumes that CBDC issuance occurs without a simultaneous reduction in bank deposits (CBDC is injected by transfer). As a result, the total liquidity supply in the economy rises, putting upward pressure on deposit interest rates and dampening investment. If instead CBDC issuance replaced deposits—such as when the central bank passes CBDC funds through to banks rather than transferring CBDC to households—the total liquidity supply would remain unchanged, preserving bank lending volumes and the overall allocation.[57]

In Andolfatto (2021), the central bank violates the neutrality conditions by offering an interest rate on CBDC that is higher than the pre-CBDC deposit rate paid by a monopolist bank. Facing this competitive pressure, the bank raises its deposit rate, as it benefits more from retaining deposits—even at a lower margin—than from losing deposit funding altogether. The model assumes the bank can lend either noncompetitively to firms or invest, at a fixed return, in another asset. Because changes in funding conditions do not affect the bank's tradeoff on the asset side, bank lending remains unchanged in partial equilibrium.[58] This conclusion changes when the bank faces a binding liquidity constraint. In that case, higher deposit funding resulting from competitive CBDC pressure leads the bank to *expand* its lending. An important insight for policy makers is that CBDC can be "relevant" even if it is not adopted in equilibrium.

In Chiu et al. (2023) oligopolistic banks keep deposit rates below competitive levels. The central bank elastically issues CBDC but does not lend to banks (and thus does not absorb deposits), thereby raising banks' funding costs and undermining neutrality. However, higher funding costs may coincide with increased bank intermediation. By providing depositors with an outside option, the introduction of CBDC reduces banks' incentives to restrict deposit funding and may lead them to extend more loans on a competitive lending market. As in Andolfatto (2021), the equilibrium shifts even when CBDC is not taken up, because the CBDC interest rate imposes a binding floor on deposit rates.

Abad et al. (2025) examine how the introduction of CBDC interacts with the functioning of the interbank market. Following the introduction of a non-remunerated CBDC, nonbanks begin withdrawing their deposits, reducing bank reserves. If withdrawals are large, some banks face reserve shortages, forcing them to borrow from the interbank market or the central bank.[59] Abad et al. (2025) assume that the central bank targets the interbank market rate according to a pre-set rule, which implies that reserve shortages raise the effective funding costs for banks. As demonstrated in Example 2, the central bank could avoid these effects by lending to banks at the deposit-equivalent rate.

Barrdear and Kumhof (2022) assume that CBDC is exclusively issued in exchange for government debt, in an operation akin to 'QE for the masses.' Consistent with the design principles in Kumhof and Noone (2021) (discussed below), this eliminates the possibility of system-wide runs on bank deposits. But it undermines neutrality unless a third party is willing to exchange debt against deposits, effectively substituting for the passthrough

[57]See Keister and Sanches (2023, Section 6).

[58]See Footnote 53.

[59]The authors abstract from matching risk on the interbank market.

funding in Example 2. In Bidder et al. (2024), CBDC is introduced through exchanges for corporate debt. This undermines neutrality because variations in the quantity of CBDC affect the overall supply of liquid assets—unlike CBDC issuance accompanied by a central bank loan to banks, which would absorb liquidity and leave the aggregate supply unchanged.

Bitter (2025) assumes that central bank loans to banks are less constrained by moral hazard frictions than deposit financing. While the central bank could, in principle, channel CBDC funds back to banks in a neutral fashion, the asymmetry allows it to deviate from such refinancing. Burlon et al. (2024) assume that central bank refinancing is subject to collateral constraints, and that the lending facility rate follows a Taylor-type policy rule rather than insulating banks from the introduction of CBDC.

In Williamson (2022b), banks are subject to collateral constraints requiring them to hold private assets (capital) or government bonds in excess of their deposit liabilities. By contrast, the central bank is unconstrained and fully backs CBDC with government bonds. If satisfying banks' collateral constraint is socially costly because banks accumulate excess capital to meet it, shifting liquidity provision to the central bank through CBDC improves welfare, all else equal, by freeing up scarce collateral. Williamson (2022b) assumes that the central bank cannot invest in banks, precluding passthrough funding that might otherwise offset the effects of CBDC introduction.[60]

Returning to the general point made earlier on the role of central bank passthrough funding in preserving neutrality, it is important to reiterate that such passthrough is not strictly necessary. Neutrality can still be maintained if, instead of directly refinancing banks on deposit-equivalent terms, the central bank invests the funds raised through CBDC issuance with a third party—provided that this third party, or another at the end of a chain of financial market transactions, refinances the banks on deposit-equivalent terms.[61] Whether such broader realignments in the financial sector are feasible, and in the interest of market participants, depends on their choice sets and objectives.[62]

Several studies examine the feasibility of broader adjustments following the introduction of CBDC, often without considering the incentives of market participants. Castrén et al. (2022) simulate the balance sheets of banks, the central bank, and other sectors under a range of scenarios that differ in how each sector adjusts its assets and liabilities in response to the introduction of CBDC. The authors derive the asset supply-demand imbalances that emerge under each scenario and find that no imbalances arise when the central bank fully re-deposits the CBDC funds with banks while in other cases, restoring equilibrium would require market-clearing price adjustments.[63] Of course, such price adjustments would trigger further adjustments.

Gorelova et al. (2022) find that, given their substantial liquidity buffers and diversified funding sources, Canadian banks would likely remain in compliance with regulatory

[60] Still, a neutral introduction of CBDC can be achieved in his setting if incentive problems in banking apply only to capital and not to government bond holdings. In this case, CBDC inherits its backing directly from the portion of bond-backed deposits it replaces.

[61] See also the discussion in Infante et al. (2023).

[62] A related point arises in Fraschini et al. (2024b).

[63] The authors also consider the effects of the introduction of a stablecoin.

liquidity requirements following the introduction of a cash-like CBDC. Juks (2018) argues that the introduction of CBDC in Sweden would likely have a small impact on banks and the broader economy under normal, non-stressed conditions, as demand for the digital currency would be limited and manageable. In times of economic stress, demand for an e-krona could rise significantly, potentially exacerbating bank runs but manageable with appropriate design features.

In Meller and Soons (2025), banks that face reserve outflows triggered by deposit conversions into CBDC can refinance through multiple channels, secured or unsecured, with varying maturities and rates depending on creditworthiness. The choice among these instruments affects not only funding costs but also compliance with liquidity regulation. Calibrating the model with supervisory data from euro area banks, the authors simulate a digital euro introduction under the assumption of unchanged spreads and demand-driven equilibrium quantities. They find that, during a smooth rollout in 2021, the banking system could have absorbed deposit outflows of up to 24% of overnight retail deposits without problems, but less in times of stress and breakdown of interbank markets.

We conclude this subsection with a brief discussion of CBDC effects on payment service providers as well as a digression on private cryptocurrencies. Regarding the former, the pro-competitive potential of CBDC emphasized by Andolfatto (2021) extends beyond banks and deposit remuneration to include payment service providers and their fees.[64] If an inexpensive CBDC payment option puts pressure on noncompetitive service providers, they have the choice between reducing fees and losing market share, mirroring the options of noncompetitive banks in the model of Andolfatto (2021). Lower fees reduce transaction costs and change the allocation, parallel to the potential effects on lending in Andolfatto (2021). By contrast, a neutral introduction of CBDC would require that the central bank adequately compensates providers for lost profits or that CBDC usage fees weakly exceed those of private payment services.

The degree of competition in the payment sector can influence allocations in other industries. Hemingway (2024) develops a model in which different sectors—physical versus online—vary in their dependence on digital payments, as cash is only available as a payment alternative for physical purchases.[65] He finds that introducing CBDC can help level the playing field and generate welfare gains by providing online retailers with an outside option, analogous to the role cash plays for physical retailers, which in turn encourages entry. If CBDC were structured not to provide such an outside option, neutrality would prevail.

Similarly, in Ahnert, Hoffmann and Monnet (2024), banks' ability to infer sellers' types and extract rents relies on sellers using deposits as their preferred payment method. The introduction of CBDC provides an alternative payment option that limits banks' information extraction, encourages more sellers to trade, and ultimately enhances overall welfare. However, the altered information structure is not an inherent feature of CBDC. If the central bank were to facilitate information sharing with banks, it could replicate the original environment, preserving the (suboptimal) equilibrium outcome.

[64]For an analysis of the two-sided market structure present in payment networks and its effect on competition, see, e.g., Rochet and Tirole (2006).

[65]See also Lagos and Zhang (2022).

Regarding private cryptocurrencies, one may ask how the introduction of CBDC differs from the creation of such a privately issued means of payment. If we reinterpret CBDC as a private cryptocurrency, and the central bank loan to a bank as a loan from the cryptocurrency issuer to the bank, then Example 2 still applies. The key difference is that, unlike the government in the CBDC case, the cryptocurrency issuer is a private agent—self-interested and optimizing. Condition 2 therefore implies additional incentive-compatibility constraints, making it more difficult to ensure neutrality when introducing a private cryptocurrency than when introducing CBDC.[66] A further difference is that while a central bank can serve as lender of last resort, it cannot necessarily do so for a cryptocurrency issuer (Skeie, 2021).

4.3 System

Turning to the final domain, we consider systemic implications of the introduction of CBDC. Recall that the second part of Condition 1 requires the policy change together with the modified balance sheet positions to remain feasible in the aggregate. The following example, which builds on Examples 1 and 2, focuses on one aggregate feasibility requirement, the aggregate resource constraint.

Example 3 (Resources)**.** Deposits carry unit operating costs $\alpha(r^b/n^b)$ for the issuing bank, as discussed in Example 2. CBDC, reserves, and a central bank loan to the bank carry unit operating costs μ, ρ, and o, respectively, and are borne by the central bank. Operating costs are incurred at the time of issuance and in the same resource. A regime change that leaves the reserves-to-deposits ratio constant at ζ^* (to satisfy (10) in Example 2) thus tightens the aggregate resource constraint by

$$\alpha(\zeta^*)\Delta n^b + \rho\Delta r^g + o\Delta\ell^g + \mu\Delta m^g.$$

For the regime change to be neutral, this expression must equal zero. Otherwise, other uses of the resource would have to change relative to the initial equilibrium, which would violate Condition 1.

Combined with the bank balance sheet restrictions (10) in Example 2 as well as the market clearing conditions for reserves and the central bank loan, the resource-neutrality requirement reduces to $(\alpha(\zeta^*) + \rho\zeta^* - o(1 - \zeta^*))\Delta n^b + \mu\Delta m^g = 0$. Imposing also the household balance sheet restriction (9) from Example 1 and CBDC market clearing implies the requirement

$$\alpha(\zeta^*) + \rho\zeta^* - o(1 - \zeta^*) = \frac{\mu}{\lambda}, \tag{11}$$

an instance of the constraint in (8).

Example 3 demonstrates that resource-neutrality of a regime change is a demanding condition if the choice sets of nonbanks and banks are to be preserved—unless balance

[66] Neutrality is most plausible when the private issuer operates under perfect competition, faces no balance sheet costs, and backs its instruments with deposits. In this case, the cryptocurrency functions merely as a veil.

sheet positions, or transactions involving these positions, incur no resource costs at all as is typically assumed in the literature.[67] Note from Conditions (9)–(10) and asset market clearing that the regime change tightens the government budget constraint in history ϵ^t by $\Delta\varphi^g + \alpha(\zeta^*)\Delta n^i$ and in history $\epsilon^{t+1|t}$ by 0. The former expression equals zero when Equation (11) holds.

Fundamentals. Niepelt (2024b) introduces resource costs of deposit-and-reserve- vs. CBDC-based monetary architectures in an otherwise standard general equilibrium framework. The costs arise both from payment operations and from social costs of (addressing) market and policy failure. In the deposit-based system, markets fail due to lack of competition in the deposit market and externalities from banks' reserve holdings; correcting these failures with fiscal instruments implies deadweight losses. In the CBDC-based system, deadweight losses are associated with pass-through funding from the central bank to banks, possibly due to political economy frictions.

When calibrated to U.S. and international data on costs of payment operations, bank vulnerability, and demand for reserves the model suggests that a CBDC-based system has higher operating costs than a deposit-and-reserve-based architecture. A second downside of the CBDC-based architecture is its crowding out of deposits, which the central bank can offset by lending to banks, but only at the cost of deadweight losses. On the other hand, only the deposit-and-reserve-based architecture suffers from inefficiencies in the banking sector, which when addressed result in tax distortions.

Collectively, the benefits of the CBDC-based architecture outweigh its disadvantages, contrary to what a narrow focus on operating costs indicates. Intuitively, the technological advantages of fractional reserve banking over narrow banking, and the social costs of pass-through funding, are minor in comparison to the excess burden created by the need to address banking sector frictions. As a result, the optimal share of CBDC in the payment system exceeds that of deposits.

Network effects (Katz and Shapiro, 1985) represent another potential source of systemic CBDC non-neutrality. When the convenience of a payment method depends on economy-wide adoption patterns, individual choices collectively shape everyone's options. While agents may be indifferent between CBDC and deposits for given adoption patterns—implying neutrality in partial equilibrium—network effects can disrupt this neutrality in general equilibrium. For example, in Agur et al. (2022), agents choose their payment portfolios based on privacy and security considerations as well as the adoption decisions of others. As a result, CBDC design choices affect equilibrium payment portfolios both directly and indirectly through network effects, and aggregate adoption evolves discontinuously.

Externalities can play a similar role. Garratt and van Oordt (2021) analyze a model in which disclosure of information generates negative externalities: While an individual chooses to disclose since the direct cost of doing so is small, data aggregation across users reveals a lot more information about the group the individual is part of—and generates

[67] The presence of fixed costs undermines the neutrality of introducing a CBDC, but does not affect the neutrality of its operating once implemented.

substantially higher costs.[68] Garratt and van Oordt (2021) suggest that CBDC issuance could mitigate these externalities by offering a digital payment system with stronger privacy protections. Murphy et al. (2024) similarly argue that a CBDC issuing central bank may better be able to trade off the social benefits of data use and privacy protection.

Infante et al. (2023) argue that the introduction of CBDC could enhance the reliability and interoperability of new digital payment systems by promoting common standards and strengthening network effects. They summarize the pertinent literature as suggesting that “a remunerated, intermediated, widely available CBDC has the prospect of accruing network externalities for the public—as opposed to allowing banks and fintechs appropriate rents—as well as limiting disruptions to the financial system stemming from the shifting fortunes of various competing private monies” (p. 25). However, if capturing these network externalities requires more centralization of payment infrastructure it could raise cyber security risks.

On the international stage, network effects shape currency competition and can affect monetary and even national sovereignty (Bindseil and Cipollone, 2025; Lane, 2025). Ikeda (2020) analyzes the implications of cross-border use of digital money—“digital dollarization”—for monetary policy in environments with sticky domestic-currency denominated prices. Digital dollarization erodes monetary policy effectiveness because the exchange rate adjusts to changes in domestic policy, causing prices expressed in the domestic currency to move as if they were fully flexible. As a result, monetary interventions lose their effectiveness in influencing real economic outcomes. While smaller, more open economies are more susceptible to this risk, a strong central bank commitment to inflation stabilization can help guard against it.

Cong and Mayer (2025) model two countries that compete to maximize the adoption of their national currencies in the face of a competing private digital currency. Users choose portfolio shares based on the convenience features of currencies, responding to national digitization efforts. Cong and Mayer (2025) show that countries' digitization efforts gradually diminish as the private currency gains ground. Initially, the country with the less widely held currency undertakes most of the digitization efforts. The country with the more widely held currency starts digitizing later, only when its currency's dominance is challenged by the private currency.

5 CBDC—Additional Dimensions

The previous section covered central domains that determine whether the introduction of CBDC is neutral or not. We now explore additional dimensions. We address heterogeneity, information frictions, financial fragility, taxation, and other frictions, and we show that they need not alter the basic logic. We also discuss monetary transmission mechanisms under non-neutral CBDC, review DSGE analyses of CBDC, and consider the role of political economy frictions.

[68] See also Solove (2013).

5.1 Heterogeneity and Information Frictions

Examples 1–3 featured a single bank and a single nonbank. This is without loss of generality when both the bank and the nonbank are representative. Otherwise, additional considerations arise. Suppose first that the government observes the type of each bank and nonbank. It can then target interventions by type—effectively implementing a series of isolated regime changes. The earlier analysis extends to this case: If each isolated change satisfies the neutrality conditions, the overall introduction of CBDC is neutral.

If the government faces more limited information, a neutral CBDC introduction still remains feasible—under the conditions discussed before—when the regime change affects types symmetrically. For example, when deposit interest rates are identical for all depositors in the initial equilibrium and banks are competitive with symmetric balance sheet costs, neutrality can be achieved through an elastic supply of central bank loans at a uniform interest rate, combined with transfers that vary with loan exposure. Even type-specific, neutral interventions may be feasible in specific circumstances.

In the most general and challenging case, the government's lack of information is binding. For example, if banks in the initial equilibrium are able to market different deposit contracts based on private information, then it may not be feasible to introduce CBDC in a neutral way. The problem arises from a violation of Condition 2: Lack of information prevents the central bank from observing and replicating choice sets, and this alters the set of options available to private sector agents and undermines the incentive compatibility of the proposal associated with neutral CBDC introduction.

Consider for instance a non-competitive deposit market and heterogeneous depositors (Fraschini et al., 2024a). When CBDC is introduced, some—but not all—nonbanks convert deposits into CBDC, perhaps because they place greater value on its liquidity services (in the notation of Example 1, attach a higher λ). If the central bank refinances the bank at the pre-CBDC deposit rate, the bank may find it profitable to lower the remuneration for the remaining depositors, exploiting their reduced supply elasticity. A neutral intervention would require the central bank to offer heterogeneous CBDC remuneration and to refinance the bank in a way that replicates the pre-CBDC deposit funding schedule, but information limitations may make this impossible.

Muñoz and Soons (2023) analyze the portfolio choice of a bank funded by investors who hold heterogeneous beliefs about the quality of bank assets. Because public money is more attractive to pessimistic investors, the introduction of CBDC changes the composition of depositors: Those who remain are more optimistic. As a result, the bank adopts a riskier portfolio, and the introduction of CBDC leads to a less than proportional decline in lending. These effects rely on the assumption that the central bank does not recycle CBDC funds back to the bank.

Of course, implementation challenges due to a lack of relevant information are not confined to settings with heterogeneous agents. Even with a representative bank and nonbank, neutral CBDC introduction requires detailed information about the economy. For example, in a setting with bank deposit market power, the neutral intervention requires information about the deposit supply function, as we discussed, but such information may not be readily available. Even if information is available contemporaneously, this may not suffice to extrapolate into the future as required for longer-lasting regime changes.[69]

Keister and Monnet (2022) point out that rather than creating information related challenges, the introduction of CBDC may improve information sets of policy makers. By providing real-time visibility into deposit outflows linked to bank distress, the introduction of CBDC could enhance central bank monitoring, enable earlier identification of weak banks, and boost depositor confidence to reduce the risk of runs.

5.2 Bank Fragility and Runs

Financial relationships may be fragile due to the presence of multiple equilibria (Diamond and Dybvig, 1983). To represent an environment in which investors may choose to run on a bank, we can define investor-specific deposits whose returns depend on whether a run occurs and how the depositor queue is ordered.[70] The analysis in Section 4 is fully compatible with this setting, and under Conditions 1 and 2, the conversion of deposits into CBDC is therefore neutral—regardless of the speed at which the process unfolds. To preserve the choice sets of investors, the government needs to offset any differences between the contingent returns on deposits in the initial equilibrium and a safe CBDC-return by implementing contingent transfers, as in Equations (3) and (5). To maintain the pre-CBDC choice set for the bank, the central bank's loan funding must mimic the fragile deposit funding, i.e., the central bank must run on the bank in some histories.[71]

Accordingly, the introduction of CBDC need not increase financial fragility—a conclusion that stands in sharp contrast to a widely held view. For example, Group of Central Banks (2021, p. 2) argues that a

> "significant shift from bank deposits into CBDCs ... could have implications for lending and intermediation by the banking sector. However, ... these impacts would likely be limited for many plausible levels of CBDC take-up, if the system had the time and flexibility to adjust. ... private sector developments may generate similar deposit substitution risks ... However additional risks to financial stability might arise if changes in the structure of the financial system due to the adoption of a CBDC were to be abrupt."

A problem with this view, discussed previously, is that it overlooks how the central bank reinvests the proceeds from CBDC issuance, implicitly treating CBDC funds as either non-investible or non-investible in banks. Another is that it (implicitly) misattributes responsibility: The banking sector is fragile to begin with, and the introduction of CBDC need not, in itself, add to that fragility. In fact, under a neutral regime change,

[69] See also Niepelt (2020).

[70] See Brunnermeier and Niepelt (2019).

[71] The degree of fragility may depend on off-equilibrium beliefs. For example, the threat of a deposit freeze in a run may be sufficient to prevent that run from happening, but absent commitment, the run equilibrium can re-emerge as investors do not expect authorities to impose a freeze, as doing so would harm agents with urgent liquidity needs (Ennis and Keister, 2009). Our definition of equilibrium incorporates beliefs about off-equilibrium choices by including them in the state. Correspondingly, our notion of neutrality requires that the relevant choice sets—defined by those states—are equivalent before and after the regime change. We return to the issue of time consistency below.

the nature and extent of fragility remain unchanged—in run states, banks lose access to cheap funding, and depositors incur losses. The only effect of the regime change is a relabeling of positions: What was previously a deposit becomes, from the bank's perspective, a risky central bank loan, and from the depositor's perspective, a combination of CBDC and transfers. Nor does a non-neutral regime change necessarily increase fragility. On the contrary, fragility may be reduced if the central bank replaces unstable deposit financing with more stable central bank lending, for instance, because this approach internalizes run externalities (Brunnermeier and Niepelt, 2019).

The neutrality perspective is also fully consistent with the Bagehot (1873) principle, which holds that, in a liquidity crisis, the central bank should act as a lender of last resort—lending freely, at a high interest rate, against good collateral. To see this, it is important to distinguish between the central bank's role in re-channeling CBDC funds to banks on deposit-equivalent terms and its role as lender of last resort when depositors run into assets other than CBDC. The Bagehot principle applies to the latter, not the former, role and policymakers may continue to adhere to it after a neutral regime change.

In Ahnert, Hoffmann, Leonello and Porcellacchia (2024), the introduction of CBDC influences run incentives through two channels. CBDC remuneration affects depositors' incentives to withdraw, thereby shaping the likelihood of runs, and it alters ex-ante portfolio choices, influencing the structure of bank funding and the interest rate on deposits, further affecting fragility. The overall impact of CBDC remuneration depends on the relative strength of these two effects.

Such non-neutral effects could, in principle, be avoided. Achieving neutrality would require that the contingent remuneration of CBDC mirrors that of deposits, ensuring that nonbanks are indifferent between the two instruments. Additionally, the central bank would need to re-channel CBDC inflows back to the banking sector on equivalent terms—and withdraw those funds in scenarios in which depositors would have run in the absence of CBDC. In the global games framework of Ahnert, Hoffmann, Leonello and Porcellacchia (2024) (building on Goldstein and Pauzner (2005)), depositors observe noisy private signals about an aggregate shock. To replicate the no-CBDC equilibrium under a CBDC regime, the central bank would need to observe the full distribution of these private signals or the aggregate shock itself, in order to match returns and replicate run strategies.

Bitter (2025) analyzes the impact of CBDC issuance on the risk of bank runs in the framework of Gertler and Kiyotaki (2015). She assumes that the central bank follows a counter-cyclical CBDC-remuneration rule and compares a "credit policy," under which the central bank recycles CBDC funds back to the banking sector at the market-clearing interest rate, with an "asset policy," under which it instead invests CBDC funds in physical capital, managing it more efficiently than households but less efficiently than banks.

The model implies that CBDC enhances financial stability by raising the threshold above which shocks cause self-fulfilling runs. Under the credit policy, the central bank's lender-of-last-resort intervention breaks the self-fulfilling dynamics of bank runs because it allows banks to continue investing in capital despite runs, thereby stabilizing asset prices. Under the asset policy, the central bank's investment policy similarly helps prevent runs by partially absorbing capital and reducing fire-sale pressure. However, CBDC does not mitigate insolvency-driven bank failures, as the central bank halts support once a bank becomes insolvent.

Bitter (2025) argues that in a bank run scenario, inflows into CBDC are preferable over flows into other asset classes because this mitigates losses, stabilising capital prices and making runs less likely from the outset. Her analysis clarifies that it is crucial for a thorough assessment of the financial stability implications of CBDC to consider general rather than partial equilibrium. With some modifications, the credit policy she considers could render the introduction of CBDC fully neutral.

Williamson (2022a) points out that (under a non-neutral regime change) CDBC-induced run risk may have its upside. In his model, CBDC increases the likelihood of a bank run by providing depositors with an attractive outside option, but it also mitigates the negative effects of a run by ensuring that transactions continue smoothly even if a run takes place.

When a regime change is not neutral and the central bank aims at curbing CBDC inflows, the natural policy tool would appear to be a reduction of CBDC remuneration. But many policy makers seem to be skeptical about the effectiveness of price instruments and favor holding limits instead, at least in times of financial stress.[72] However, such holding limits do not resolve run problems and may create other difficulties, as Cecchetti and Schoenholtz (2022) point out:[73]

> "[C]apping the amount of CBDC in periods of strain could limit runs into CBDC, but would not halt runs. Any scarcity of CBDC would result in a premium for CBDC relative to other central bank liabilities (such as currency in circulation and bank reserves) and to insured deposit balances. That premium would encourage runs into other safe, liquid instruments that are close substitutes for CBDC, such as Treasury bills and paper currency ..."

Kumhof and Noone (2021) propose several lines of defense against 'digital bank runs,' including adjustable CBDC remuneration; no guaranteed convertibility at par between CBDC, reserves, and deposits; and issuing CBDC only in exchange for government debt instruments.[74] These measures aim to protect banks from direct or indirect deposit outflows into CBDC, but they undermine neutrality, as discussed in Section 4, and come at the cost of segmenting payment instruments. Kumhof and Noone (2021) argue that under their proposal, parity between central bank money and deposits would generally be maintained even without guaranteed convertibility. By contrast, they caution that limits on the quantity of CBDC held in an account "run the risk of not maintaining parity even during normal times" (p. 561), and that flexible remuneration schemes may not be effective during a market panic and could face implementation challenges.

[72] If the conditions for a neutral regime change are otherwise satisfied, quantity restrictions are irrelevant: Neutrality reflects indifference, so the restrictions merely select an equilibrium, provided they are properly coordinated with the transfers τ. Only when neutrality conditions are otherwise not met do quantity restrictions become relevant.

[73] Baeriswyl et al. (2021) and Monnet and Niepelt (2023) similarly argue that applying holding limits could compromise some of the potential benefits associated with the introduction of CBDC.

[74] See also Barrdear and Kumhof (2022).

Bindseil (2020) rejects the proposal by Kumhof and Noone (2021) on the grounds that it would place into question core principles of central banking relating to convertibility. As an alternative, Bindseil (2020) proposes a two-tiered remuneration scheme, aligned with long-standing central bank practices, under which CBDC balances above a specified threshold would earn lower interest than those below it.[75] He suggests that such a system could help bolster political support for maintaining very low interest rates during periods of stress.

Infante et al. (2023) also consider the proposal by Kumhof and Noone (2021). They argue that although the approach could help dampen spillover effects across markets, it would also result in non-uniform pricing, as market participants may be unable or unwilling to fully eliminate price differences between CBDC, reserves, and deposits. More broadly, they suggest that most central banks would regard the absence of direct convertibility as either unacceptable or incentive-incompatible, even if it might improve financial stability.

Carapella et al. (2024) discuss tools like tiered remuneration, access limits, transaction size limits, holding limits, and convertibility restrictions to curb flight-to-safety into CBDC and CBDC hoarding. They highlight that quantity limits may not be time-consistent and could spur secondary CBDC markets, where parity depends on arbitrageurs stepping in to correct price gaps during stress if direct convertibility is not guaranteed. For example, "wrapped CBDC tokens" backed one-to-one by claims against the central bank could be used to circumvent quantity constraints, and more broadly, quantity limits could be bypassed through securities issued and traded outside regulatory oversight.

5.3 Taxes

In Equations (2)–(7), we abstracted from taxes on portfolio positions and returns when assessing feasibility and incentive compatibility. However, neutrality may also hold in the presence of such distorting taxes. For example, with a proportional tax on deposit returns, the neutrality conditions in Examples 1 and 2 continue to apply, and they still ensure that a regime change preserves government revenue net of balance sheet costs.[76]

Neutrality also follows with nonlinear taxes, provided the tax functions shape agents' choice sets in ways that satisfy Conditions 1 and 2. One class of tax functions that meet this requirement maps the sum of pre-tax portfolio returns, transfers, and balance sheet costs into a tax obligation. As long as changes in transfers and the affected balance sheet positions satisfy Equations (3) or (5), tax liabilities remain unchanged, thereby satisfying Condition 1. Condition 2 is also satisfied, assuming these positions and transfers do not enter objectives. By contrast, more targeted taxes—such as those that differentiate between deposits and CBDC—may undermine the neutrality of a regime change. Yet this type of non-neutrality arises from the tax system itself and can, in principle, be precluded

[75]See also Tercero-Lucas (2023).

[76]Without loss of generality, we can disregard taxes on CBDC, reserves, and the central bank loan. A deposit tax paid by nonbanks reduces R_+^{m*} relative to R_+^{n*} if neutrality holds. Compared to a setting without such taxes, a reduction in deposit holdings therefore results in a smaller rise in government interest payments on CBDC. However, it also causes a larger drop in revenue from deposit taxes.

through appropriate policy design.

Naturally, neutrality is unaffected by tax functions that depend on equilibrium choices unrelated to the regime change. Moreover, changes in the tax rate on CBDC interest income can substitute for adjustments in CBDC remuneration.

5.4 Peripheral Model Elements

Since Conditions 1 and 2 are sufficient, the specific structure of a model is irrelevant for CBDC neutrality as long as it does not violate these conditions. For example, if a model satisfies Conditions 1 and 2 under flexible prices, CBDC introduction remains neutral even with price rigidities, unless those rigidities affect the feasibility or attractiveness of the proposed balance sheet adjustments. Similarly, it is irrelevant whether banks exercise market power when extending loans or mortgages; households or firms rely on bank credit through a "bank lending channel" (Bernanke and Blinder, 1988); regulation constrains a bank's loan book; or incentive compatibility requirements impose specific ownership structures on financial assets or physical capital—provided Conditions 1 and 2 are satisfied.

This highlights the importance of distinguishing between fundamental sources of CBDC non-neutrality—analyzed in Section 4—and model elements that become relevant only when those fundamental sources are present, as in some of the DSGE models discussed below. The mere fact that a model element interacts with CBDC does not imply that it is a fundamental driver of CBDC relevance.

5.5 Monetary Policy Transmission

When CBDC is introduced in a neutral manner, the monetary transmission mechanism is unaffected because agents' choice sets remain unchanged. Under non-neutral introduction, by contrast, transmission may be altered.[77]

Jiang and Zhu (2021) examine how the interest rates on reserves and CBDC jointly influence deposit and loan rates, by altering the cost of creating deposits when reserve requirements bind, and by changing the relative attractiveness of lending versus holding reserves when banks hold excess reserves. Jiang and Zhu (2021) assume that CBDC is a perfect substitute for bank deposits as a means of payment. With perfect competition in the deposit market, the CBDC rate therefore pins down the deposit rate, and changes in the reserve rate are fully transmitted to loan rates.

In Niepelt (2024b) monetary policy operates through changes in the prices of liquidity services—from reserves, held by banks, and from CBDC and deposits, held by nonbanks. CBDC- and deposit-liquidity prices affect nonbank liquidity demand, and indirectly consumption, as in Sidrauski (1967), while the price of reserve liquidity shapes bank balance sheets and operating costs. Changes in interest rates also alter bank lending, investment, and the aggregate operating costs of the payment system in deposit- and CBDC-based monetary architectures.

[77] See also Infante et al. (2022) for a discussion.

The optimal policy in either monetary architecture follows a generalized version of the Friedman (1969) rule, which accounts for the resource costs of payment operations. The optimal interest rate on reserves includes a Pigou (1920)-style subsidy to ensure that banks internalize an externality from reserve holdings, and a deposit subsidy encourages them to charge the efficient liquidity premium. Consequently, the two central bank liabilities—reserves and CBDC—should pay different interest rates, reflecting their distinct social costs and externalities. Implementing this optimal policy requires the government to price discriminate between wholesale and retail holders of central bank liabilities.

Chen and Filippin (2025a) extend the model in Niepelt (2024b) by incorporating a sector with nominal rigidities. This adds the traditional New Keynesian monetary transmission mechanism. Bhattarai et al. (2024) examine the effects of a monetary policy shock within a framework that similarly incorporates demand for central bank money and CBDC, alongside bank lending, production, and price rigidities. The shock transmits through three main channels: the New Keynesian channel, where higher interest rates reduce consumption and output and impact inflation; a liquidity or "New Monetarist" channel, where a narrower spread between bond and payment instrument rates reduces the opportunity cost of holding payment instruments, boosting consumption and output; and a bank lending channel, where increased funding costs reduce lending and investment.

An increase in the interest rate on reserves incentivizes banks to issue more deposits at a narrower spread. In the absence of CBDC, this could stimulate economic activity via the liquidity channel. However, with CBDC, issued at a fixed interest rate, the average spread on payment instruments falls by less, weakening the liquidity channel's effectiveness. Consequently, the contractionary effects stemming from the New Keynesian and bank lending channels become relatively more important.

Under a non-neutral regime change, the CBDC interest rate provides the central bank with a tool to directly influence nonbanks' intertemporal terms of trade, bypassing the banking sector. As Bordo and Levin (2017) highlight, this could be a powerful policy instrument for managing the business cycle once complementary measures to eliminate an effective lower bound on interest rates were implemented. After such an elimination, CBDC could obviate the need for traditional monetary policy tools such as QE or credit subsidies, and remove the necessity of maintaining an "inflation buffer." This would allow for a shift towards monetary policy strategies focused on targeting the price level rather than inflation, offering enhanced long-term planning certainty.

Potential approaches to removing the lower bound include abolishing cash or eliminating high-denomination bills.[78] Alternatively, cash balances could be taxed, or the exchange rate between cash and other forms of money could be allowed to float (Gesell, 1916, 1958; Eisler, 1932).[79]

[78]While this could also raise the costs of illegal activity (Rogoff, 2016), the trade-offs between curbing crime and restricting cash usage for legitimate activities remain unclear (McAndrews, 2017). Restricting cash usage would further undermine privacy, imposing private and social costs (Kahn et al., 2005).

[79]See also Goodfriend (2000) and Buiter (2009), respectively. For an overview of related approaches, see Agarwal and Kimball (2019).

5.6 DSGE Analyses

Barrdear and Kumhof (2022) calibrate a rich DSGE model to U.S. data and find that introducing CBDC—issued in exchange for government debt—raises GDP. This increase is driven by a reduction in real interest rates, as defaultable government debt is replaced with non-defaultable, low-interest CBDC. The resulting decline in distortionary taxation and lower transaction costs further contribute to the output gain. Either the quantity or the holding cost of CBDC can be used to help stabilize the business cycle, particularly when CBDC and bank deposits are poor substitutes in payments. Barrdear and Kumhof (2022) also argue that CBDC enhances financial stability.

Gross and Schiller (2021) examine the role of passthrough funding and CBDC remuneration in a DSGE model with moral hazard frictions, calibrated to euro area data. The frictions apply symmetrically to deposit funding and central bank loans. Under a full allotment regime, the introduction of CBDC therefore does not impair bank funding; the central bank can stabilize the financial sector and cushion the real economy from shocks. However, when allotment is limited, CBDC introduction leads to disintermediation, reducing bank lending and negatively affecting investment. By adjusting CBDC remuneration, the central bank can discourage CBDC adoption and mitigate these adverse effects.

Assenmacher et al. (2023) develop a model that integrates elements from New Monetarist and New Keynesian frameworks, featuring competitive banks operating under financial frictions. In their setup, CBDC and bank deposits are perfectly substitutable as means of payment, with the central bank issuing CBDC in exchange for capital securities and targeting the liquidity premium. Calibrating their model to the euro zone, they find that the introduction of CBDC does not substantially alter the economy's impulse responses to macroeconomic shocks; rather, it tends to dampen and smooth their effects on output and inflation. The liquidity-premium targeting rule affects bank funding costs, offering a channel for business cycle stabilization. When the liquidity premium is stabilized less aggressively, the model's responses to shocks increasingly resemble those in a setting without CBDC.

Assenmacher et al. (2024) analyze an open-economy model of the euro zone in which banks possess market power in the deposit market. CBDC is introduced in exchange for reserves or cash and, in the baseline scenario, is not remunerated. Its introduction relaxes a cash-in-advance constraint, weakening banks' market power. In steady state, CBDC raises welfare and does not disintermediate banks. However, upon issuance, demand for CBDC temporarily overshoots, and this leads to reduced bank lending. The authors evaluate various policy tools to manage the transition and find that imposing a holding limit of approximately EUR 3,000 per capita could balance the tradeoff between mitigating banking sector disintermediation and supporting increased payment variety.

Bidder et al. (2024) develop a DSGE model featuring leverage-constrained banks and a system-wide bank run risk that varies with bank leverage. In their framework, CBDC is introduced through exchanges for corporate debt. This reduces the deposit liquidity premium, shrinks bank balance sheets, and lowers run risk. However, CBDC also increases run risk by offering a more accessible and attractive alternative to deposits than cash. Calibrated to euro area data, the interplay between these stabilizing and destabilizing forces results in disintermediation and a net rise in run risk. Imposing low CBDC holding limits can mitigate this outcome by curbing large-scale shifts away from deposits, such that "slow disintermediation overturns welfare losses of fast disintermediation" (p. 4).

In Burlon et al. (2024), banks operate under binding capital adequacy, liquidity, and—when borrowing from the central bank—collateral (government bonds) constraints. While collateral requirements limit refinancing options, CBDC-deposit substitution does not tighten the liquidity constraint. Issuing CBDC expands aggregate liquidity services. Calibrated to euro area data, the model implies that CBDC crowds out deposits. The expansion of the central bank's balance sheet raises central bank profits and seignorage, supporting public spending and boosting private consumption.

On the other hand, banks face higher funding costs from replacing cheap deposits with collateralized borrowing, compressing net interest margins and eroding bank equity and lending. Welfare rises due to improved liquidity services, declines due to bank disintermediation, and is positively affected by a stabilization effect on bank lending—particularly under countercyclical CBDC interest rate rules. Simulations indicate strong CBDC demand: At an annual CBDC interest rate of -3%, holdings reach nearly 20% of quarterly GDP.

In the New Keynesian DSGE framework of Paul et al. (2025), cash, deposits, and CBDC are imperfect substitutes, and banks possess market power both in issuing deposits and in lending to firms. Both factors—imperfect substitutability and market power—determine the spread between deposit rates and the policy rate, which in turn affects bank profitability. Due to financial frictions, changes in bank profitability influence the supply of credit. In addition to bank loans, firms can also access financing through the bond market.

When calibrated to U.S. data, the deposit spread co-moves with the policy rate in the absence of CBDC. The introduction of CBDC reduces the spread but has limited effects on intertemporal substitution and investment. The optimal CBDC rate is approximately one percentage point below the policy rate, effectively curbing bank deposit market power, particularly when interest rates are high. When the model is calibrated to the euro area, the benefits of introducing CBDC are smaller because bank lending plays a more important role. CBDC leads to reduced bank lending not because banks lack funds, but because substituting deposit funding with central bank borrowing diminishes bank profitability under the authors' assumptions.

In an open economy, a central question is whether foreigners can access a domestic CBDC. When they are free to adjust positions, an interest parity condition links CBDC remuneration, the foreign bond interest rate, CBDC liquidity benefits, and the rate of exchange rate appreciation. In Ferrari Minesso et al. (2022), this CBDC-based interest parity condition is active while cross-border cash and deposit holdings are excluded and portfolio adjustment costs limit changes in cross-border bond holdings. Ferrari Minesso et al. (2022) show that this can amplify the exchange rate response to shocks, as foreigners rebalance more aggressively into CBDC than they would into bonds if only the latter were internationally traded (see also Benigno et al. (2022) and Ikeda (2022)).

Kumhof et al. (2023) analyze a two-country DSGE model with two CBDCs and fewer restrictions on cross-border asset holdings. As in Kumhof and Noone (2021), CBDCs are issued solely against national government bonds. Kumhof et al. (2023) find that the introduction of CBDC by a single country generates gains in output and welfare. The optimal policy features a CBDC interest rate that increases relative to the rate on reserves during economic contractions, contributing to lower volatility in both the exchange rate and gross cross-border banking exposures.

Cova et al. (2022) examine the impact of a monetary policy shock in an open economy model where cash competes with CBDC and a foreign-issued stablecoin. They find that the magnitude of the shock's effects depends on the type of backing the stablecoin possesses.

5.7 Political Economy

It is one question whether policymakers can implement a neutral regime change on economic grounds; as we have seen, this is often the case. Another question is whether they are willing and able to do so on political grounds. To answer the latter, we need to broaden our notion of neutrality, which so far treated policy as a primitive, to politico-economic equivalence, which treats the set of admissible policy choices as a model primitive (Gonzalez-Eiras and Niepelt, 2015). Under this framework, neutrality Conditions 1 and 2 must be extended to also reflect feasibility and indifference on the part of political decision-makers (e.g., voters and politicians). That is, politico-economic equivalence also requires that policy choices be optimal given the objectives of these actors and the institutions governing decision-making. In particular, choices must be time consistent (Kydland and Prescott, 1977; Barro and Gordon, 1983).[80]

There are many reasons why politico-economic equivalence may fail in the context of CBDC. For example, passthrough funding from the central bank to commercial banks may alter voters' understanding—and political support—of the distributive implications of the monetary architecture; the CBDC-induced expansion of the central bank's balance sheet could make seignorage a more salient source of government funding, increasing political pressure on the monetary authority and altering its ex post incentives; or the successful introduction of CBDC could shift payment preferences and weaken political support for cash.[81]

Other reasons for non-neutrality in politico-economic equilibrium are more benign, as they relate to potential Pareto improvements. For instance, as discussed in the context of bank runs, rather than replicating the status quo by mimicking a depositor run, the central bank could do better by internalizing run externalities and avoiding the inefficient run equilibrium (Brunnermeier and Niepelt, 2019). Or, as noted by Keister and Monnet (2022), CBDC issuance could expand policymakers' information set, enhancing their ability to intervene effectively.

Fernández-Villaverde et al. (2021) adopt a Diamond and Dybvig (1983) framework and assume that the central bank—but not commercial banks—can commit to not liqui-

[80] Gonzalez-Eiras and Niepelt (2015) relate these additional restrictions to the choice sets of political decision-makers and the state variables in their programs.

[81] Tucker (2017) and Cecchetti and Schoenholtz (2018) discuss potential politico-economic repercussions of CBDC.

dating long-term projects prematurely. This commitment advantage renders central bank deposit contracts run-proof and gives the central bank a competitive edge, effectively conferring market power. Fernández-Villaverde et al. (2021) caution that under pressure from lobbying groups, this power may enable the central bank to deviate from offering the socially optimal deposit contract.

Schilling et al. (2024), building on the Diamond and Dybvig (1983) framework augmented with nominal contracts (Skeie, 2008), show that the government can uniquely implement optimal allocations—without run risk—by relying on off-equilibrium inflation threats. However, if such threats are not time consistent, a trilemma arises among allocative efficiency, bank stability (i.e., run prevention), and price stability. This trilemma exists regardless of whether the central bank issues CBDC. It disappears if the central bank controls the money stock and can make it state-contingent, allowing threats to be tied to money supply rather than the price level. If CBDC balances can be made state-contingent while deposits cannot, or vice versa, the severity of the trilemma thus depends on the monetary architecture.[82]

Niepelt (2024a) argues that profits resulting from banks' money creation at non-competitive rates could be at risk if, following the introduction of CBDC, political constraints were to prevent the central bank from providing pass-through funding on deposit-equivalent terms. Letting $-\psi^{-1}$ denote the elasticity of nonbanks' liquidity demand as perceived by banks, the profit component of the revenue illustrated in Figure 2 equals ψ times that revenue.[83] Assuming $\psi = 1/3$ (Drechsler et al., 2017; Wang et al., 2022; Pasqualini, 2021; Niepelt, 2024b), this profit component exposed to political risk averages approximately 0.22% of GDP over the past fifty years. In other words, the introduction of CBDC could place a substantial part of bank profits in jeopardy if central banks chose, or were forced to, abstain from pass-through funding on deposit-equivalent terms.

6 Conclusion

The conditions for a change in the monetary architecture to be neutral are stringent. But in the case of CBDC, they are much less stringent than concerns about an induced credit crunch and financial instability seem to suggest. Central banks can go a long way to insulate banks and the asset side of their balance sheets from the consequences of CBDC, by providing passthrough funding at deposit-equivalent terms; when they decide against that option, markets might partly step in.

We have identified several fundamental factors that render the introduction of CBDC non-neutral. In the nonbank domain, non-neutrality can arise from nonlinear substitution across liquidity sources or from constraint multiplicity, due to the multidimensionality of liquidity services. While constraint multiplicity appears empirically more relevant than nonlinear substitution, the literature has focused on the latter. In the banking domain, non-neutrality can arise from specialness of deposits, whereby deposits serve functional

[82] See also Skeie (2021).

[83] Using the notation of Example 2, profits equal $n^b(1-\zeta^*)(R_+^{f*} - R_+^{\ell*})/R_+^{f*}$. This compares with the total revenue, $n^b(R_+^{f*} - R_+^{n*})/R_+^{f*}$, whose GDP-share is illustrated in Figure 2.

roles in banks' optimization problems—beyond mere funding—that central bank financing cannot fulfil equally. Without specialness, the financing of banks can be decoupled from the issuance of payment instruments. Finally, in the system domain, non-neutrality arises whenever CBDC and deposits differ in their general equilibrium implications due, for example, to asymmetric network effects, externalities, resource requirements, or other social costs.

In stark contrast to these fundamental sources, many other frictions need not undermine neutrality. Lack of competition, a two-tier monetary architecture, maturity transformation, costs of liquidity services or balance sheet positions (subject to conditions), financial fragility, price stickiness, or a bank-lending channel, among many others, are perfectly compatible with a neutral change of monetary architecture.

Rather than on the fundamental sources of non-neutrality, the literature has mostly—and often implicitly—focused on policy-related sources. As our examples show, the assumptions about the central bank's operating framework and policies accompanying the introduction of CBDC are crucial for the macroeconomic consequences of CBDC. In the benchmark case with passthrough funding, the introduction of CBDC may have no macroeconomic consequences at all. This suggests that policy, rather than fundamental macroeconomic factors, may well be the most important determinant of the allocative and distributive implications of CBDC.[84]

Against that background, political economy considerations appear to be of first-order importance and call for further research. Even when the policy instruments exist to shape the effects of CBDC, it is far from clear that policymakers can flexibly employ them given political constraints; this affects the viability of CBDC plans ex ante. If, for example, the introduction of CBDC makes the monetary architecture more transparent, shifting political support away from cheap bank financing (and possibly lending) based on passthrough funding and exposing a substantial share of bank profits to political risk, then strong resistance from interest groups should be expected early on.

Our discussion also has broader implications. One touches upon the interpretation of the neutrality benchmark. While neutrality implies a lower bound on the welfare consequences of a regime change, it also suggests that the introduction of CBDC can often be made Pareto improving through small adjustments in the accompanying policy. This is the case when the intervention enlarges the choice set of (benevolent) policy makers by Pareto superior outcomes, for instance because the central bank replaces small depositors as bank creditor and internalizes run externalities. When the neutrality conditions are violated, a Pareto improving monetary regime change may still be possible, for example when CBDC requires fewer resources or relaxes other equilibrium constraints.

Another implication is that, ceteris paribus, policymakers have significantly more control over the macroeconomic consequences of introducing CBDC than over those of private payment innovations, such as cryptocurrencies, whose issuers pursue independent objectives. Even if a private payment instrument shares the same features as CBDC and produces identical general equilibrium effects, there may still be a case for preferring the

[84] Bindseil and Senner (2024) criticize the macroeconomic CBDC literature on the grounds that modeling assumptions are disconnected from actual policy plans (e.g., regarding CBDC remuneration). But the disconnect runs deeper as the literature yields prescriptions that some policy plans appear to ignore.

public over the private instrument.

A further implication concerns the framing of the policy debate. The introduction of CBDC should not be cast narrowly as a technical innovation in the payments sphere with potential macroeconomic effects that should best be contained. Fundamentally, it represents a shift in the topology of banking and a transformation of the broader monetary architecture. As such, it raises deeply political questions that reach beyond the mandate of technocratic institutions such as central banks. While central banks are natural contributors to the debate, they are not well placed to assume responsibility when it comes to deciding about the introduction of CBDC.

A Data Sources

In this appendix, we describe the data sources for Figure 1.

Swiss Franc: Reserves, cash in circulation, monetary base, and M1 until 1950 are taken from `https://www.snb.ch/dam/jcr:34c67480-8d1b-4171-8a7e-7a4a0a56cb44/histz_gm.n.xls` (Tables 1.3 and 2.2). M1 between 1950 and 1984 is taken from Table 2.3 of the same source. Reserves, cash in circulation, and monetary base after 1950 are taken from `https://data.snb.ch/en/topics/snb/cube/snbmoba`. M1 after 1984 is taken from `https://data.snb.ch/en/topics/snb/cube/snbmonagg`.

U.S. Dollar: Reserves; cash in circulation; monetary base; and M2 are taken from Fred series `BOGMBBM#` (from 1959); Fred series `MBCURRCIR#` (from 1959); Friedman and Schwartz (1982, p. 122), Fred series `SBASENS`, and Fred series `BOGMBASE` (before 1918, 1918–1958, and after 1958, respectively); and Friedman and Schwartz (1982, p. 122) (re-scaled) and Fred series `M2SL` (before and after 1959, respectively).

B Neutral Regime Change: Formal Discussion

In this appendix, we formalize the discussion in Section 3.

B.1 Economy

Private sector agents are indexed by $i \in \mathcal{I}$, and the government is denoted g.

Choices, Constraints, and Objectives. We denote the contingent choices of private sector agent i in the event tree originating in history ϵ^t by $c^i(\epsilon^t) \in \mathbb{R}^{|c^i(\epsilon^t)|}$, where $|\cdot|$ denotes cardinality. Similarly, we denote the government's policy by $c^g(\epsilon^t) \in \mathbb{R}^{|c^g(\epsilon^t)|}$.

In history ϵ^t, the constraints that agent i faces going forward are given by

$$C^{i,n}(c^i(\epsilon^t), s^i(\epsilon^t); \epsilon^t) \leq 0, n = 1, 2, \ldots,$$

where n indexes the constraint functions and $s^i(\epsilon^t)$ denotes agent i's state in history ϵ^t. The choice set of agent i then is given by

$$\mathcal{C}^i(s^i(\epsilon^t); \epsilon^t) \equiv \{c^i(\epsilon^t) \in \mathbb{R}^{|c^i(\epsilon^t)|} | C^{i,n}(c^i(\epsilon^t), s^i(\epsilon^t); \epsilon^t) \leq 0, n = 1, 2, \ldots\}.$$

We denote the objective of agent i in history ϵ^t by $U^i(\cdot;\epsilon^t)$, a scalar function of $(c^i(\epsilon^t), s^i(\epsilon^t))$.

Letting $c(\epsilon^t) \in \mathbb{R}^{|c^g(\epsilon^t)|+\sum_{i\in\mathcal{I}}|c^i(\epsilon^t)|}$ denote the union of $c^g(\epsilon^t)$ and all $c^i(\epsilon^t), i \in \mathcal{I}$, and letting $s^a(\epsilon^t)$ denote the economy's exogenous state in history ϵ^t, we represent the aggregate constraints by

$$A^n(c(\epsilon^t), s^a(\epsilon^t); \epsilon^t) \leq 0, n = 1, 2, \ldots,$$

where n indexes the constraint functions. The aggregate choice set is given by

$$\mathcal{A}(s^a(\epsilon^t);\epsilon^t) \equiv \{c(\epsilon^t) \in \mathbb{R}^{|c^g(\epsilon^t)|+\sum_{i\in\mathcal{I}}|c^i(\epsilon^t)|} | A^n(c(\epsilon^t), s^a(\epsilon^t); \epsilon^t) \leq 0, n = 1, 2, \ldots\}.$$

Equilibrium. In history ϵ^t, the economy is characterized by $s^a(\epsilon^t)$, $\mathcal{A}(s^a(\epsilon^t);\epsilon^t)$, and $\{\mathcal{C}^i(\cdot;\epsilon^t), U^i(\cdot;\epsilon^t)\}_{i\in\mathcal{I}}$. An equilibrium in history ϵ^t is a policy $c^{g*}(\epsilon^t)$ and a collection of private sector choices and states, $\{c^{i*}(\epsilon^t), s^{i*}(\epsilon^t)\}_{i\in I}$, such that[85]

i. policy and private sector choices are feasible in the aggregate, $c^*(\epsilon^t) \in \mathcal{A}(s^a(\epsilon^t);\epsilon^t)$;

ii. private sector choices are individually feasible and optimal, $c^{i*}(\epsilon^t) \in \mathcal{C}^i(s^{i*}(\epsilon^t);\epsilon^t)$ maximizes $U^i(\cdot, s^{i*}(\epsilon^t);\epsilon^t)$, for all $i \in I$; and

iii. states $s^{i*}(\epsilon^t)$ determining private sector constraints are consistent with outcomes on and off the equilibrium path, for all $i \in I$.

B.2 Regime Change

To improve legibility, we suppress ϵ^t arguments when this does not cause confusion.

Starting from the initial equilibrium $(c^{g*}, \{c^{i*}, s^{i*}\}_{i\in I})$, the regime change prescribes a policy change, Δc^g, and a proposed change of private sector choices, $\{\Delta c^i\}_{i\in I}$. The policy change and the proposal imply the new policy $c^{g*} + \Delta c^g$ and the new choices $\{c^{i*} + \Delta c^i\}_{i\in I}$. The regime change may also imply new states, $\{s^{i*} + \Delta s^i\}_{i\in I}$. (The plus sign reads as "modified by." When policy or choices are collections of scalars, the plus sign is interpreted literally.)

B.3 Neutrality

The first condition for neutral change is that the new policy and proposed private sector choices are feasible:

Condition 1. Proposed private sector choices are individually feasible given the implied new states, and the new policy and proposed private sector choices are feasible in the aggregate:

i. $c^{i*} + \Delta c^i \in \mathcal{C}^i(s^{i*} + \Delta s^i;\epsilon^t)$, for all $i \in I$; and

ii. $c^* + \Delta c \in \mathcal{A}(s^a;\epsilon^t)$.

[85] Recall the convention to include competitive prices in the policy.

The second condition addresses incentive compatibility:

Condition 2. The policy change and proposed change of private sector choices leave objective values unchanged. Moreover, if a private sector choice is individually feasible after the regime change, then the same choice, net of the proposed adjustment, is feasible prior to the regime change:

i. $c^i \in \mathcal{C}^i(s^{i*};\epsilon^t) \;\Rightarrow\; U^i(c^i, s^{i*};\epsilon^t) = U^i(c^i + \Delta c^i, s^{i*} + \Delta s^i;\epsilon^t)$, for all $i \in I$; and

ii. $\tilde{c}^i \in \mathcal{C}^i(s^{i*} + \Delta s^i;\epsilon^t) \;\Rightarrow\; \tilde{c}^i - \Delta c^i \in \mathcal{C}^i(s^{i*};\epsilon^t)$, for all $i \in I$.

If Condition 2 is satisfied, then the proposal is incentive compatible. To see this, suppose to the contrary that there exists an individually feasible and preferred $\tilde{c}^i \neq c^{i*}+\Delta c^i$, such that $U^i(\tilde{c}^i, s^{i*}+\Delta s^i;\epsilon^t) > U^i(c^{i*}+\Delta c^i, s^{i*}+\Delta s^i;\epsilon^t)$. Condition 2 then implies $\tilde{c}^i - \Delta c^i \in \mathcal{C}^i(s^{i*};\epsilon^t)$, and $U^i(\tilde{c}^i - \Delta c^i, s^{i*};\epsilon^t) = U^i(\tilde{c}^i, s^{i*} + \Delta s^i;\epsilon^t)$, and $U^i(c^{i*}, s^{i*};\epsilon^t) = U^i(c^{i*}+\Delta c^i, s^{i*}+\Delta s^i;\epsilon^t)$. Since the agent chose c^{i*}, this entails $U^i(c^{i*}+\Delta c^i, s^{i*}+\Delta s^i;\epsilon^t) = U^i(c^{i*}, s^{i*};\epsilon^t) \geq U^i(\tilde{c}^i - \Delta c^i, s^{i*};\epsilon^t) = U^i(\tilde{c}^i, s^{i*} + \Delta s^i;\epsilon^t)$, establishing a contradiction.

If neither Δs^i nor Δc^i directly enter an objective function, or if the effects of Δs^i and Δc^i on the objective cancel, then the first part of Condition 2 is satisfied. And if the proposal exactly undoes the effect on i's choice set that results from the change of state, i.e., if

$$\mathcal{C}^i(s^{i*};\epsilon^t) = \{c^i \in \mathbb{R}^{|c^i|} | C^{i,n}(c^i + \Delta c^i, s^{i*} + \Delta s^i;\epsilon^t) \leq 0, n = 1, 2, \ldots\}, \tag{1}$$

then it follows that individual feasibility of some choice $c^i + \Delta c^i$ after the regime change implies feasibility of c^i before the regime change; that is, the second part of Condition 2 is satisfied.

Theorem 1. Consider an initial equilibrium in history ϵ^t. A regime change satisfying Conditions 1–2 is neutral except for the policy change and the proposal and implied new states.

Proof. From Conditions 1 and 2, private sector agents are able and willing to follow the proposal given the changed states, and from Condition 1, the regime change is feasible. Accordingly, $c^{g*} + \Delta c^g$ and $\{c^{i*} + \Delta c^i, s^{i*} + \Delta s^i\}_{i\in I}$ satisfy the first two requirements of equilibrium, and these objects are identical to the initial equilibrium objects except for the policy change and the proposal and implied new states. By construction, the new states reflect the modified policy and the proposed new choices on and off the equilibrium path, so they satisfy the last equilibrium requirement. □

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