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CENTRAL BANK DIGITAL CURRENCY AND MONETARY ARCHITECTURE

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JEL Classification: E42, E51, G21, G28

Keywords: Monetary architecture, Central bank digital currency, Private money, Neutrality, Lender of last resort

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Central Bank Digital Currency and Monetary Architecture

Dirk Niepelt*

February 8, 2026

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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.

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1 Introduction

The financial architecture is undergoing a profound transformation. On one front, real and financial assets are being tokenized—that is, represented on shared digital ledgers, changing how they are created, traded, and held. 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.

What macroeconomic consequences might follow from the introduction of CBDC? If adopted at scale, CBDC could displace bank deposits, decouple payment services from traditional bank intermediation, and place established banking models under pressure. Many policy makers are concerned that this may affect the role of banks in channelling savings into investment, and they warn that by offering a safe public alternative to deposits, CBDC could disrupt credit provision and endanger financial stability.

Others—often speaking after leaving office—conversely emphasize 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. . . .
>
> 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.

Section 2 sets the stage by providing background context on the monetary architecture and outlining the policy debate surrounding CBDC, including considerations of stability, efficiency, privacy, financial inclusion, monetary sovereignty, and related issues. Section 3

[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.

then introduces a general framework to clarify the macroeconomic consequences of the introduction of CBDC and the displacement of deposits. Designed to structure the subsequent discussion, this framework is built around a neutrality result that establishes sufficient conditions for the regime change not to alter equilibrium outcomes (beyond a few balance sheet positions).

Intuitively, if CBDC were to displace cash rather than bank deposits, macroeconomic outcomes would change little, as bank funding would remain unaffected. We show that, under fairly general conditions, banks—and macroeconomic outcomes more broadly—can likewise be insulated from the introduction of CBDC even when it crowds out deposits, regardless of whether deposits are a cheap source of bank funding, bank lending is essential for economic activity, or the economy is subject to financial and other frictions. This insulation requires the central bank to recycle the funds raised through CBDC back to banks, either directly or indirectly, on deposit-equivalent terms.

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, arising from policy choices that could, in principle, be adjusted to achieve neutrality.

We find that research so far has mostly focused on policy-related sources of non-neutrality, often without making this focus explicit. Many conclusions regarding the relevance of CBDC rely on assumptions about policy that, if modified, imply that CBDC is largely irrelevant. Model elements such as price rigidities, market power, a bank lending channel, or regulatory constraints need not break this irrelevance. Nevertheless, fundamental sources of non-neutrality do exist. 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 relevant—related to resource costs, network effects, or externalities, among others—have received less attention.

In Section 5, we broaden the discussion to include heterogeneity, information frictions, bank fragility and runs, and taxation. 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. One implication is that, when the conditions for neutrality are satisfied, the introduction of CBDC is Pareto improving whenever it opens relevant policy space. 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 policy debate. In scenarios with non-neutral introduction, CBDC should not be cast narrowly as a technical innovation in the payments system with potential macroeconomic side effects. 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 what policies accompany it.

2 Monetary Architecture

2.1 Public and Private Money

The monetary architecture of modern economies exhibits a two-tier structure. Nonbanks transact using bank deposits, claims on deposits, or cash—a liability of the central bank. Banks, by contrast, settle payments among themselves 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 privately issued monetary instruments as "private money."

Private money need not be backed by public money. Indeed, banks create most deposits through lending, not in exchange for cash or reserves (e.g. McLeay et al., 2014).[4] As a consequence, private and public money need not track each other. Historically, private money has exceeded public money, and their ratio—the money multiplier—has varied over time.[5] Appendix A reviews historical trends, noting in particular that expansions

[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] Money multiplier analysis (Phillips, 1920) characterizes the limits of this money creation process.

[5] The textbook definition of the money multiplier also includes cash held by the public in the numerator.

of public money during and after the financial crisis coincided with a large increase in reserves, and that cash remains widely used as a store of value despite declining payment use.[6]

Views on the merits of private versus public money creation vary widely. Central banks consider both their central position in the financial system and the uniformity of money to be central to fulfilling their mandate,[7] yet they generally accept that money creation can be delegated to private intermediaries under appropriate regulation (BIS, 2003). Banking models in the tradition of Diamond and Dybvig (1983) portray banks as managers of scarce short-term resources, emphasizing the role of insurance and coordination. By contrast, many macroeconomic models treat monetary liquidity as essentially costless to produce, offering no clear rationale for letting private intermediaries create it (Friedman, 1969).

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 inherently unstable fractional reserve banking (Knight et al., 1933; Fisher, 1935, 1936; Benes and Kumhof, 2012).[8] A related line of argument maintains that the social net benefit of private money creation may at times fall short of the private benefit to banks, 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.'[9]

Deposit-to-GDP ratios and deposit spreads, reported in Appendix A, suggest that money creation generates a substantial gross profit from deposit-taking, roughly 0.67% of GDP in the long run for the U.S. When interest rates are low, as in the 2010s or during the COVID-19 pandemic, deposit spreads narrow at the effective lower bound on deposit rates, compressing this profit. Conversely, when rates are high, deposit spreads typically widen, possibly reflecting limited competition in the deposit market (Drechsler et al., 2017), and associated gross profits increase.

2.2 Retail Central Bank Digital Currency

This paper is concerned with retail central bank digital currency (CBDC), defined as digital, widely accessible, central bank money. Unlike deposits, CBDC is issued by—and remains a liability of—the central bank, even if end-user services, including onboarding, wallet provision, or regulatory compliance may be outsourced to private service providers

[6]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]Money 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 broader monetary conditions.

[8]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.

[9]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.

such as banks.[10] Unlike cash, CBDC is a digital payment instrument usable online, and in practice nonbanks would use it as they use deposits—through mobile, online, and card payments. Unlike reserves, nonbanks—not just financial institutions—may hold and use CBDC, making it effectively "Reserves for All." At the same time, unlike the Chicago plan, CBDC does not restrict banks' ability to create money, but is intended to complement private forms of digital money by providing a public alternative.[11]

The concept of Reserves for All is not new, if one sets aside the online functionality and platform aspects. "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).[12] The modern discussion dates back to Tobin (1985) who emphasizes the benefits of 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 safety and preserving sound incentives.[13] 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 ... 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"

[10] In a "one-tier" model, the central bank interacts directly with end users. 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. A potential U.S. CBDC would be privacy-protected, intermediated (by the private sector), widely transferable, and identity-verified (Board of Governors, 2022).

[11] See the "money flower" taxonomy of means of payment in Bech and Garratt (2017) and BIS (2018).

[12] See also 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.

[13] High compliance-related fixed costs, driven by concerns about the safety of payment and saving instruments and the stability of the financial system, may also reduce competition.

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.[14] 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.[15]

Some central banks engaged early.[16] They 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 BigTech firms that monetize synergies between payments and data collection (Auer et al., 2022).

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.[17] 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., Auer et al. (2020)).[18]

Not all rationales for CBDC proposals are entirely convincing.[19] For example, eliminating the effective lower bound on interest rates is not compelling even if one supports the goal of empowering monetary policy: this would require increasing the cost of holding cash (see Section 5). In fact, a non-remunerated CBDC could raise the effective lower bound from slightly negative to essentially zero. Similarly, supporting unconventional 'helicopter drop' policies provides no justification, as CBDC is not a prerequisite even if it could facilitate them. To foster financial inclusion, CBDC is neither the only nor necessarily the most effective tool.[20] And reducing criminal activity has no clear economic link to CBDC adoption as well, unless the latter is accompanied by abolishing cash or high-denomination bills—a measure that would also constrain legitimate activities, imposing

[14]See also Groff (2013), Kaminska (2014), Motamedi (2014), and Andolfatto (2015). Niepelt (2015) focuses on the reserves-for-all aspect of CBDC. Raskin and Yermack (2016) discuss dollarization-type challenges for central banks posed by private cryptocurrencies. Kahn et al. (2019) discuss whether technological advances strengthen the case for tokenized electronic cash.

[15]See Berentsen and Schär (2018). Raskin and Yermack (2016), Bordo and Levin (2017), Bordo (2021), and Bordo and Roberds (2023) place CBDC and private virtual currencies in broader historical context, relating them to earlier shifts in monetary history and the history of economic thought. Raskin and Yermack (2016) note that Milton Friedman anticipated and welcomed in the late twentieth century, how an internet-based digital currency could constrain monetary policy discretion.

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

[17]See Niepelt (2019).

[18]For an overview of CBDC projects, see Boar and Wehrli (2021), Kosse and Mattei (2023), Di Iorio et al. (2024), Illes et al. (2025), and `https://www.atlanticcouncil.org/cbdctracker/`. 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 (Auer et al., 2020).

[19]See Engert and Fung (2017) and Mancini-Griffoli et al. (2018).

[20]Brazil's instant payment platform Pix—supported by the central bank but not based on CBDC—has widely expanded access to financial services. 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.

both private and social costs (Kahn et al., 2005).[21]

The case for CBDC on the grounds of preserving central bank seigniorage is weak in regions where cash holdings remain stable even as cash use declines, or where new private forms of money, such as stablecoins, are more heavily backed by central bank money than deposits, potentially increasing seigniorage. Finally, the motivation to maintain public access to central bank money, is debatable.[22] On the one hand, the decline in public cash use has partly been driven by central banks and governments themselves through outsourcing money creation to banks, shifting cash management costs to the private sector, and constraining cash transactions to combat informal economic activity. In this sense, it is partly self-inflicted and reflects the paradoxical stance of governments to discourage use of state money. On the other hand, 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 convincing motivations for introducing CBDC include mitigating financial stability risks in a leveraged banking system and fostering competition in the payments sector. Both arguments resonate not only with Tobin (1985, 1987) and the broader literature on financial instability and market power in banking and payments, but also connect directly to CBDC's character as public money—run-proof and providing the public with an outside option that disciplines private issuers. We return to these points later.

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 seigniorage or supporting other policy objectives.[23] For example, Board of Governors (2022, p. 15) states that[24]

> "[t]he dollar's international role benefits the United States by, among other things, lowering transaction and borrowing costs . . . 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. dollar, global use of the dollar could decrease—and a U.S. CBDC might help preserve the international role of the dollar."

Lane (2025) argues that

> "Europe's reliance on foreign payment providers has reached striking levels . . . This dependence exposes Europe to risks of economic pressure and coercion

[21] See also Rogoff (2016) and McAndrews (2017).

[22] See Sveriges Riksbank (2017, 2018) on the objective to secure public access.

[23] See also Brunnermeier and Landau (2022). Brunnermeier et al. (2019) argue that private platform currencies could unbundle functions of money, contributing to the formation of "digital currency areas."

[24] 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.

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."

Another frequently cited motivation for introducing CBDC is to enhance user autonomy in response to widespread privacy intrusions by private digital service providers.[25] The degree of privacy a CBDC provides ultimately depends on its regulatory framework, technological design, and system architecture.[26] Beyond these factors, broader societal attitudes toward government and institutional trust influence the perceived privacy differences between publicly and privately issued payment instruments.[27] Central banks have therefore explicitly linked CBDC development to legislative commitments ensuring privacy protections, alongside exploration of technical solutions designed to give users meaningful control over their data (Torres Vives et al., 2024).

However, much of the public views CBDC as a vehicle for potential 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).[28] 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.

Since many CBDC 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 questioned whether there would be substantial demand for it.[29] 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.[30]

[25] These intrusions are often enabled by users' own behavior, giving rise to the so-called "privacy paradox" (Norberg et al., 2007). Borrowing-constrained users of digital payment platforms may willingly forgo privacy in order to commit to debt repayments. A privacy-preserving CBDC could weaken such commitment (Brunnermeier and Payne, 2025).

[26] See Auer and Böhme (2021), Board of Governors (2022), and Murphy et al. (2024). Chaum et al. (2021) propose a CBDC model that combines transaction privacy with regulatory compliance.

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

[28] Still, central banks often are "preferred digital currency issuers" (Patel and Ortlieb, 2020, p. 19).

[29] Bofinger and Haas (2020) reject the case for digital central bank cash substitutes; in their view, market power in global payment networks calls for a supranational policy response.

[30] Concerns about either 'too low' or 'too high' CBDC uptake have motivated efforts to forecast adoption, 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).

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. 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.[31] 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.[32] But as we will discuss below, caps on CBDC holdings have their problems, related to adoption, market segmentation, and the risk to miss out on some of the opportunities CBDC affords.

The subsequent analysis and discussion centers on the macroeconomic implications of CBDC. Following Tobin, it emphasizes the public issuer nature of CBDC—Reserves for All—rather than the technical infrastructure underlying the payment system.[33] This approach aligns with much of the macroeconomic and banking literature. Instead of delving into technical specifics, it typically assumes rather than models the liquidity and convenience features of CBDC, even though they fundamentally depend on payment system technology.

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.[34] 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.

[31] 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 (Bindseil and Senner, 2024). None of the three central banks plans to offer remuneration. The ECB plans to allow natural persons who are permanent residents or temporary residents (e.g., travelers) to hold digital euro. Its proposed "waterfall" model would transfer any digital euro holdings above the cap into a linked bank account, while the "reverse waterfall" would draw funds from that account if needed (Bindseil et al., 2024).

[32] Burlon et al. (2024) find that euro area banks reliant on deposit funding experience stock price reactions to digital euro news, until planned holding limits are announced.

[33] See Auer and Böhme (2020), Auer et al. (2022), Group of Central Banks (2024a), and Group of Central Banks (2024b) for design and legal considerations. In 2021, most central banks lacked legal authority to issue CBDC (Boar and Wehrli, 2021).

[34] See, e.g., Di Iorio et al. (2024). For estimates of reconciliation costs in today's financial architecture, see Mainelli and Milne (2016).

3 Conceptual Framework

In this section, we establish conditions for the neutral introduction of CBDC. We will use these conditions, which generalize Brunnermeier and Niepelt (2019), to identify sources of non-neutrality and to structure the subsequent discussion. We derive the conditions in an abstract setting rather than a specific, fully specified model, dispensing with nonessential elements that would 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 a regime change preserves agents' opportunities and satisfies aggregate consistency requirements, equilibrium outcomes remain effectively unchanged.

Ricardian equivalence (Barro, 1974) offers an illustration. Rather than showing in a given model that the timing of tax collections does not affect equilibrium outcomes, a more insightful approach is to establish that agents' choice sets remain unchanged under a broad range of modeling assumptions, and to infer neutrality in a wide class of models. We follow a similar approach for CBDC, showing that if newly sourced CBDC funds are channeled back to banks—directly or indirectly—on terms comparable to those of deposits, banks and macroeconomic outcomes remain largely unchanged under broad conditions. 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 an economy comprising heterogeneous households, firms, and banks (some of which may reside abroad) and a consolidated government composed of a central bank and a fiscal authority. 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 arbitrary assets and sources of liquidity or convenience demand.[35]

Private-sector agents and the government make *choices*. For example, agents in the private sector may choose consumption, production and portfolios, and agents with market power may set prices. The government's choices or *policy* may include paths for public consumption, central bank and 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 restrictions. The constraints depend on factors beyond the agent's control, which we refer to as their *state*. For example, the state of a competitive agent includes 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*, e.g., utility or profit,

[35]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, 2024).

which depends on the agent's choices and state. *Aggregate constraints* represent, e.g., market clearing conditions, the government budget constraint, or 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.

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 over the continuation histories 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.[36]

3.2 Regime Change

Starting from some initial equilibrium, we consider a *regime change* that consists of 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.[37]

The specific regime change we consider pairs the introduction of CBDC with few proposed changes of private-sector balance sheet positions. The policy change includes (at most) altered reserve and CBDC issuance by the central bank and modified central bank lending to banks.[38] The proposed changes of private-sector choices include (at most) changes in nonbanks' deposit and CBDC holdings as well as banks' reserve holdings and borrowing from the central bank. Other private-sector choices and equilibrium outcomes, including prices and the allocation, could in principle change; however, under a neutral regime change, they remain unaffected (see below).

Our focus on these balance sheet positions reflects the most plausible scenario for CBDC introduction, in which nonbanks convert deposits into CBDC balances, replacing claims on banks with claims on the central bank. This deprives the bank of an important source of funding, a fact that has triggered concerns about the implications for financial stability and bank lending. The scenario resembles a nonbank withdrawing cash at an ATM: deposits are exchanged for central bank liabilities, and the bank loses deposit funding. With cash withdrawals, the bank's cash holdings fall; with CBDC, reserves are drained, or the bank maintains the length of its balance sheet by obtaining new funding.

An alternative scenario is direct interaction between nonbanks and the central bank, swapping CBDC for cash. In this case, banks are not directly involved, and any macroeconomic consequences would likely arise from differences in convenience, privacy, or trans-

[36]For the last equilibrium requirement, consider a monopolist. The firm's state includes the demand function it perceives to face, and consistency requires this function to match the demand that would actually result following deviations from the firm's optimal choice. The specific off-equilibrium refinement is not important as long as it is maintained across environments.

[37]For example, the proposal may imply a new perceived demand curve for a monopolist.

[38]In some contexts, discussed in Appendix C, the policy change may also alter transfers.

action costs across payment instruments. Similar considerations apply to the baseline scenario and are discussed later, along with other possibilities, such as CBDC issued in exchange for government bonds or via helicopter drops. 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 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 n, r, m, ℓ denote deposit, reserve, CBDC, and central-bank-loan balance sheet positions, respectively, the policy change we consider is given by

$$\Delta m^g, \Delta r^g, \Delta \ell^g,$$

representing the modified CBDC and reserve issuance in history ϵ^t as well as the central bank loan to the bank, respectively. Under the policy change we consider, these changes in history ϵ^t are reversed in each of the immediate successor histories. For example, when the government issues additional CBDC in history ϵ^t, $\Delta m^g > 0$, 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.

The proposed balance sheet adjustments in the private sector are

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

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 equilibrium asset market clearing as encoded in the aggregate constraints, $\Delta n^b = \Delta n^i$, $\Delta m^g = \Delta m^i$, $\Delta r^g = \Delta r^b$, and $\Delta \ell^g = \Delta \ell^b$, and that it does not interfere with nonnegativity constraints on balance sheet positions. We also assume that it does not change the asset span so that agents can attain the same set of state-contingent payoffs.[39]

3.3 Neutrality

We are interested in sufficient conditions for a *neutral* regime change—a change that does not alter equilibrium outcomes except for the directly affected balance sheet positions. The first condition for neutrality is that the new policy and the proposed private-sector choices are feasible:

[39] See Geanakoplos (1990) for incomplete market economies and changes in the asset span.

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.

Condition 1 requires that the proposal be individually feasible for each private-sector agent. This would not be the case, for instance, if the policy or proposed balance sheet adjustments violated budget constraints. Condition 1 further requires feasibility at the aggregate level; for example, the regime change must be consistent with market clearing.

While Condition 1 is necessary for the implementability of a regime change, it is not sufficient as it does not guarantee that private-sector agents actually want to follow the proposal. This is addressed by 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 it equals a feasible choice prior to the regime change coupled with the proposed adjustment.

Condition 2 requires that utility, profits, or any other private-sector objective do not directly change as a consequence of the joint effect of the policy change and the proposal. This requirement would typically be violated, for example, if utility depended directly on individual policy instruments or on the structure of balance sheets. It also requires that the regime change does not enlarge the effective choice set of private-sector agents, ensuring incentive compatibility. For instance, if the proposal is for the household to swap one unit of deposits for one unit of CBDC, and after the regime change the household can choose to hold one unit of each, Condition 2 requires that it would have been feasible to hold two units of deposits (and no CBDC) before the change.

Feasibility and incentive compatibility imply:

Theorem 1. A regime change satisfying Conditions 1–2 is neutral.

As mentioned before, Condition 1 requires budget feasibility. In particular, changes in expenditures for convenience or liquidity must be linked to changes in costs associated with managing or administering balance sheet positions (see Appendix B). In the case of nonbank i, the former are given by $\sigma^{n*}\Delta n^i + \sigma^{m*}\Delta m^i$ where $\sigma^{x*} \equiv 1 - \mathbb{E}[\mathrm{sdf}^*_+ R^{x*}_+]$ denotes the spread on a generic asset x (with R^{x*}_+ and sdf^*_+ the equilibrium gross rate of return and stochastic discount factor, respectively),[40] and the latter by $\Delta\varphi^i$.[41] Budget constraints also require aggregate balance-sheet costs to remain unchanged,

$$\Delta\varphi^g + \Delta\varphi^i + \Delta\varphi^b = 0. \tag{1}$$

If the costs represent resource requirements, Condition 1 demands that Equation (1) holds for each resource individually.

In the examples we consider, Condition 2 is straightforward to verify. The first part holds because either proposals and states do not enter private-sector objectives at all

[40] We write sdf^*_+ for $\mathrm{sdf}^*(\epsilon^{t+1|t})$, etc. The spread is nonzero when the asset enters an objective or a nonbudget constraint; it measures the unit cost of the associated convenience or liquidity benefit.

[41] For example, if swapping deposits for CBDC ($\Delta m^i > 0$, $\Delta n^i < 0$) reduces fees, then $\Delta\varphi^i < 0$. The neutrality result in Brunnermeier and Niepelt (2019) abstracts from balance sheet costs.

or their changes exactly offset one another. The second part holds because a property stronger than what that part of the condition requires is satisfied, namely that the proposal exactly offsets the effect of the state change on agents' choice sets, leaving private-sector agents in exactly the same position as before the regime change (see Appendix B):

$$\text{(choice set} \mid \text{initial state)} = \text{(choice set} \mid \text{new state) net of proposal.} \tag{2}$$

Equation (2) also guarantees that the first part of Condition 1 is satisfied.

4 CBDC—Central Domains

In this section, we use the neutrality conditions to organize and interpret how the literature has attributed a role to CBDC. Our analysis focuses on three domains affected by CBDC: the nonbank, the bank, and the system as a whole, where general equilibrium effects cannot be directly traced 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 further dimensions and generalizations.

4.1 Nonbank

We start with an example of a household, focusing on partial equilibrium for now. For simplicity, we assume that convenience or liquidity benefits of deposits and CBDC are identical, deposit and CBDC returns have the same risk characteristics, and the regime change does not alter balance-sheet costs, $\Delta\varphi^i = 0$. None of these assumptions are necessary for neutrality as we show in Appendix C.

Example 1 (Household)**.** Household i has money-in-the-utility-function preferences (Sidrauski, 1967) that depend on the sum of deposit and CBDC liquidity services, $n^i + m^i$. Deposits and CBDC therefore carry identical liquidity premia. Under our assumption about risk characteristics, the household's Euler equations reduce to $R_+^{m*} = R_+^{n*}\ \forall\epsilon^{t+1|t}$.

The regime change tightens the household's budget constraint in history ϵ^t by $\Delta n^i + \Delta m^i$ and relaxes it in history $\epsilon^{t+1|t}$ by $R_+^{n*}\Delta n^i + R_+^{m*}\Delta m^i$. Individual feasibility demands that these effects equal zero in each history. Moreover, incentive compatibility requires the asset swap to have no effect on the objective function, i.e., we must have $\Delta n^i + \Delta m^i = 0$. We conclude that under the restrictions

$$\left.\begin{aligned} \Delta m^i &= -\Delta n^i \\ R_+^{m*} &= R_+^{n*} \quad \forall\epsilon^{t+1|t} \end{aligned}\right\} \tag{3}$$

the proposal satisfies the first parts of Conditions 1 and 2 for the household. It also satisfies the second part of Condition 2 because Equation (2) applies: after reversing the swap the household finds itself in exactly the same position as before the regime change. Hence, the household is indifferent to the regime change, and neutrality holds (in partial equilibrium) 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 logic applies if the household faces a cash-in-advance constraint as in Lucas (1982), a shopping time constraint as in Saving (1971), or some other type of constraint that depends linearly on n^i and m^i. What matters is not the source of liquidity or convenience benefits, but that these benefits can be substituted across payment instruments.

In particular, as emphasized by Brunnermeier and Niepelt (2019), neutrality requires a constant marginal rate of substitution between deposit and CBDC liquidity benefits (not necessarily equal to one, see the generalized case in the appendix); otherwise, Condition 1 is violated. A non-constant rate of substitution breaks neutrality because, for given spreads and expenditures, substituting one means of payment by the other reduces total liquidity benefits. Put differently, a portfolio adjustment that alters the marginal rate of substitution in equilibrium would require a corresponding change in spreads, making the regime change non-neutral. In practice, this potential source of non-neutrality appears negligible, since deposits and CBDC should readily substitute for one another.[42]

Nevertheless, many papers in the literature assume that nonlinear aggregates of deposits and CBDC 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). Abad et al. (2025) and Burlon et al. (2024) calibrate the elasticity of substitution between payment services 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 relative convenience and substitutability of CBDC and deposits shape money demand and seigniorage.

In Assenmacher et al. (2021), substitutability between deposits and CBDC is limited because factors of production exhibit a finite elasticity of substitution and can only be bought with factor-specific means of payment. Lamersdorf et al. (2024) similarly assume that CBDC is an essential means of payment—ruling out neutrality by design—that banks purchase on behalf of their clients, settling the purchases with reserves. This creates a reserve management problem for banks analogous to that described by Poole (1968).

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. Neutrality thus 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—neutrality typically breaks down. A similar

[42] A household that is indifferent at the margin between paying one rent or mortgage installment with deposits and another with CBDC should easily be able to pay both installments with either.

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.[43]

The marginal rate of substitution between deposit and CBDC liquidity may capture various non-financial benefits. 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, the rate of substitution may reflect payment instrument choices of other agents, for instance because of 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; we establish this in the bank context. In contrast, fixed costs break indifference across instruments before the introduction of CBDC, but cease to matter once both instruments are in use.

Policy. When the marginal rate of substitution between deposit and CBDC liquidity benefits differs from one, neutrality requires transfers between the household and the government, see the generalized Example C-1 in Appendix C. As we discuss there, neutrality may prevail even without transfer instruments as long as additional balance sheet positions may adjust. More generally, neutrality follows independently of transfers when the nonbank is the taxpayer, or is owned by the taxpayer. The key point is that ownership linkages can substitute for contingent transfers.[44]

However, neutrality may be compromised when CBDC remuneration is inappropriate. If the interest rate on a newly introduced CBDC fails to satisfy the generalized version of the condition $R_+^{m*} = R_+^{n*} \ \ \forall \epsilon^{t+1|t}$, 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.

4.2 Bank

Turning to the second domain, we consider the partial-equilibrium implications of a regime change for a bank. We start again with an example. For simplicity, we abstract from bank market power and costs of managing the deposit franchise, assume risk-free interest on reserves, and impose a fixed regulatory reserves-to-deposit ratio, ζ^*. None of these assumptions are necessary for neutrality; in Appendix C, we relax them and allow reserve holdings to affect bank operating costs.

Example 2 (Bank)**.** Bank b finances its reserve holdings and lending through deposits and, following a regime change, also through a central bank loan. (Other funding sources

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

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

and investments may exist but play no role in the analysis.) In the initial equilibrium, the bank pays gross interest $n^b R_+^{n*}$ on deposits.

The regulatory restriction requires $\Delta r^b = \zeta^* \Delta n^b$. Accordingly, the bank's budget constraint in history ϵ^t tightens by $\Delta r^b - \Delta n^b - \Delta \ell^b = (\zeta^* - 1)\Delta n^b - \Delta \ell^b$. The effect on the budget constraint in history $\epsilon^{t+1|t}$ depends on the terms of the central bank loan. To make the bank indifferent between raising deposits (partly invested in reserves) and borrowing from the central bank, the interest rate on the loan must satisfy $R_+^{\ell*} = (R_+^{n*} - \zeta^* R_+^{r*})/(1-\zeta^*)$; with this rate, borrowing $1-\zeta^*$ units at the central bank costs the same as raising one unit from depositors and investing the share ζ^* in reserves. We conclude that under the restrictions

$$\left.\begin{aligned} &\Delta r^b = \zeta^* \Delta n^b \\ &\Delta \ell^b = -(1-\zeta^*)\Delta n^b \\ &R_+^{\ell*} = (R_+^{n*} - \zeta^* R_+^{r*})/(1-\zeta^*) \quad \forall \epsilon^{t+1|t} \end{aligned}\right\} \tag{4}$$

the proposal satisfies the first part of Condition 1 for the bank. Since Equation (2) applies and since the bank does not value the balance sheet composition beyond its financial consequences, it also satisfies Condition 2. Accordingly, neutrality holds (in partial equilibrium) as far as the bank is concerned.

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 (net of reserves) funds back to banks. If it chooses to do so at appropriate terms, it transfers CBDC seigniorage to banks, leaving the bank's environment effectively unchanged.[45] This turns the central bank into an intermediary, transforms private into public money, and decouples bank funding from liquidity provision (Brunnermeier and Niepelt, 2019). The refinancing occurs largely mechanically: when deposits are transferred to the central bank and the latter 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 remain incomplete if they do not account for this funding.

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 (on net). The question thus is not whether deposit outflows make way for alternative sources of bank funding, but rather which sources of funding replace the outflows and on what terms. Below, we return to the question whether financial markets can

[45]Note that the loan balances the fall in deposits net of reserves; see also Kim and Kwon (2023).

substitute for central bank loans in general equilibrium and also discuss CBDC injections by transfer.

The generalized Example C-2 in Appendix C shows that the same mechanism can operate when banks possess deposit market power. The restrictions in (4) ensure that bank budget constraints are satisfied and the central bank loan is priced appropriately. Bank market power imposes additional, off-equilibrium restrictions on the loan: to preserve the 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.

The generalized example also clarifies how balance-sheet costs affect neutrality. If the bank bears operating costs associated with the deposit franchise—for instance, because payment operations are costly—but incurs no operating costs on the central bank loan, then the loan interest rate must be correspondingly higher to leave the bank indifferent. Because franchise costs are incurred in history ϵ^t, whereas loan interest charges accrue in successor histories, budget feasibility requires a compensatory transfer in history ϵ^t that is reversed in the successor histories. In circumstances analogous to those discussed in the context of Example 1, these transfers can be dispensed with.

Fundamentals. For the bank's choice set to remain unchanged, the central bank loan must fully replicate 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. Demandable deposits may help banks mitigate internal frictions such as free-riding among depositors or holdup between management and depositors (Calomiris and Kahn, 1991; Diamond and Rajan, 2001).[46] Deposits held by borrowers may also improve banks' ability to monitor their creditworthiness (Mester et al., 2007). The functions that these theories attribute to deposits or depositors can, in principle, be performed by a central bank loan or by the central bank itself. Given its superior information access and legal authority, the central bank is typically in a better position than individual depositors to discipline bank management; and it could also share relevant transaction data from CBDC holders, helping to replicate the monitoring benefits associated with deposits. Moral hazard frictions similarly need not break neutrality as long as they apply symmetrically to both deposits and a central bank loan (Gross and Schiller, 2021).

A related argument concerns complementarities between deposits and lending commitments, which both generate liquidity demands for banks to meet (Kashyap et al., 2002). When these demands are imperfectly correlated, banks can economize on costly holdings of liquid assets.[47] As before, however, such complementarities only imply specialness if the central bank cannot replicate them. Appendix C presents an example in which deposits,

[46] 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).

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

whether pre-existing or newly created through the drawdown of credit lines, interact with liquid asset holdings and affect operating costs, without breaking neutrality.[48]

Piazzesi and Schneider (2022) similarly emphasize the costs banks incur from holding assets to back deposits. Because of these costs, liquidity services are provided most efficiently when balance sheets remain lean and money is created only when needed, as with credit lines. They conclude that if commercial banks have an advantage in offering credit lines, CBDC-induced crowding out can raise balance-sheet costs and break 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.[49] They find that CBDC reduces bank deposits, with one quarter of the decline passed through to lending, as banks partly offset lost deposits with wholesale funding. Smaller banks are more affected. When CBDC is intermediated through banks, which adds convenience, the effect is amplified. Whited et al. (2023) exclude central bank pass-through funding. With such funding, deposit-CBDC substitution could be neutral as Example 2 shows.

Policy. Even if the central bank is able to sterilize the effect of CBDC issuance on banks' choice sets, it may choose not to pursue this strategy. A case in point involves regulatory constraints that treat deposit and central bank funding asymmetrically.[50] For instance, in Example 2, neutrality 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 fully replace deposit funding, but only the share 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. This appears to mark a significant departure from established practice, in which central banks typically demand collateral when funding banks. However, 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.

[48] Pulley and Humphrey (1993), Egan et al. (2022), and Darst et al. (2025) offer empirical assessments.

[49] Imperfectly competitive banks set the deposit rate to equalize marginal funding costs across sources and determine the lending rate by balancing marginal investment returns (Klein, 1971; Monti, 1972). Deposit-taking and lending decisions are separable, so deposit market shocks do not affect lending, when an alternative funding source or investment opportunity is perfectly elastic. Whited et al. (2023) introduce costly wholesale financing and capital regulations, which connect banks' deposit and loan policy choices.

[50] 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.

Chen and Filippin (2025b) explicitly introduce a collateral constraint on central bank lending in a framework that otherwise satisfies neutrality.[51] To preserve 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 tradeoffs highlighted by policymakers. In their framework, issuing CBDC at a competitive rate erodes the liquidity premium on deposits and makes bank lending more expensive. At the same time, CBDC increases the total supply of liquidity in the economy, facilitating exchange. The optimal CBDC amount balances these opposing effects; the introduction of CBDC tends to enhance welfare when pre-CBDC investment is not too far below the first-best 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.[52]

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. Because changes in funding conditions do not affect the bank's tradeoff on the asset side, bank lending remains unchanged in partial equilibrium.[53] This changes when the bank faces a binding liquidity constraint. In that case, higher deposit funding resulting from the competitive CBDC pressure leads the bank to *expand* its lending. An important insight 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 breaking 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 func-

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

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

[53] See Footnote 49.

tioning of the interbank market. Following the introduction of a non-remunerated CBDC, nonbanks withdraw 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. 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), this eliminates the possibility of system-wide runs on bank deposits. But it breaks neutrality unless a third party is willing to exchange debt against deposits, effectively substituting for the passthrough funding in Example 2. In Bidder et al. (2024), CBDC is introduced through exchanges for corporate debt. This breaks 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.[54]

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 also follows 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.[55] Whether such broader realignments in the financial sector are feasible, and in the interest of market participants, depends on their choice sets and objectives.[56]

Several studies examine the feasibility of broader adjustments following the introduc-

[54]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.

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

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

tion 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. Of course, such price adjustments could 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 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.

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, 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.[57] 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 the central bank to compensate providers for lost profits, or CBDC usage fees exceeding those of private services.

The degree of competition in the payment sector can influence the allocation 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.[58] 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

[57] 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).

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

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 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.

Regarding private cryptocurrencies, one may ask how the introduction of CBDC differs from creating such a privately issued means of payment. The restrictions in Example 2 still apply if we reinterpret CBDC as a private cryptocurrency and the central bank loan as a loan from the cryptocurrency issuer to the bank. However, Condition 2 imposes additional incentive-compatibility constraints because the issuer is private and self-interested, and this tightens the conditions under which neutrality holds relative to CBDC.[59] A further difference is that a central bank cannot act as lender of last resort for a cryptocurrency issuer (Skeie, 2021).

4.3 System

Turning to the general equilibrium domain, we consider systemic implications of CBDC. Recall that Condition 1 requires the policy change together with the modified balance sheet positions to be feasible in the aggregate. The following example, which builds on generalizations of Examples 1 and 2 (see Examples C-1 and C-2 in Appendix C), focuses on one aggregate feasibility requirement, the aggregate resource constraint.

Example 3 (Resources)**.** Deposits carry unit operating costs $\alpha(\zeta)$ with $\zeta \equiv r^b/n^b$ for the issuing bank (in Example 2, we set $\alpha \equiv 0$). CBDC, reserves, and central bank loans to banks carry unit operating costs μ, ρ, and o, respectively, which are borne by the central bank. Operating costs are incurred upon issuance and in the same resource. A regime change subject to the constant reserves-to-deposits ratio ζ^* thus tightens the 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.

The bank balance sheet Restriction (4) in Example 2 and market clearing for reserves and the central bank loan reduce the resource-neutrality requirement to $(\alpha(\zeta^*) + \rho\zeta^* - o(1-\zeta^*))\Delta n^b + \mu\Delta m^g = 0$. Additionally imposing the household balance sheet restriction and CBDC market clearing implies

$$\alpha(\zeta^*) + \rho\zeta^* - o(1-\zeta^*) = \frac{\mu}{\lambda}, \tag{5}$$

an instance of Constraint (1). Here, λ denotes the ratio of unit CBDC liquidity services to unit deposit liquidity services, which we set to one in Example 1.[60]

[59] Neutrality holds when the private issuer is perfectly competitive, faces no balance-sheet costs, and backs its instruments with deposits. In this case, the cryptocurrency functions merely as a veil.

[60] Asset market clearing and the restrictions derived in Examples C-1 and C-2 imply that the regime

Fundamentals. Example 3 demonstrates that resource neutrality is generally not satisfied if the choice sets of nonbanks and banks are to be preserved—unless balance sheet positions, or transactions involving them, are assumed to be costless, as is typical in the literature.[61] In contrast, Niepelt (2024) introduces resource costs of deposit-and-reserve-versus 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 tax distortions. 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 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 in the model, 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—even abstracting from the sector's fragility. 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 instrument depends on economy-wide adoption patterns, individual choices collectively shape everyone's options. This can break neutrality in general equilibrium, even when agents are indifferent between CBDC and deposits in partial equilibrium, for given adoption patterns. 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 play a similar role. Garratt and van Oordt (2021) analyze a model in which disclosure of information generates negative externalities: an individual chooses to disclose since the direct cost of doing so is small, but data aggregation across users reveals a lot more information about the group the individual is part of—and generates substantially higher costs.[62] Garratt and van Oordt (2021) suggest that CBDC issuance can 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

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 zero. The former term vanishes when Equation (5) is satisfied.

[61] Fixed costs break neutrality at the introduction of CBDC, but not for increases or decreases.

[62] See also Solove (2013).

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).[63] 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. While smaller, more open economies are more susceptible to this risk, a strong central bank commitment to inflation stabilization can help guard against it.

4.4 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 or policy related sources of CBDC non-neutrality and model elements that are relevant only when those 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 makes CBDC relevant.

[63] Cong and Mayer (2025) analyze a model in which countries maximize the adoption of their national currencies in the face of a competing private digital currency. 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, and taxation, 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.

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 options available to private-sector agents and violates incentive compatibility for a neutral CBDC proposal.

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, because they place greater value on its liquidity services. 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.

More generally, information related implementation challenges are not confined to settings with heterogeneous agents. Even with a representative bank and nonbank, neutral CBDC introduction requires detailed information about the economy, which the public sector may lack. 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, it may not suffice to extrapolate into the future as required for longer-lasting neutral regime changes.[64]

Rather than creating information related challenges, the introduction of CBDC may improve information sets of policy makers. Keister and Monnet (2022) analyze the case where the introduction of CBDC enhances central bank monitoring by providing real-time visibility into deposit outflows linked to bank distress. This enables earlier identification of weak banks, and boosts 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.[65] 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.[66]

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

[64] See also Niepelt (2020).

[65] See Brunnermeier and Niepelt (2019).

[66] 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. 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 includes beliefs about off-equilibrium choices 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.

> 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, the nature and extent of fragility remain unchanged. Moreover, even if the regime change is non-neutral, it need not increase fragility. On the contrary, fragility may be reduced if the central bank replaces unstable deposit financing with more stable central bank lending, internalizing 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 by letting the contingent remuneration of CBDC mirror 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 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.

Finally, 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 the central bank aims at curbing CBDC inflows—for example, due to concerns about non-neutralities—the natural policy tool would 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.[67] However, such holding limits do not resolve run problems at the source and may create other difficulties, as Cecchetti and Schoenholtz (2022) point out:[68]

> "[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.[69] These measures aim to protect banks from direct or indirect deposit outflows into CBDC, but they break 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.

[67] If the conditions for a neutral regime change are otherwise satisfied, quantity restrictions are irrelevant: neutrality reflects indifference, so the restrictions merely select a policy and equilibrium. Only when neutrality conditions are otherwise not met do quantity restrictions become relevant.

[68] 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.

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

Bindseil (2020) and Infante et al. (2023) reject the proposal by Kumhof and Noone (2021) on the grounds that it would place into question core principles of central banking relating to convertibility and uniform pricing. As an alternative, Bindseil (2020) proposes a two-tiered remuneration scheme, under which CBDC balances above a specified threshold would earn lower interest than those below it.[70] He suggests that such a system could help bolster political support for maintaining very low interest rates during periods of stress.

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

So far, we have 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 (and in Appendix C) continue to apply, and they still ensure that a regime change preserves government revenue net of balance sheet costs.[71]

Neutrality also holds with nonlinear taxes, provided the tax functions shape agents' choice sets in ways consistent with Conditions 1 and 2. One class of such tax functions maps the sum of pre-tax portfolio returns, balance-sheet costs, and, possibly, transfers into a tax obligation. Choice sets remain unchanged in this case, and tax liabilities are unaffected. By contrast, taxes that distinguish between deposits and CBDC may break neutrality. However, this form of non-neutrality stems from the tax design itself and can, in principle, be avoided through appropriate policy choices.

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 Monetary Policy Transmission

When CBDC is introduced in a neutral manner, leaving agents' choice sets unchanged, the monetary transmission mechanism is unaffected. Under non-neutral introduction, by

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

[71] 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.

contrast, transmission may be altered.[72]

Jiang and Zhu (2021) examine how interest 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. The CBDC rate therefore pins down the deposit rate, and changes in the reserve rate are fully transmitted to loan rates.

In Niepelt (2024) 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.

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 (2024) 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

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

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. 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).[73]

5.5 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 symmetric liquidity benefits and moral hazard frictions of CBDC and deposits, calibrated to euro area data. 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 area, 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

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

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 seigniorage, 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, or domestic agents holding foreign-currency denominated securities, can access a domestic CBDC. When they can, an interest parity condition links CBDC remuneration, the foreign bond interest rate, CBDC liquidity benefits, and the 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 in this setting CBDC 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.

5.6 Political Economy

Even when instruments exist to implement a neutral regime change, policymakers may choose otherwise, raising the question of whether such implementation is politically incentive compatible. To examine this issue, we broaden our notion of neutrality from one that treats 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). Within this framework, Conditions 1 and 2 are supplemented with additional requirements that reflect feasibility and optimality from the perspective of political decision-makers, such as voters and politicians. In particular, for a policy to be implementable, it must be time consistent (Kydland and Prescott, 1977; Barro and Gordon, 1983).[74]

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 seigniorage 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.[75]

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

[75] Tucker (2017) and Cecchetti and Schoenholtz (2018) discuss political repercussions of CBDC.

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 liquidating 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.[76]

Among the political conflicts surrounding CBDC, its potential impact on the cost of deposit funding appears particularly salient. If banks create money non-competitively, the resulting profits are directly exposed to political risk insofar as, following the introduction of CBDC, political constraints could limit pass-through funding on deposit-equivalent terms. Letting $-\psi^{-1}$ denote the elasticity of nonbanks' liquidity demand as perceived by banks, the net profit corresponding to the gross amount illustrated in Figure A-2 in Appendix A is equal to ψ times that gross amount. Assuming $\psi = 1/3$ (Drechsler et al., 2017; Wang et al., 2022; Pasqualini, 2021; Niepelt, 2024), this net profit exposed to political risk averages approximately 0.22% of GDP over the past fifty years. In other words, if banks have market power over deposits, introducing CBDC could put a substantial share of their profits at risk, rationally motivating deposit-dependent banks to lobby against its introduction.

6 Conclusion

Our analysis highlights conditions under which a change in monetary architecture is neutral and identifies key sources of potential non-neutrality related to the introduction of CBDC.

[76] See also Skeie (2021).

In the nonbank domain, non-neutrality fundamentally arises from nonlinear substitution across liquidity sources or from constraint multiplicity, which reflects the multidimensionality of liquidity and convenience services. While constraint multiplicity appears empirically more relevant, the literature has predominantly focused on nonlinear substitution.

In the bank domain, non-neutrality fundamentally arises when deposits are special—that is, when they serve roles beyond mere funding that other forms of financing cannot equally fulfill. Without specialness, bank financing can be decoupled from the issuance of payment instruments: central banks can insulate banks from the consequences of CBDC by providing passthrough funding at deposit-equivalent terms; when they choose not to, markets may partially compensate.

Finally, in the system domain, non-neutrality fundamentally arises when CBDC and deposits differ in their general equilibrium implications due to, for example, asymmetric network effects, externalities, resource requirements, or other social costs.

In stark contrast to these fundamental sources, many other frictions need not break neutrality. Lack of competition, a two-tier monetary architecture, maturity transformation, costs of managing 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 fundamental sources of non-neutrality, the literature has mostly focused on policy-related sources, often without making this focus explicit. This risks overstating the macroeconomic significance of CBDC by conflating its direct effects with those arising from complementary policy choices. Our analysis suggests that the central bank's operating framework and policies accompanying the introduction of CBDC are crucial for the macroeconomic consequences. Policy, rather than fundamental economic factors, may well be the most important determinant of the allocative and distributive implications of CBDC.[77]

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 and this shifts political support away from cheap bank financing (and possibly lending), then resistance from interest groups should be expected early on.

Our discussion has broader implications. One concerns the interpretation of the neutrality benchmark. While neutrality sets a lower bound on the welfare consequences of a regime change, it also implies that the introduction of CBDC is Pareto improving when the intervention meaningfully enlarges the choice set of (benevolent) policy makers, 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 or may not be possible.

[77] 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.

Another implication is that, ceteris paribus, policymakers have considerably 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 characteristics of CBDC and generates identical general equilibrium effects, there may still be a case for preferring the 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

A.1 Public and Private Money

A.1.1 Swiss Franc and U.S. Dollar

Figure A-1 shows the historical evolution of public and private money components denominated in Swiss francs and U.S. dollars. The solid lines indicate Swiss franc M1, including cash held by the public, sight deposits, and transaction accounts at banks and postal institutions; and U.S. dollar M2, a broader measure that also includes small-denomination time deposits and retail money market fund balances. These two measures expanded at similar average rates over the past century.

The other lines indicate public money components. The ratio of Swiss franc M1 to public money remained relatively stable until the 1980s, then more than tripled before collapsing during the global financial crisis. The ratio of U.S. dollar M2 to public money 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 public money during and after the financial crisis were accompanied by a sharp rise in the reserve components, reflecting lender-of-last-resort interventions followed by quantitative easing and exchange rate stabilization policies (Pattipeilohy, 2016). At their peak, reserves accounted for nearly 90% of Swiss franc public money and close to 70% of U.S. dollar public money. Bazot et al. (2025) report similar magnitudes for many other currency areas, with cash shares in central bank liabilities often starting to decline before 2000.

While the use of cash as a means of payment has declined in recent years, it remains widely used as a store of value (Bayeh et al., 2024; Bech et al., 2018; Jiang and Shao, 2020; Khiaonarong and Humphrey, 2022; Zamora-Pérez, 2021).

A.1.2 Data Sources

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).

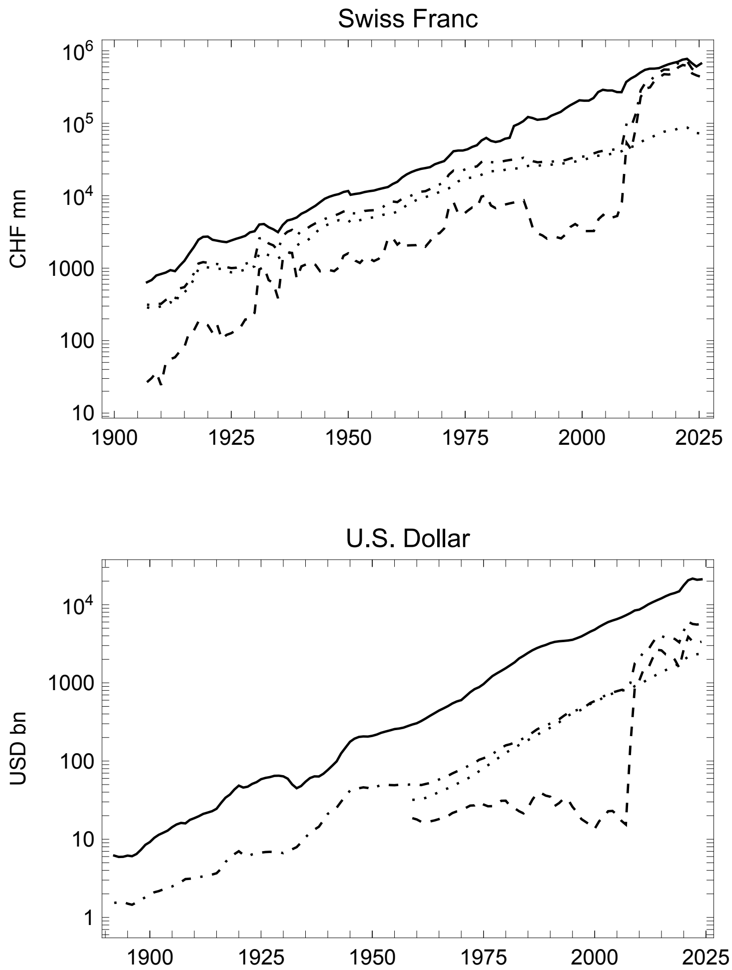

Figure A-1: Public and private money components, Swiss franc and U.S. dollar. The solid lines indicate M1 (Swiss franc) or M2 (U.S. dollar); the dot-dashed lines public money; the dotted lines cash in circulation; and the dashed lines reserves held by commercial banks at the central bank.

A.2 Gross Profits From Deposit-Taking

A.2.1 Bounds for U.S. Deposit-to-GDP Ratio times Deposit Spread

Figure A-2 shows bounds for the U.S. deposit-to-GDP ratio multiplied by the deposit spread, both on an annual basis. This quantity represents the interest income depositors forego by holding deposits rather than a risk-free but illiquid asset or, equivalently, the gross profit 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-19 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 profit. 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 gross profit increases.

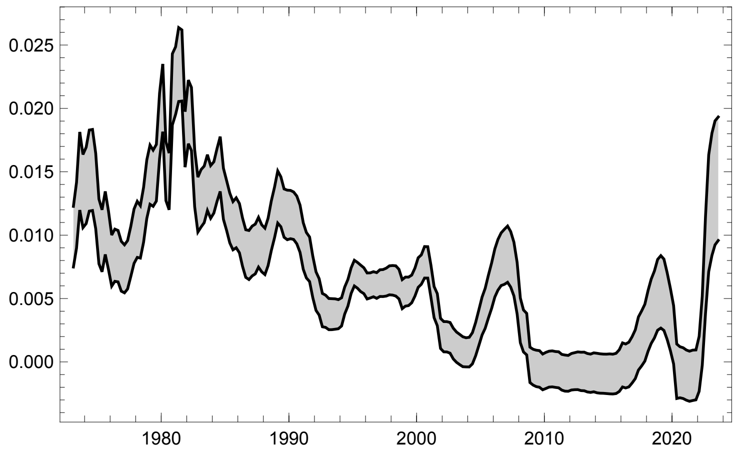

Figure A-2: Bounds for U.S. deposit-to-GDP ratio times deposit spread.

A.2.2 Data Sources

All data is measured at the quarterly frequency or aggregated from weekly or monthly data.

Figure A-3 illustrates alternative measures of the deposit-to-GDP ratio (annualized). We measure GDP based on the FRED series `GDP` (Gross Domestic Product, Billions of Dollars, Quarterly, Seasonally Adjusted Annual Rate). The solid line depicts the (normalized) FRED series `DPSACBW027SBOG` (Deposits, All Commercial Banks, Billions of U.S. Dollars, Quarterly, Seasonally Adjusted); we refer to this series as "long (FRED)." The dashed line depicts the (normalized) sum of the discontinued FRED series `TCDSL` (Total Checkable Deposits, Billions of Dollars, Quarterly, Seasonally Adjusted) and `SAVINGSL` (Savings Deposits: Total, Billions of Dollars, Quarterly, Seasonally Adjusted); we refer to this series as "short (FRED)." The dotted line depicts the series used in Nagel (2016) and also by Bianchi and Bigio (2022);[i] we refer to this series as "short (Nagel)."

Figures A-4 and A-5 illustrate alternative measures of annual gross interest rates that we use to construct measures of deposit spreads. The solid line in Figure A-4 depicts the FRED series `TB3MS` (3-Month Treasury Bill Secondary Market Rate, Discount Basis, Quarterly). The dashed line depicts the safe, illiquid benchmark rate used by Kurlat (2019), and the dotted and dot-dashed lines, respectively, depict the rates on savings and checking accounts constructed by Kurlat (2019).[ii] The solid line in Figure A-5 again depicts the FRED series `TB3MS`. The dashed and dotted lines, respectively, depict the benchmark and deposit rates used by Nagel (2016).[iii]

Figure A-6 illustrates alternative measures of the annual deposit spread. The solid line depicts the spread resulting from the Kurlat (2019) data where we construct the deposit rate as a weighted average of the rates on savings and checking accounts, using

[i]See `https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/KHNXYJ&version=1.1`, file `AggregateDataAndFigures.xlsx`; it represents the (normalized) sum of `savdep`, `timedepl100k` and `transdep`.

[ii]We thank Pablo Kurlat for providing the data.

[iii]See file `AggregateDataAndFigures.xlsx`, series `Deposit rate` and `Fed funds rate`.

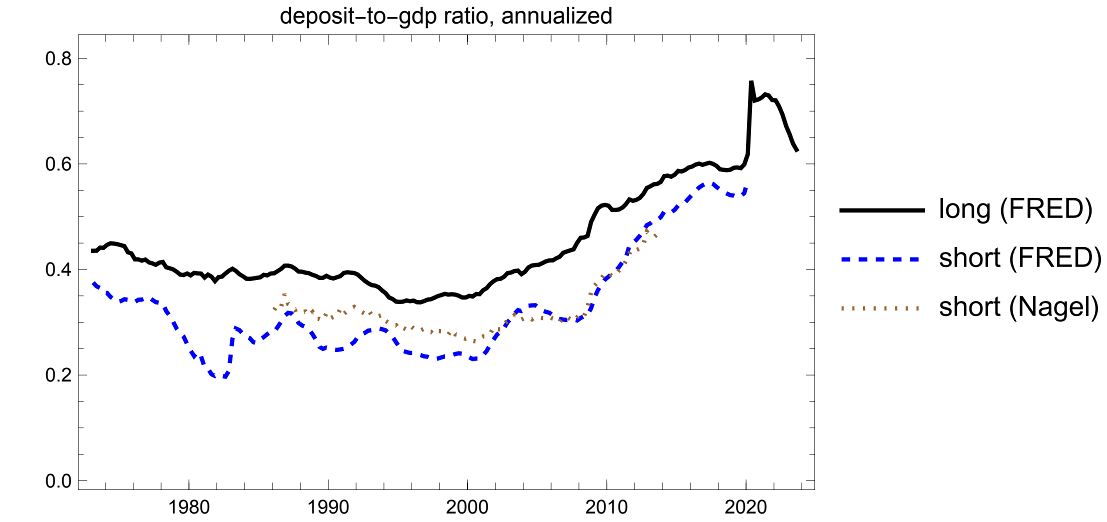

Figure A-3: Measures of the deposit-to-GDP ratio.

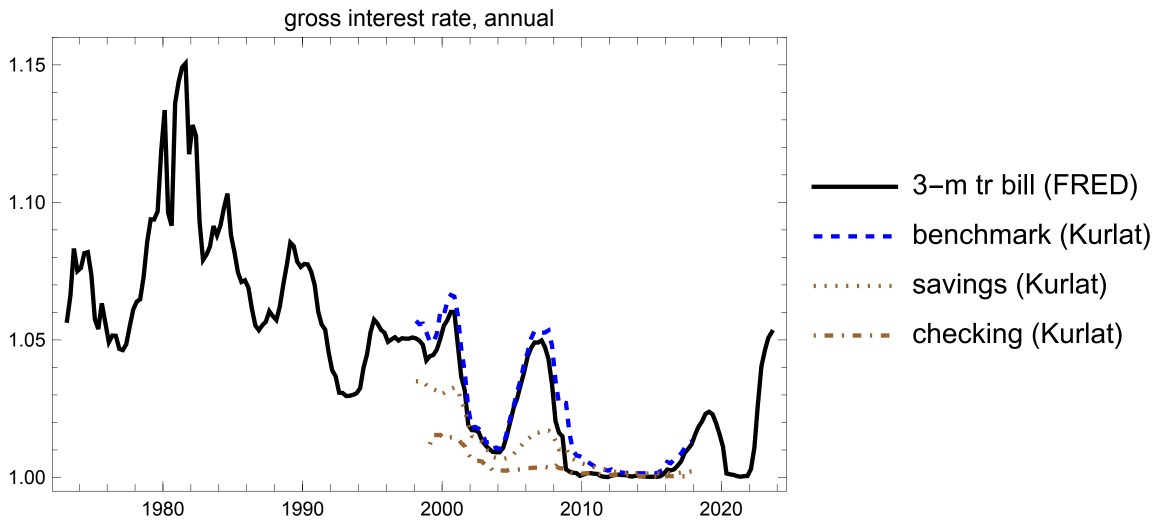

Figure A-4: Measures of gross interest rates.

the components of "short (FRED)" as weights. The dashed line depicts the spread that results from the Nagel (2016) data. For comparison, the figure also depicts the average spread estimated by Hanson et al. (2015, p. 453) and Van den Heuvel (2022, p. 34); these averages are represented by the (dash-)dotted lines whose lengths indicate the respective sample periods.

Figure A-7 illustrates alternative measures of the object of interest, the product of the annual deposit spread and the annualized deposit-to-GDP ratio. The solid line depicts the product computed based on the Kurlat spread and the "short (FRED)" deposit-to-GDP ratio. The dashed line depicts the product computed based on the Nagel spread and the "short (Nagel)" deposit-to-GDP ratio. The averages of these two series lie between 0.3 and 0.4 percent.

Since the latter two series are short and heavily influenced by the post-financial crisis

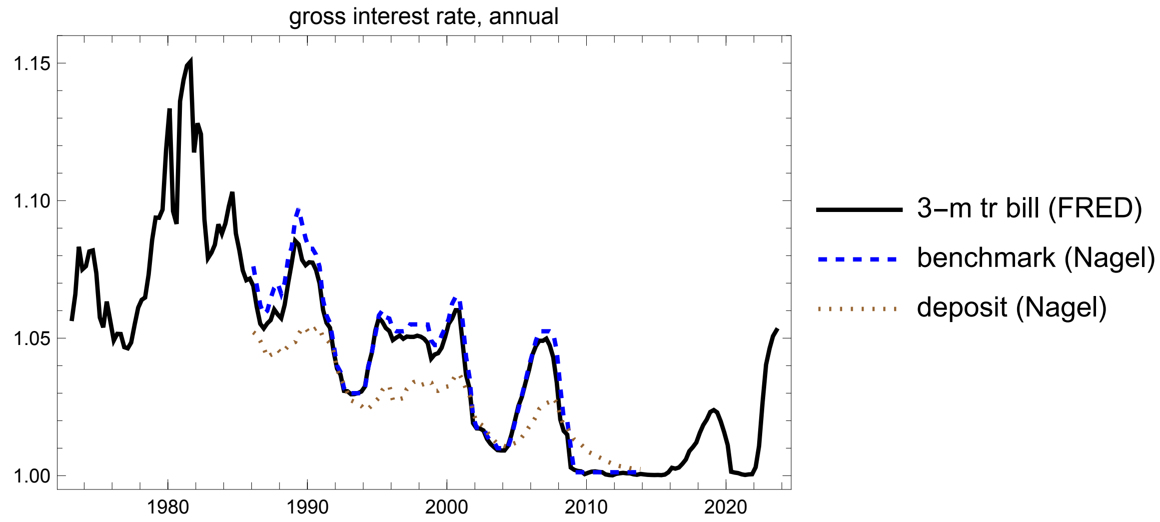

Figure A-5: Measures of gross interest rates.

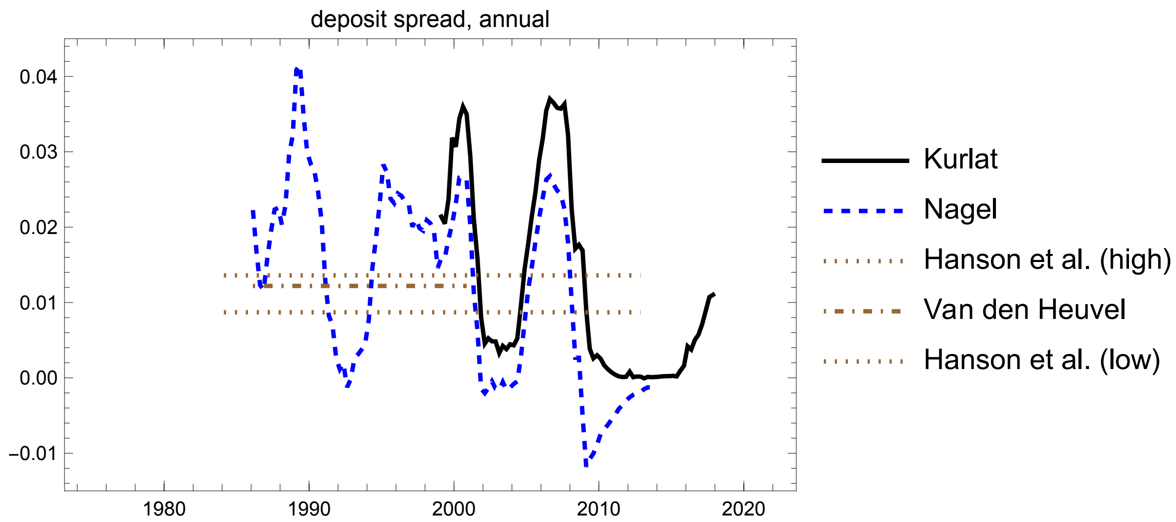

Figure A-6: Measures of the deposit spread.

period of very low interest rates we use the information from our other, longer series to extrapolate values of the object of interest. In particular, we regress both "short (FRED)" and "short (Nagel)" on "long (FRED)" and a constant, and we regress the deposit spread according to the Kurlat and Nagel data on `TB3MS` and a constant. Figures A-8–A-11 report for each of the four cases the actual (short) data series and the (longer) predicted series. Evidently, the simple specifications capture most of the relevant variation in the measured data.

The bounds shown in Figure A-2 are based on the products of the predicted series in Figures A-8 and A-10, on the one hand, and Figures A-9 and A-11, on the other. The upper bound series averages 0.85% of GDP, the lower bound series averages 0.48% of GDP, and the average of these two values is 0.67% of GDP.

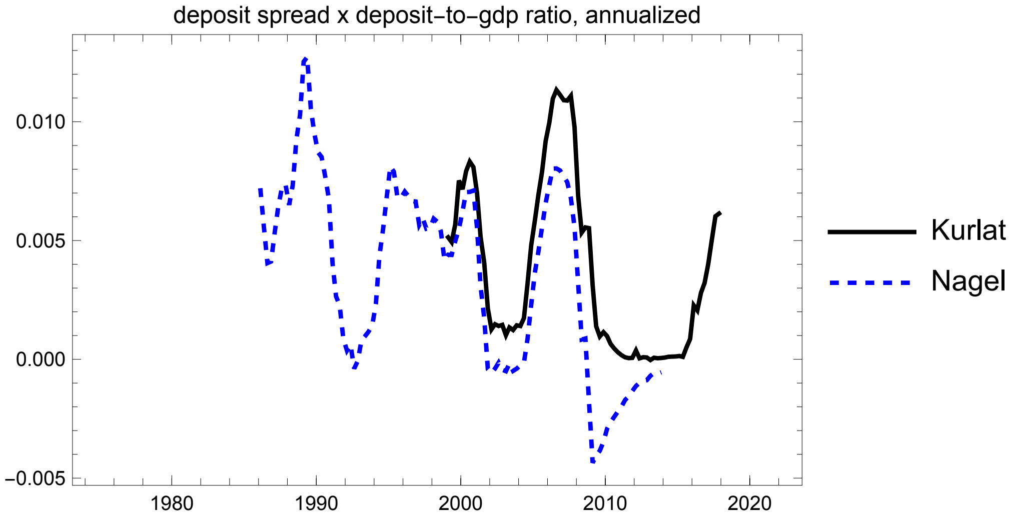

Figure A-7: Measures of the deposit spread times the deposit-to-GDP ratio.

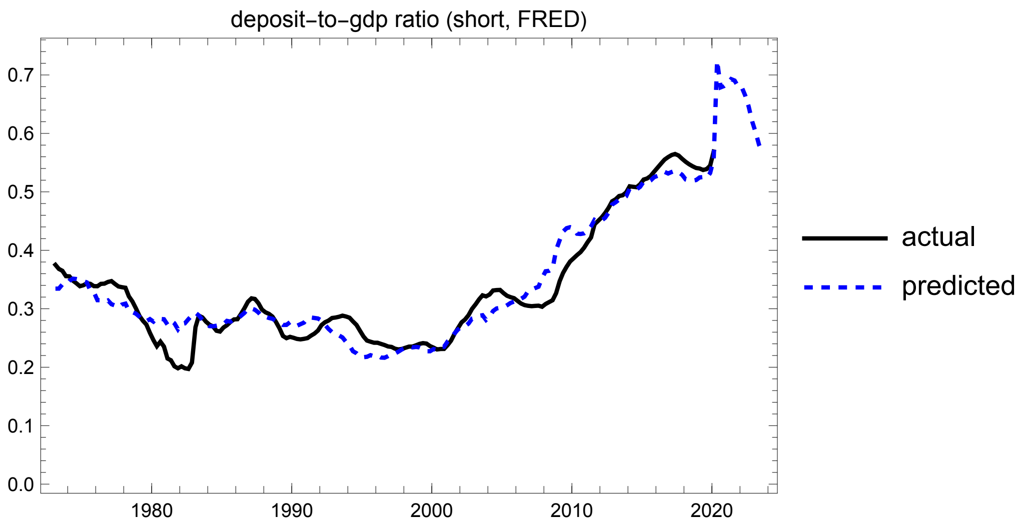

Figure A-8: Actual and predicted deposit-to-GDP ratio (short, FRED).

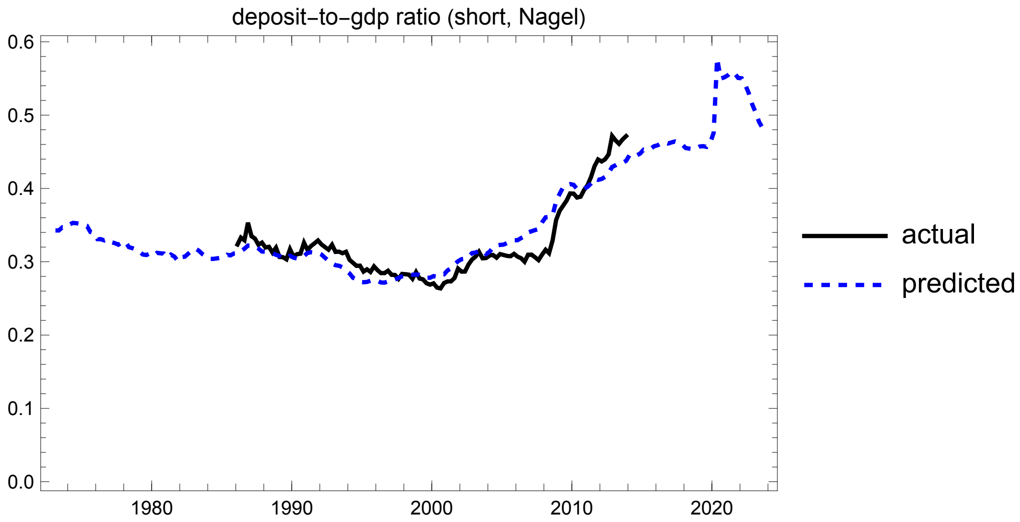

Figure A-9: Actual and predicted deposit-to-GDP ratio (short, Nagel).

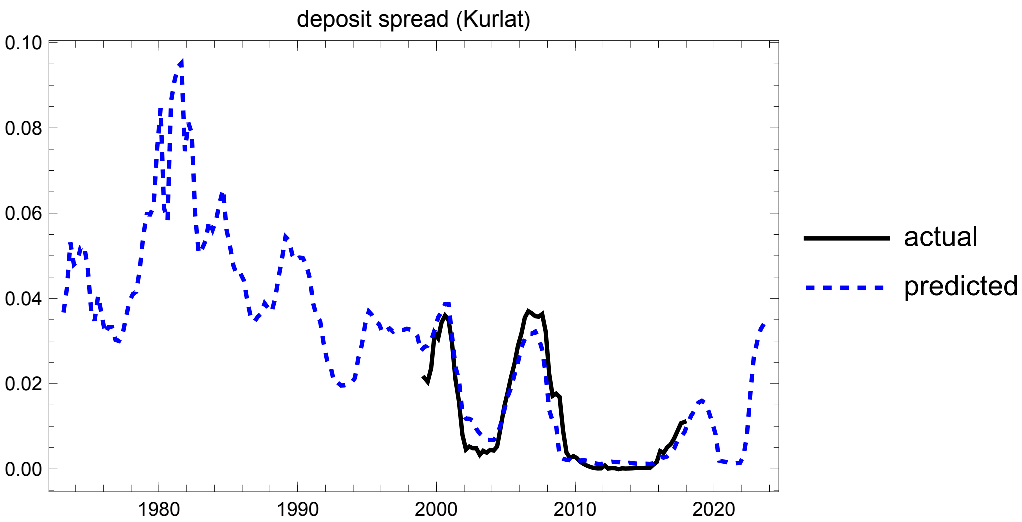

Figure A-10: Actual and predicted deposit spread (Kurlat).

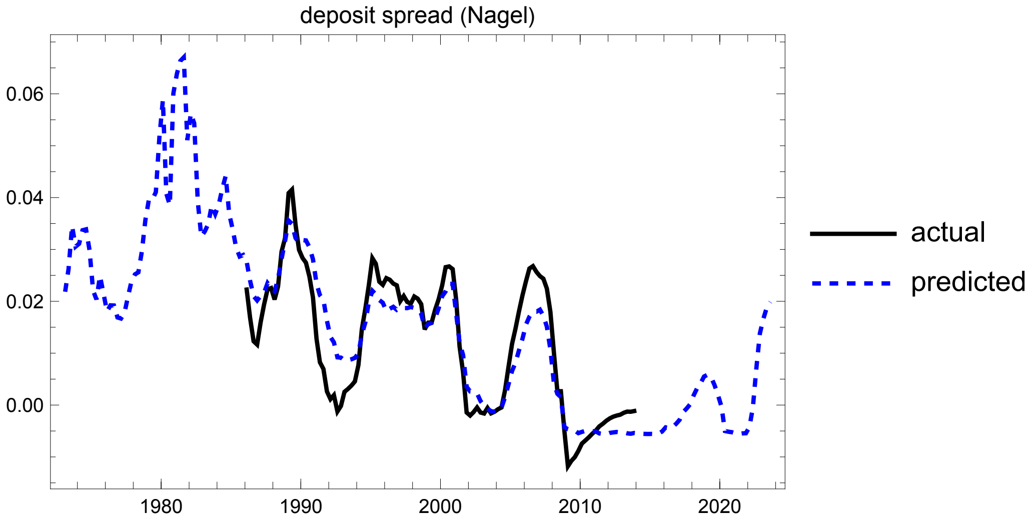

Figure A-11: Actual and predicted deposit spread (Nagel).

B Conceptual Framework: Formal Discussion

In this appendix, we formalize the discussion in Section 3. Conditions B-1 and B-2, Equations (B-1) and (B-8), and Theorem B-1 correspond to Conditions 1 and 2, Equations (2) and (1), and Theorem 1 in the main text, respectively.

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[iv]

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 $i \in I$.

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

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

The second condition addresses incentive compatibility:

Condition B-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 B-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 B-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 B-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

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

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 B-2 is satisfied.

Theorem B-1. Consider an initial equilibrium in history ϵ^t. A regime change satisfying Conditions B-1–B-2 is neutral.

Proof. From Conditions B-1 and B-2, private-sector agents are able and willing to follow the proposal given the changed states, and from Condition B-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. □

While the implications of Conditions B-1 and B-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, breaking 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 B-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 B-1 and B-2 applied to the budget constraints entail

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

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

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

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

Equation (B-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. According to Equation (B-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 breaking neutrality. For simplicity, we abstract from balance-sheet costs in period $t + 1$.

Equations (B-4) and (B-5) impose parallel restrictions on the bank's budget constraints. Equation (B-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 (B-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 (B-3) from Equation (B-2), and similarly Equation (B-5) from Equation (B-4), and taking expectations conditional on information in history ϵ^t yields

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

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

where we denote the equilibrium spread on generic asset x by $\sigma^{x*} \equiv 1 - \mathbb{E}[\mathrm{sdf}_+^* R_+^{x*}]$. As with Conditions (B-2)–(B-5), the implied Equations (B-6) and (B-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 (B-6)–(B-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 (B-6)–(B-7) and the parallel condition for the government therefore imply the neutrality requirement

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

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 B-1) also imply Condition (B-8), for each resource individually.

C Examples 1–2: Generalizations

In this appendix, we relax simplifying assumptions made in Examples 1 and 2. Unlike in the main text, we allow for transfers, $\Delta\tau^j, \{\Delta\tau_+^j\},\ j = i, b, g$. Transfer changes must sum to zero in each history.

C.1 Nonbank

This example generalizes Example 1 in the main text.

Example C-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. The household's Euler equations thus imply

$$\lambda(1 - \mathbb{E}[\text{sdf}_+^* R_+^{n*}]) = 1 - \mathbb{E}[\text{sdf}_+^* R_+^{m*}]. \tag{C-9}$$

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.[v]

We conclude that the restrictions

$$\left.\begin{aligned}
&\Delta m^i = -\lambda^{-1}\Delta n^i \\
&R_+^{m*} \text{ satisfies (C-9)} \\
&\Delta\tau^i = (1 - \lambda^{-1})\Delta n^i \\
&\Delta\tau_+^i = (R_+^{m*}/\lambda - R_+^{n*})\Delta n^i \quad \forall\epsilon^{t+1|t}
\end{aligned}\right\} \tag{C-10}$$

guarantee that the regime change satisfies the first part of Condition B-1 as well as the first part of Condition B-2 for the household. It also satisfies the second part of Condition B-2 because Equation (B-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 holds as far as the household is concerned.

Example C-1 clarifies that neutrality under $\lambda \neq 1$ requires transfers between the household and the government, $\Delta\tau^i \neq 0$. This is an implication of 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;[vi] with stochastic returns, the time-$(t+1)$ transfer generally must be stochastic as well.

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

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

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 C-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 characterized in Example C-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.[vii] 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 C-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 breaks neutrality when the altered financial wealth distribution affects the equilibrium allocation—but not otherwise. Neutrality prevails in spite of mis-matched return characteristics when the nonbank is the taxpayer, or is owned by the taxpayer. The key point is that ownership linkages can substitute for contingent transfers.[viii]

C.2 Bank

This example generalizes Example 2 in the main text.

Example C-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

[vii] 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.

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

shrinks. 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:

$$\zeta^* = \arg\min_{\zeta} n^b\{\alpha(\zeta) + \zeta\mathbb{E}[\mathrm{sdf}^*_+(R^{b*}_+ - R^{r*}_+)]\},$$

where R^{b*}_+ denotes interest on loans.

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 $-R^{n*}_+ - (1-\zeta^*)\beta - (n^b + \ell^b/(1-\zeta^*))\partial R^{n*}_+/\partial n^b$.[ix] Indifference thus requires

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

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

$$\left.\begin{aligned}
&\Delta r^b = \zeta^*\Delta n^b\\
&\Delta\ell^b = -(1-\zeta^*)\Delta n^b\\
&R^{\ell*}_+ = R^{n*}_+/(1-\zeta^*) + \beta \quad \forall\epsilon^{t+1|t}\\
&\Delta\tau^b = \alpha(\zeta^*)\Delta n^b\\
&\Delta\tau^b_+ = -(R^{r*}_+\zeta^* + \beta(1-\zeta^*))\Delta n^b \quad \forall\epsilon^{t+1|t}\\
&\text{with}\quad \beta = (\alpha(\zeta^*) - \zeta^*\mathbb{E}[\mathrm{sdf}^*_+ R^{r*}_+])/((1-\zeta^*)\mathbb{E}[\mathrm{sdf}^*_+])
\end{aligned}\right\} \tag{C-11}$$

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

satisfies the first part of Condition B-1 for the bank.[x] It also satisfies Condition B-2 for the bank as long as the changes do not alter the value of the bank's objective function for reasons unrelated to cash flows and liquidity. This follows, again, because Equation (B-1) applies: conditional on the changed transfers and the central bank's loan supply schedule, the modified balance sheet positions in (C-11) 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 to it.

[x] If R^{r*}_+ is deterministic, the fourth line reduces to $\Delta\tau^b_+ = -\alpha(\zeta^*)\Delta n^b/\mathbb{E}[\mathrm{sdf}^*_+]$.

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