Implications of Financial Architecture Change

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Abstract

We analyze change in the financial architecture due to retail CBDC and new private currencies. We derive conditions for "neutral" change without effect on the allocation or the price system, and we identify causes of nonneutrality related to payment preferences; fiscal instruments; technology; deposit complementarities; political frictions; and the mode of liquidity injection. Effects of private currencies are harder to offset than of CBDC. Our analysis provides a unifying perspective on CBDC models. It values central bank lender-of-last-resort guarantees for banks at 0.25% of GDP for the U.S.

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1 Introduction

The financial architecture faces seismic shifts. New private currencies make inroads into payment systems that have traditionally been dominated by public-private partnerships of monetary authorities and commercial banks built on national currencies. These partnerships are subject to change as well. With the advent of retail central bank digital currency (CBDC) or "reserves for all," financial intermediation and payments decouple and bank business models are put to the test.

How wide-ranging will the macroeconomic implications of this regime change be? An emerging literature, discussed below, offers first insights and points to important roles of policy and various elements in the economic environment. It leaves open, however, how these specific elements relate to each other and how fundamental they are.

The aim of this paper is to provide a general, unifying perspective on the ongoing regime change and to identify key factors that determine its macroeconomic implications.[1] Rather than examining specific setups to obtain model specific conclusions we ask under what conditions regime change generally leaves the allocation and the price system unaffected, and we use the answer to identify fundamental factors that break neutrality and make the change have material effects. Against this background we discuss models in the literature and we apply our theoretical results to gauge the market value of implicit lender-of-last-resort guarantees in contemporary financial architecture.

We begin the analysis by laying out an abstract monetary economy that nests a large set of models, including prominent ones in the literature. Our setup allows for many sectors, complex frictions, and rich heterogeneity. It accommodates multiple financial intermediaries, general sources of supply and demand for liquidity as well as arbitrary regulatory constraints or information limitations that can give rise to financial constraints or a "bank lending channel." We do not impose functional form assumptions on preferences, technology or other primitives; rather than optimality conditions, the analysis emphasizes choice sets of agents.

Within this general setup, we identify conditions under which a regime change—a change of financial architecture—is neutral. We define a regime change as an internally consistent change of balance sheet positions in the private and public sectors, potentially accompanied by transfers. And we define such a change to be neutral if it does not alter the equilibrium allocation or price system. Our neutrality conditions ensure that the regime change does not alter the effective choice sets of agents. This implies that except for balance sheet positions and transfers the equilibrium objects do not change either.

Following this abstract analysis, we interpret the neutrality conditions in the CBDC context. We show that depending on the return characteristics of deposits and CBDC the preservation of budget sets may require contingent transfers whose present value equals zero for each agent. We also show that the wealth distribution and the private sector's liquidity holdings must not change if neutrality is to be guaranteed. Intuitively, and in line with Brunnermeier and Niepelt (2019), changes in the wealth distribution alter choice sets

[1] Another ongoing regime change concerns the replacement of cash by (private) digital payment instruments. The two developments are conceptually independent although cash substitution motivates some central banks to pursue deposit-CBDC substitution.

(and thus choices) and unchanged wealth levels at unchanged prices demand unchanged liquidity holdings. Both nonlinear aggregation of liquidity services and nonadmissibility of wealth-neutral transfers can break neutrality.

We identify four additional fundamental factors that undermine neutrality in the CBDC context. They relate to the marginal rate of transformation between different sources of liquidity; deposit-specific complementarities; the mode of CBDC injection; and state variables. Either of these four factors compromises the key adjustment mechanism to render a regime change neutral, which operates by seamlessly re-channeling CBDC funds back to banks experiencing deposit outflows.

First, neutrality cannot be ensured if the marginal rate of transformation between liquidity from CBDC and deposits (or other sources of liquidity that CBDC replaces) differs from unity. Intuitively, when the aggregate resource requirements of CBDC and deposit based liquidity provision differ neutrality must fail. We relate this restriction to models of CBDC and bank operating or balance sheet costs (Piazzesi and Schneider, 2022; Niepelt, 2024) as well as of CBDC and the interbank market (Abad et al., 2023; Lamersdorf et al., 2023).

Second, neutrality may fail when deposits are "special" in the sense that they feature complementarities with other bank balance sheet positions that alternative sources of funding do not feature. Such a situation could result due to liquidity regulation or differential monitoring incentives. It could also arise if deposit funding required less collateral than other sources of bank funding, for instance because the central bank insisted on collateral when lending to banks. We discuss why this latter point, which is often made in the policy debate, raises deeper questions.

We also point out that incentive constraints and collateral requirements in the banking sector do not *per se* undermine neutrality even if the central bank does not face them to the same extent, as in Williamson (2022).[2] After all, such frictions in the banking sector do not prevent the central bank from channelling CBDC funds back to the constrained financial institutions. Similarly, the empirical fact that deposit funding reduces financing costs and improves hedging (e.g., Whited et al., 2023) does not imply specialness when an appropriately structured central bank loan can mimic these properties.

Third, the mode of CBDC injection matters. Intuitively, CBDC injected by transfer, as in Keister and Sanches (2023) or Chiu et al. (2023), or by quantitative-easing type swaps of government bonds against CBDC, as in Kumhof and Noone (2021) or Barrdear and Kumhof (2022), increase the supply of liquidity. To balance supply and demand the price of liquidity services falls (or other prices adjust) and this undermines neutrality. In contrast, injections that maintain the supply of liquidity to nonbanks, for example in the form of deposit-CBDC substitution, can be neutral.[3]

Finally, we turn to sources of nonneutrality related to sequential policy making. To do so, we need to broaden our definition of equilibrium. Policies now are endogenous rather than exogenous objects; sets of admissible policy choices over time replace policies as model primitives; and there is the additional equilibrium requirement that policies

[2]See also Böser and Gersbach (2020).

[3]Injections also are neutral if CBDC replaces cash and the private sector views both central bank liabilities as perfect substitutes. Banks are not affected in this trivial scenario, which we disregard.

must be ex-post incentive compatible, i.e., time consistent (Gonzalez-Eiras and Niepelt, 2015). As a consequence, the conditions for neutrality transcend Conditions 1–3 and imply restrictions on state variables that affect ex-post incentives. Intuitively, policy makers (re-)optimize differently after a regime change that alters political state variables (such as central bank balance sheet length) even if these variables are irrelevant ex ante. We relate this source of nonneutrality to discussions about the political consequences of CBDC (Tucker, 2017; Cecchetti and Schoenholtz, 2018).[4]

In stark contrast to these fundamental sources of nonneutrality many other frictions need *not* undermine neutrality. We show, for example, that lack of competition in the banking sector, a two-tier monetary architecture with both reserves and bank money, or costs and benefits of maturity transformation are perfectly compatible with neutral regime change. In fact, a regime change may even be neutral when deposit and CBDC services generate resource costs (subject to the condition on the marginal rate of transformation) or if bank and central bank balance sheet length or central bank pass-through funding produce social costs.

These findings qualify frequent suggestions in the policy debate according to which the introduction of CBDC would have major (positive or negative) macroeconomic consequences. As our results show, it is very much in the hands of policy makers to choose whether CBDC has such wide ranging effects. And as they also show, some of the implications occasionally attributed to CBDC actually follow from orthogonal model assumptions.

We emphasize the implications of these findings for the possibility of Pareto improving regime change. When the neutrality conditions are satisfied a strict Pareto improvement is feasible as long as the intervention strictly enlarges the effective choice set of policy makers or if the initial equilibrium lies inside the Pareto frontier. When the conditions are not satisfied a Pareto improving regime change still is possible as long as CBDC requires fewer resources or relaxes other equilibrium constraints. We also discuss how strongly the neutrality baseline hinges on direct central bank refinancing of banks as opposed to bank funding obtained from other sources.

Next, we turn to new private currencies or "cryptocurrencies." We argue that the CBDC analysis applies largely unchanged with one important exception: The incentives of a private currency issuer introduce additional constraints on the set of implementable equilibria after a regime change. Conditional on the other sources of nonneutrality this makes it more difficult to offset the effects of a private currency than of CBDC. A competitively issued stablecoin subject to no operating costs and *no inherent* liquidity benefits constitutes the very special case of a cryptocurrency that *can* satisfy the conditions for neutrality. We also discuss the introduction of bubbly, unbacked crypto assets. Following Tirole (1985) we argue that such bubbly assets cannot generate liquidity benefits and that their introduction materially changes the equilibrium.

Finally, we exploit our neutrality conditions to gauge the value of central-bank lender-of-last-resort guarantees in contemporary financial architecture. We rely on the fact that the status quo can be mapped into an architecture with central bank funding of banks at

[4]See also Keister and Monnet (2022) and Niepelt (2020, 2021).

favorable terms: Rather than issuing deposits (possibly exerting market power), partly investing them in reserves and running a costly deposit franchise banks could borrow from the central bank. The effective choice set of banks would remain unaltered as long as the central bank posted a loan supply schedule commensurate to the deposit funding schedule under the status quo, controlling for operating costs, reserve holdings, and interest on reserves. We argue that the difference between funding at market rates and central bank funding at the deposit mimicking rate determines the effective liquidity rent on bank deposits in general equilibrium and thus, implicitly, the value of the central bank's lender-of-last-resort guarantee for banks. Relying on recent literature on liquidity premia we estimate a time series for this value for the U.S. and find that it averages a quarter percent of GDP.

Related Literature. Our approach to establishing sufficient conditions for neutral regime change by comparing choice sets follows Gonzalez-Eiras and Niepelt (2015) and Brunnermeier and Niepelt (2019) as well as a classic literature on equivalence results including Modigliani and Miller (1958), Barro (1974), Wallace (1981), Bryant (1983), Chamley and Polemarchakis (1984), and Sargent (1987, 5.4). We show how the equivalence perspective can be applied in the context of financial architecture change and how it allows to identify potential sources of nonneutrality, and we use it to gauge the value of central-bank lender-of-last-resort guarantees for commercial banks.

The growing literature on the macroeconomic implications of CBDC and private cryptocurrencies contains many contributions in addition to the papers already cited. For example, in Andolfatto (2021) the introduction of CBDC leads noncompetitive banks to raise the deposit rate, with positive effects on financial inclusion although CBDC does not circulate in equilibrium.[5] Burlon et al. (2022) conduct a quantitative DSGE analysis in a model with CBDC that contains several of the sources of nonneutrality discussed above. Schilling et al. (2020) analyze conflicts between allocative efficiency, price stability, and financial stability that are present in monetary economies including a CBDC based system. Design options for CBDC are the focus of Kahn et al. (2018), Bindseil (2020), and Auer and Böhme (2020), among others. Garratt and van Oordt (2021) analyze the disciplining effect of CBDC on agents that exploit consumer information.

Our empirical analysis of the value of lender-of-last-resort guarantees connects to the recent literature on liquidity premia including Hanson et al. (2015), Nagel (2016), Kurlat (2019), Van den Heuvel (2022), and Bianchi and Bigio (2022).

Structure. Section 2 develops the general neutrality conditions. In Section 3 we apply these conditions in the context of CBDC and we relate our findings to the literature; we also discuss normative aspects and the role of central bank pass-through funding. Section 5 contains the parallel discussion of private cryptocurrencies. In Section 6 we compute the value of lender-of-last-resort guarantees. Section 7 concludes.

[5] For a qualification of this result, see Niepelt (2024).

2 Neutral Regime Change

In this section, we introduce an abstract economy and its equilibrium and we establish sufficient conditions for neutral regime change. In subsequent sections, we apply the conditions in the context of CBDC and private cryptocurrencies.

2.1 Economy

We consider an economy with private sector agents, indexed by $i \in I$; and a government, denoted g. Private sector agents may reside abroad. Preferences, technologies, and other primitives may be subject to exogenous shocks. Time is discrete and indexed by t; histories of shocks up to and including t are indexed by ϵ^t.

We allow for arbitrary assets. We also allow for arbitrary commodities in the usual sense, but since asset positions may enter objectives or affect choice sets in general ways (not only via budget sets)[6], we avoid the term "commodity" altogether and use the term "allocation" to include asset positions.

Choices, Constraints, and Objectives. Private sector agents and the government make *choices* across histories. For example, the private sector may choose consumption or portfolios and the government public consumption, central bank balance sheet positions, or tax functions. We denote i's or g's choice by c^i or c^g, respectively; c^g is the *policy*.

Private sector agents and the government face *factors* beyond their control, which we denote by f^i and f^g, respectively. The former could include prices (if i is a price taker) or supply and demand functions (if i has market power), and the latter the equilibrium relationship between labor supply and the tax rate on labor income. The economy is also subject to an exogenous factor, f^e, representing for instance endowments or the initial distribution of asset holdings; f^e may be contained in f^g or $f^i, i \in I$.

Private sector agents and the government are subject to *individual constraints*, e.g., dynamic budget constraints, no-Ponzi game conditions, technological constraints, or regulatory constraints. We represent i's individual constraints as $C^{i,s}(c^i, f^i) \leq 0, s = 1, 2, \ldots$, and the government's individual constraints as $C^{g,s}(c^g, f^g) \leq 0, s = 1, 2, \ldots$; C denotes the set of all individual constraints. Moreover, the economy faces *aggregate constraints*, A, e.g., market clearing conditions.[7] Letting c denote the union of all choices and f the union of all factors, we represent aggregate constraints as $A^s(c, f) \leq 0, s = 1, 2, \ldots$,

The *choice set* of i is $\mathcal{C}^i(f^i) \equiv \{c^i | C^{i,s}(c^i, f^i) \leq 0, s = 1, 2, \ldots\}$, and similarly $\mathcal{C}^g(f^g) \equiv \{c^g | C^{g,s}(c^g, f^g) \leq 0, s = 1, 2, \ldots\}$ for the government. The aggregate choice set is $\mathcal{A}(f) \equiv$

[6] For example, asset positions may enter objectives when households and firms "like" liquidity as in Sidrauski (1967); they may enter constraints through "payment-in-advance" constraints as in Clower (1967); or they may enter cost functions when acquiring balances requires resources as in Baumol (1952) and Tobin (1956).

[7] Another example of an aggregate constraint are economy wide productivity effects of investment choices as in Romer (1986). The distinction between aggregate and government individual constraints does not imply that the government can disregard the former. A Ramsey government takes both types of constraints into account.

$\{c|A^s(c,f) \leq 0, s = 1,2,\ldots\}$. Finally, each private sector agent has an *objective*, which we denote by U^i, a function of (c^i, f^i). We denote by U the set of all objectives.

Equilibrium. An *equilibrium* conditional on f^e and c^g, $\mathcal{E}(f^e, c^g)$, is a collection $(\{c^i, f^i\}_{i\in I}, f^g, f)$ such that $c^g \in \mathcal{C}^g(f^g)$; $c \in \mathcal{A}(f)$; and for all $i \in I$, c^i maximizes $U^i(\cdot, f^i)$ subject to $c^i \in \mathcal{C}^i(f^i)$.[8] Note that f, f^g, and $f^i, i \in I$, are mechanically implied by f^e and c.

The competitive equilibrium in a production economy without government constitutes a simple example. The exogenous factor f^e then contains endowments; equilibrium prices are elements of $f^i, i \in I$; demands and supplies are elements of c^i and satisfy $\mathcal{C}^i$ and $\mathcal{A}$; and $c^g = \mathcal{C}^g = \emptyset$.

2.2 Regime Change

Starting from some initial equilibrium $\mathcal{E}(f^e, c^{g*}) = (\{c^{i*}, f^{i*}\}_{i\in I}, f^{g*}, f^*)$, we consider a *regime change*, which consists of a policy change and a proposed change of allocation or "proposal."

Let Δc^g denote the policy change, which gives rise to the new policy $c^{g*} + \Delta c^g$. (In this abstract economy, the plus sign has the meaning of "modified by;" in our subsequent applications, a policy change will mostly amount to a change of scalars allowing for a literal interpretation of the plus sign.) Similarly, let Δc^i denote the change of i's choice as implied by the proposal, which gives rise to the new choice $c^{i*} + \Delta c^i$. If the government changes policy and all other agents follow the proposal, i's factor changes to $f^{i*} + \Delta f^i$, the government's factor changes to $f^{g*} + \Delta f^g$, and the aggregate factor changes to $f^* + \Delta f$.

2.3 Neutrality

We are interested in sufficient conditions under which the regime change is consistent with a new equilibrium that is identical to the initial equilibrium except for the proposed change of allocation.[9] In other words, we are interested in sufficient conditions for a *neutral* (except for the proposal) regime change.

A first condition for neutral regime change is obvious:

Condition 1. $c^{g*} + \Delta c^g \in \mathcal{C}^g(f^{g*} + \Delta f^g)$; and $c^{i*} + \Delta c^i \in \mathcal{C}^i(f^{i*} + \Delta f^i)$ for all $i \in I$.

Condition 1 stipulates that it is individually feasible for the government to choose $c^{g*} + \Delta c^g$ when it faces $f^{g*} + \Delta f^g$, and similarly that it is individually feasible for any private sector agent to follow the proposal conditional on its modified factor. While Condition 1 is necessary for the regime change to be implementable it is not sufficient (even abstracting from aggregate constraints for now) because it does not guarantee that private sector agents want to follow the proposal. We could directly impose such a condition, but checking whether it is met in a particular application would require information that we do not generally have without solving the full model. We therefore impose a more tractable condition on choice sets and objectives:

[8] The equilibrium may not be unique.

[9] Recall that we use the term "allocation" to include asset positions.

Condition 2. $c^i \in \mathcal{C}^i(f^{i*})$ implies $U^i(c^i, f^{i*}) = U^i(c^i + \Delta c^i, f^{i*} + \Delta f^i)$ for all $i \in I$. Moreover, $\tilde{c}^i \in \mathcal{C}^i(f^{i*} + \Delta f^i)$ implies $\tilde{c}^i - \Delta c^i \in \mathcal{C}^i(f^{i*})$ for all $i \in I$.

The first part of Condition 2 stipulates that starting from any individually feasible choice of a private sector agent in the environment before the regime change, modifying the agent's choice and factor according to the regime change does not alter the value of the agent's objective. The second part asserts that every individually feasible choice in the environment after the regime change is identical to a feasible choice in the environment before the regime change, modified by the proposal's Δc^i. In combination, the two parts imply that in the environment after the regime change, the proposal is incentive compatible.[10]

While Condition 1 ensures that private sector agents can follow the proposal, Condition 2 guarantees that they choose to do so. For general environments (sufficiency), this requires the condition to be rather strong, but specific applications may allow for a substantial relaxation. For example, if neither Δf^i nor Δc^i directly enters i's objective function (for all $i \in I$), then the first part of Condition 2 is satisfied. Or, if the proposal exactly undoes the effect of the changed environment on i's choice set, i.e., if

$$\mathcal{C}^i(f^{i*}) = \{c^i | C^{i,s}(c^i + \Delta c^i, f^i + \Delta f^i) \leq 0, s = 1, 2, \ldots\}, \tag{1}$$

then it follows that $c^i + \Delta c^i \in \mathcal{C}^i(f^{i*} + \Delta f^i) \Rightarrow c^i \in \mathcal{C}^i(f^{i*})$ such that the second part of Condition 2 is satisfied.[11] We will use this fact below.

The last condition we impose guarantees that the regime change is feasible at the aggregate level:

Condition 3. $c^* + \Delta c \in \mathcal{A}(f^* + \Delta f)$.

It is violated, for example, if a regime change conflicts with market clearing conditions. Note that the condition parallels Condition 1; we do not need to impose a condition parallel to Condition 2 because aggregate constraints do not enter private sector agent programs. We then have the following result:

Theorem 1. Consider an equilibrium conditional on f^e and c^{g*}. A regime change satisfying Conditions 1–3 is neutral except for the proposed change of allocation.

Proof. From Condition 1, $c^{g*} + \Delta c^g$ satisfies the government's individual constraints. From Conditions 1 and 2, private sector agents are able to and want to follow the proposal. From Condition 3, the regime change satisfies aggregate constraints. We conclude that the regime change is consistent with an equilibrium that is identical to the initial equilibrium except for the proposed change of allocation. □

[10] Suppose there exists an individually feasible and preferred $\tilde{c}^i \neq c^{i*} + \Delta c^i$, such that $U^i(\tilde{c}^i, f^{i*} + \Delta f^i) > U^i(c^{i*} + \Delta c^i, f^{i*} + \Delta f^i)$. The condition implies $\tilde{c}^i - \Delta c^i \in \mathcal{C}^i(f^{i*})$, $U^i(\tilde{c}^i - \Delta c^i, f^{i*}) = U^i(\tilde{c}^i, f^{i*} + \Delta f^i)$, and $U^i(c^{i*}, f^{i*}) = U^i(c^{i*} + \Delta c^i, f^{i*} + \Delta f^i)$. Since the agent chose c^{i*}, we have $U^i(c^{i*} + \Delta c^i, f^{i*} + \Delta f^i) = U^i(c^{i*}, f^{i*}) \geq U^i(\tilde{c}^i - \Delta c^i, f^{i*}) = U^i(\tilde{c}^i, f^{i*} + \Delta f^i)$. We have established a contradiction.

[11] The second part of Condition 1 is satisfied as well in this case.

3 CBDC

We now apply Conditions 1–3 in the context of a regime change that involves the introduction of CBDC.

3.1 Economy

The economy is as described in Section 2. The set of private sector agents includes (possibly heterogeneous) households, firms, and banks, that may reside abroad. The consolidated government consists of a central bank and a fiscal authority.

3.2 Regime Change

Without loss of generality we focus on a regime change in history ϵ^t and its immediate successor histories, $\{\epsilon^{t+1|t}\}$. Also without loss of generality, we assume that the regime change affects at most a single bank, $b \in I$, in addition to the government, g, as well as a nonbank, $i \in I$. The extension to multiple histories and multiple banks or nonbanks is immediate.

Recall that the regime change involves a policy change, Δc^g, and proposals for private sector changes, $\Delta c^i, \Delta c^b$, which in turn give rise to changed factors, $\Delta f^i, \Delta f^b, \Delta f^g, \Delta f$. We restrict the policy change to affect reserve and CBDC issuance by the central bank; central bank lending to the bank; and lump-sum transfers between the government and private sector agents. As we will see, transfers may not always be needed.

The proposed changes of allocation in the private sector are restricted to balance sheet adjustments, namely changes in deposits (issued by the bank and held by the nonbank); the bank's reserve holdings and borrowing from the central bank; and the nonbank's CBDC holdings.

Formally, letting τ denote transfers and n, r, m, ℓ positions in deposits, reserves, CBDC, and the central bank loan, respectively, the policy change is given by

$$\begin{aligned}
&\Delta m^g(\epsilon^t), \Delta r^g(\epsilon^t), \Delta \ell^g(\epsilon^t),\\
&\Delta \tau^j(\epsilon^t), \{\Delta \tau^j(\epsilon^{t+1|t})\},\ j = i, b,\\
&\Delta \tau^g(\epsilon^t), \{\Delta \tau^g(\epsilon^{t+1|t})\}.
\end{aligned}$$

The first line represents the modified CBDC and reserve issuance as well as the loan to the bank, respectively. The second line represents the changes in lump-sum transfers that the nonbank and the bank receive in history ϵ^t and the immediate successor histories. The last line represents changes in lump-sum transfer payments to the government. In turn, the proposed balance sheet adjustments in the private sector are given by

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

where the first line represents the increase in the nonbank's exposure to deposits and CBDC, and the second line represents changes in the bank's deposit and central bank

loan liabilities as well as reserve holdings, respectively.[12]

Note that a regime change does not allow for any other balance sheet adjustments including physical capital positions or the bank's loan book. An admissible regime change thus is robust to arbitrary frictions that give a role to the ownership structure of capital, and it is similarly robust to arbitrary forms of a "bank lending channel" that renders the allocation dependent on bank loans (Bernanke and Blinder, 1988). More generally, the regime change does not alter any element of the allocation other than the affected balance sheet positions, nor does it affect the price system.

Two further remarks are in order. First, the change in the central bank loan to banks, represented by $\Delta\ell^g(\epsilon^t)$ and $\Delta\ell^b(\epsilon^t)$, may be interpreted more broadly. Rather than having the central bank extend a loan to the bank, the central bank could extend the same loan to a third party as long as this party passes the funds on to the bank at unchanged terms. The latter condition is a strong one because it is a priori unclear whether the third party would be willing to engage in such a transaction.

Second, we have framed the regime change as the "introduction" of CBDC, while the policy change we actually model amounts to a quantity change of the CBDC in circulation. This raises the question whether the introduction of CBDC amounts to the same as an increase in its quantity from zero. This is indeed the case if CBDC is a redundant asset—which we assume from now on.

We impose from the outset that the regime change satisfies asset market clearing (encoded in A). That is, the change in the bank's deposit liabilities equals the total change in households' and firms' deposit holdings, $\Delta n^b(\epsilon^t) = \Delta n^i(\epsilon^t)$; ditto for CBDC, $\Delta m^g(\epsilon^t) = \Delta m^i(\epsilon^t)$; and reserve as well as loan changes in the balance sheets of the bank and the central bank match, $\Delta r^g(\epsilon^t) = \Delta r^b(\epsilon^t)$ and $\Delta\ell^g(\epsilon^t) = \Delta\ell^b(\epsilon^t)$. Moreover, transfer changes must sum to zero in each history.

3.3 Conditions 1 and 2

For Condition 1 to be satisfied, the policy change and the proposed change of balance sheet positions must have offsetting effects on budget constraints (at unchanged prices) in the histories of the regime change; otherwise, the other elements of the allocation as well as prices could not remain unchanged in the new equilibrium. Formally, denoting equilibrium gross rates of return on a generic asset x by $R^{x*}(\epsilon^{t+1|t})$, neutrality entails

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

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

$$\Delta r^b(\epsilon^t) + \Delta\varphi^b(\epsilon^t) = \sum_{x=\ell,n} \Delta x^b(\epsilon^t) + \Delta\tau^b_t(\epsilon^t), \tag{4}$$

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

[12] The changes in policy as well as the proposed changes in balance sheet positions are scalars. Accordingly, we can interpret the plus sign in $c^{i*} + \Delta c^i$ etc. literally.

Equation (2) states that the change in transfers to nonbank i in history ϵ^t equals the contemporaneous changes in the agent's deposit and CBDC exposures as well as increased flow costs, $\Delta\varphi^i(\epsilon^t)$. The latter are functions of balance sheet positions and arise, for example, if i bears costs to manage the positions. According to Equation (3), the financial payoff implications of the balance sheet changes in the immediate successor histories must be offset by transfer changes such that the regime change does not affect outcomes subsequently.[13]

Equations (4) and (5) impose parallel restrictions for reserves, deposits, and the central bank loan that derive from the bank's budget constraint. Since transfers add to zero in each history, Equations (2)–(5) imply that the government budget constraints are satisfied as well if and only if the change of flow costs borne by the government, $\Delta\varphi^g(\epsilon^t)$, balances the summed changes borne in the private sector,

$$\Delta\varphi^g(\epsilon^t) + \Delta\varphi^i(\epsilon^t) + \Delta\varphi^b(\epsilon^t) = 0. \tag{6}$$

To satisfy Condition 2, the regime change must not increase household wealth at unchanged prices as this would increase demand, undermining market clearing for goods and assets other than the affected balance sheet positions. Similarly, the regime change must not reduce household wealth. For general ownership structures of nonbanks and banks, this requires the market value of transfers received by the nonbank and the bank to equal zero. Formally, $\Delta\tau^j(\epsilon^t) + \mathbb{E}[\text{sdf}^*(\epsilon^{t+1|t})\Delta\tau^j(\epsilon^{t+1|t})|\epsilon^t] = 0, j = i, b$, where we let $\text{sdf}^*(\epsilon^{t+1|t})$ denote the equilibrium stochastic discount factor (SDF) between ϵ^t and $\epsilon^{t+1|t}$.

Wealth neutrality has implications for convenience or liquidity. Subtracting the SDF-weighted Equation (3) from Equation (2) and taking expectations yields

$$\sum_{x=n,m} \Delta x^i \left(1 - \mathbb{E}[\text{sdf}^* R^{x*}]\right) + \Delta\varphi^i = \Delta\tau^i(\epsilon^t) + \mathbb{E}[\text{sdf}^*\Delta\tau^i(\epsilon^{t+1|t})], \tag{7}$$

where we suppress histories to ease legibility except where this would create ambiguity.[14] A parallel condition holds for the bank and the government.[15] Since the right-hand side of Equation (7) equals zero, the left-hand side must equal zero as well, which imposes restrictions on the proposed changes in balance sheet positions. If the positions pay equilibrium rates of return that satisfy $\mathbb{E}[\text{sdf}^* R^{x*}] = 1$, then Equation (7) automatically holds whenever the changes in transfers to an agent net of flow costs are wealth neutral. But if returns satisfy $\mathbb{E}[\text{sdf}^* R^{x*}] \neq 1$ because positions affect U or enter C not only through budget constraints, then the changes in the affected balance sheet positions must satisfy cross restrictions: each agent's total holding costs (net of revenues) due to the premia $1 - \mathbb{E}[\text{sdf}^* R^{x*}]$ plus flow costs must remain unaltered.

The preceding arguments rest on the implicit assumption that changes in the affected balance sheet positions have a one-to-one effect on budget constraints in history ϵ^t and effects scaled by gross rates of return in the immediate successor histories, that is, the

[13] For simplicity we abstract from flow costs at the time when assets are repaid.

[14] Equation (7) generalizes Lemma 1 in Brunnermeier and Niepelt (2019) who abstract from flow costs.

[15] Let $\sigma^{x*} \equiv 1 - \mathbb{E}[\text{sdf}^* R^{x*}]$. We have $\Delta r^b \sigma^{r*} - \sum_{x=\ell,n} \Delta x^b \sigma^{x*} + \Delta\varphi^b = \Delta\tau^b(\epsilon^t) + \mathbb{E}[\text{sdf}^*\Delta\tau^b(\epsilon^{t+1|t})]$ and $\Delta\ell^g \sigma^{\ell*} - \sum_{x=m,r} \Delta x^g \sigma^{x*} + \Delta\varphi^g = \Delta\tau^g(\epsilon^t) + \mathbb{E}[\text{sdf}^*\Delta\tau^g(\epsilon^{t+1|t})]$.

argument relies on the absence of taxes on transactions or returns. This implicit assumption can be relaxed, however, to allow for taxes. Most evidently, when taxes on asset returns are proportional and independent of the identity of asset owners, then we may simply interpret the gross returns R^{x*} in Equations (2)–(5) and (7) as after-tax returns and all arguments go through.

More interestingly, the arguments may also go through when taxes are nonlinear and even agent specific. All that is needed is that the tax functions shape agents' choice sets in ways that satisfy Conditions 1 and 2. One class of tax functions that meets this requirement is the class of arbitrary nonlinear functions of the *sum* of the pre-tax portfolio returns plus transfers. As long as changes in transfers and affected balance sheet positions satisfy Equations (3) or (5), such changes do not alter the tax function value either and Condition 1 thus is satisfied. Condition 2 is satisfied as well (if the affected balance sheet positions and transfers do not enter objectives) because Equation (1) holds. In the following, we disregard taxes on affected balance sheet positions and on transfers.

Equations (2)–(7) operationalize Conditions 1 and 2 in the context of the introduction of CBDC. To illustrate their scope, we turn next to a few examples. The first example focuses on the implications of regime change for a household (or firm). It demonstrates, among other things, that neutral regime change does not require identical convenience or liquidity benefits of deposits and CBDC.

Example 1 (Household)**.** Household i has "money in the utility function" preferences (Sidrauski, 1967). The liquidity services of deposits and CBDC are a weighted sum of the household's holdings 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 CBDC premium relative to deposits equals λ.[16] The regime change does not alter flow costs ($\Delta\varphi^i = 0$).

The regime change tightens the household's budget constraint in history ϵ^t by $\Delta n^i + \Delta m^i - \Delta\tau^i(\epsilon^t)$ and relaxes it in history $\epsilon^{t+1|t}$ by $R^{n*}\Delta n^i + R^{m*}\Delta m^i + \Delta\tau^i(\epsilon^{t+1|t})$. For the asset swap to have no effect on the objective function (first part of Condition 2) it must be the case that $\Delta n^i + \lambda\Delta m^i = 0$. To additionally leave budget constraints unaffected (Condition 1), we then need $(1-\lambda^{-1})\Delta n^i = \Delta\tau^i(\epsilon^t)$ and $(R^{m*}/\lambda - R^{n*})\Delta n^i = \Delta\tau^i(\epsilon^{t+1|t})$, which also implies that the regime change is wealth neutral.[17]

We conclude that the restrictions

$$\left.\begin{aligned} \Delta m^i &= -\lambda^{-1}\Delta n^i \\ \Delta\tau^i(\epsilon^t) &= (1-\lambda^{-1})\Delta n^i \\ \Delta\tau^i(\epsilon^{t+1|t}) &= (R^{m*}/\lambda - R^{n*})\Delta n^i \end{aligned}\right\} \tag{8}$$

guarantee that the regime change satisfies Condition 1 as well as the first part of Condition 2 for household i. Unter the same restrictions, the second part of Condition 2 is satisfied as well because Equation (1) applies: Conditional on the changed transfers, the swap of balance sheet positions enables the household to choose from exactly the same set of options as before the regime change. As a consequence, the household is indifferent about the regime change and neutrality prevails.

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

[17] We have $\Delta\tau^i(\epsilon^t) - \Delta\varphi^i + \mathbb{E}[\text{sdf}^*\Delta\tau^i(\epsilon^{t+1|t})] = \Delta n^i\{(1-\lambda^{-1}) + \mathbb{E}[\text{sdf}^*(R^{m*}/\lambda - R^{n*})]\} = 0$.

Three remarks are in order. First, the "money in the utility function" assumption in Example 1 is not important for the result. A parallel logic applies if the household faces a cash-in-advance constraint (Lucas, 1982), a shopping time constraint (Saving, 1971), or some other type of constraint that gives rise to a single linear restriction like $\Delta n^i + \lambda \Delta m^i = 0$.

Second, when CBDC and deposits have different convenience or liquidity properties ($\lambda \neq 1$), then equivalence requires payments between the household and the government, $\Delta\tau^i(\epsilon^t) \neq 0$. This is an implication of the household's budget constraint in history ϵ^t and the fact that constant convenience or liquidity requires a change in the portfolio value $m^i + n^i$. In history $\epsilon^{t+1|t}$, such payments are needed for the same reason; moreover, they need to be history contingent if R^{m*} and R^{n*} are linearly independent. History contingent transfers always suffice to implement the necessary payments between the household and the government. But depending on the return characteristics of $R^{m*}/\lambda - R^{n*}$, transfers in the two periods might not be needed and might instead be replaced by exposure to some asset.[18]

Third, the transfer and balance sheet changes represented in (8) have fiscal implications for the government. In history ϵ^t, the intervention tightens the government budget constraint by $\Delta\tau^i(\epsilon^t) - \Delta m^i = \Delta n^i$, and in history $\epsilon^{t+1|t}$ by $\Delta\tau^i(\epsilon^{t+1|t}) + R^{m*}\Delta m^i = -R^{n*}\Delta n^i$. Whether neutral regime change is feasible in general equilibrium therefore depends on the government's interaction with the bank, to which we turn next.

The following example illustrates the fiscal consequences of this interaction as well as the budgetary implications of a regime change for the bank. It demonstrates, among other things, that Conditions 1 and 2 neither require constraints on affected balance sheet positions to be linear nor agents to be competitive.

Example 2 (Bank)**.** Bank b finances its reserve holdings and loans to firms and households out of deposits and, after the regime change, a central bank loan. Due to deposit market power, the bank perceives a less than perfectly elastic deposit funding schedule. In the initial equilibrium, this schedule is represented by $R^{n*}(n^b)$, such that deposit funding n^b gives rise to gross interest payments $h(n^b) \equiv n^b \cdot R^{n*}(n^b)$ in the subsequent period. Deposit operations (e.g., payments) generate flow costs $\varphi^b = \alpha(\zeta)n^b$, which depend on the reserves-to-deposits ratio $\zeta \equiv r^b/n^b$. Underlying the choice of ζ is a cost minimization problem of the bank.[19]

We set $\Delta\zeta = 0$ 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 $\Delta r^b + (\alpha(\zeta^*) - 1)\Delta n^b - \Delta\ell^b - \Delta\tau^b(\epsilon^t)$ or $(\zeta^* + \alpha(\zeta^*) - 1)\Delta n^b - \Delta\ell^b - \Delta\tau^b(\epsilon^t)$. How the regime change affects the budget constraint in history $\epsilon^{t+1|t}$ depends on the terms of the central bank loan. By posting a central bank loan funding schedule that renders the total post-intervention supply of deposits and central bank loans commensurate to the deposit supply in the initial equilibrium, the central bank preserves the bank's trade-offs as far as the amount of funding available for bank lending is concerned.

[18] The cash flows associated with exposure to that asset must only enter the budget constraints.

[19] The equilibrium reserves-to-deposits ratio minimizes the costs of deposit operations on the one hand and foregone interest on lending on the other, $\zeta^* = \arg\min_\zeta n^b(\mathbb{E}[\text{sdf}^*\{(R^{b*} - R^{r*})\zeta + \alpha(\zeta)R^{b*}\}])$.

This is achieved if bank liabilities (n^b, ℓ^b) imply gross interest payments

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

where β denotes a constant that is yet to be determined. Note that if the central bank loan funding schedule implies these gross interest payments, then both the value of h and the bank's perceived market power (encoded in the derivative of h) are unaffected by the composition of bank funding as long as $n^b + \ell^b/(1-\zeta^*)$ remains constant. Moreover, the gross interest rate on deposits depends on the quantity of deposits plus the scaled central bank loan amount, and the gross interest rate on the central bank loan equals $R^{n*}/(1-\zeta^*) + \beta$.

Parameter β must be such that the bank is indifferent between issuing deposits and borrowing from the central bank. Issuing one unit of deposits subject to the unit operating costs $\alpha(\zeta^*)$ and (optimally) investing fraction ζ^* in reserves generates the marginal cash flow $1-\alpha(\zeta^*)-\zeta^*$ in history ϵ^t and $\zeta^* R^{r*} - R^{n*} - (n^b + \ell^b/(1-\zeta^*))\partial R^{n*}/\partial n^b$ in history $\epsilon^{t+1|t}$. The alternative, borrowing $1-\zeta^*$ units of the central bank loan, generates the marginal cash flows $1-\zeta^*$ and $-R^{n*} - (1-\zeta^*)\beta - (n^b + \ell^b/(1-\zeta^*))(1-\zeta^*)\partial R^{n*}/\partial \ell^b = -R^{n*} - (1-\zeta^*)\beta - (n^b + \ell^b/(1-\zeta^*))\partial R^{n*}/\partial n^b$. Indifference thus requires

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

That is, β must compensate for the operating costs and the return on reserves that materialize with deposit but not with central bank loan funding.

With $\Delta\ell^b = -(1-\zeta^*)\Delta n^b$, the regime change leaves h (and its derivative, and thus the bank's perceived market power) unaffected and the bank receives exactly the same funding net of reserve holdings as before the regime change. This allows the bank to extend the same amount of loans as before the regime change if $\alpha(\zeta^*)\Delta n^b = \Delta\tau^b(\epsilon^t)$. The constraint in history $\epsilon^{t+1|t}$ remains unaffected as well if $R^{r*}\Delta r^b - \beta\Delta\ell^b + \Delta\tau^b(\epsilon^{t+1|t}) = 0$. Wealth neutrality then is ensured.

We conclude that a regime change

$$\left.\begin{aligned}
&\Delta r^b = \zeta^* \Delta n^b \\
&\Delta \ell^b = -(1-\zeta^*)\Delta n^b \\
&\Delta\tau^b(\epsilon^t) = \alpha(\zeta^*)\Delta n^b \\
&\Delta\tau^b(\epsilon^{t+1|t}) = -(R^{r*}\zeta^* + \beta(1-\zeta^*))\Delta n^b \\
&\text{with} \quad \beta = (\alpha(\zeta^*) - \zeta^*\mathbb{E}[\mathrm{sdf}^* R^{r*}])/((1-\zeta^*)\mathbb{E}[\mathrm{sdf}^*])
\end{aligned}\right\} \tag{9}$$

satisfies Condition 1 for the bank.[20] It also satisfies Condition 2 for the bank as long as the changes in transfers and affected balance sheet positions do not alter the value of the bank's objective function. This follows, again, because Equation (1) applies: Conditional on the changed transfers and the central bank's loan supply schedule, the changes in

[20] If R^{r*} is deterministic then the fourth condition reduces to $\Delta\tau^b(\epsilon^{t+1|t}) = -\alpha(\zeta^*)\Delta n^b/\mathbb{E}[\mathrm{sdf}^*]$.

balance sheet positions summarized in (9) enable the bank to choose from exactly the same set of options as before the regime change. The bank thus is indifferent about the regime change.

Several remarks are in order. First and most importantly, the key policy instrument to insulate the bank from the consequences of the CBDC introduction is the central bank loan, $\Delta\ell^b$. By issuing CBDC, crowding out deposits, and simultaneously lending to the bank, the central bank intermediates between nonbanks and the bank. It transforms "private money" into "public money" and decouples bank funding from liquidity provision (Brunnermeier and Niepelt, 2019).

Second, bank deposit market power does not undermine this insulation strategy; it only imposes additional constraints on central bank lending: Not only does the central bank loan have to be priced appropriately, it also has to be supplied less than perfectly elastically to preserve the bank's trade-off regarding its funding choice.

Third and related, while the restrictions in (9) ensure that the regime change satisfies bank budget constraints and is wealth neutral, they do not ensure that the bank's choice set (effectively) remains unchanged. The latter requires in addition the commensurate central bank loan funding schedule.

Fourth, the deposit operating costs in the example constitute an instance of flow costs φ^b, and the functional relationship between these flow costs and reserves and deposits constitutes a nonlinear constraint that shapes the bank's choice set. This and the previous point show that neutrality does not require linear constraints.

Fifth, equivalence requires payments between the government and the bank. In the case of the household, the need for payments arose from differences in convenience or liquidity benefits between CBDC and deposits or from differences in their return characteristics. In the case of the bank, in contrast, the need arises from the fact that even with identical (present values of) marginal costs, deposit- and central bank loan-based financing strategies generate different time profiles of cash flows.[21]

Finally, the transfer and balance sheet changes represented in (9) have fiscal implications. In history ϵ^t, the intervention tightens the government budget constraint by $(\alpha(\zeta^*) - \zeta^* - (1-\zeta^*))\Delta n^b = (\alpha(\zeta^*) - 1)\Delta n^b$, and in history $\epsilon^{t+1|t}$ by $(\zeta^* R^{r*} + (1-\zeta^*)R^{\ell*} - \zeta^* R^{r*} - \beta(1-\zeta^*))\Delta n^b = R^{n*}\Delta n^b$.

These effects add to the payments from the government to the household identified in Example 1, namely Δn^i and $-R^{n*}\Delta n^i$. The total outflows from the government therefore sum to $\alpha(\zeta^*)\Delta n^b$ and zero in histories ϵ^t and $\epsilon^{t+1|t}$, respectively. This implies that the regime change depicted in Examples 1 and 2 can only be implemented if it is associated with an $\alpha(\zeta^*)\Delta n^b$ reduction of government flow costs in history ϵ^t. Clearly, this implication is consistent with, and actually corresponds to, Equation (6), which requires total flow costs to remain constant after the regime change. Moreover, on the aggregate level it connects to the economy's resource constraints, to which we turn next.

[21] For a related point in a different setting, see Bassetto and Kocherlakota (2004).

3.4 Condition 3

By construction the regime change is consistent with asset market clearing for affected balance sheet positions. But it may violate other aggregate consistency requirements such as resource constraints. The following example illustrates this.

Example 3 (Resources)**.** Payment operations require resources. Deposits carry unit operating costs $\alpha(r^b/n^b)$ for the issuing bank (as discussed in Example 2), where α is a decreasing function of the reserves-to-deposits ratio. CBDC and reserves carry unit operating costs μ and ρ, respectively, and a central bank loan to the bank carries unit operating costs o for the central bank. All costs arise in the form of the same resource.

A regime change that leaves the reserves-to-deposits ratio constant at ζ^* enters the resource constraint in A as

$$\alpha(\zeta^*)\Delta n^b + \rho\Delta r^g + o\Delta\ell^g + \mu\Delta m^g. \tag{10}$$

For the regime change to be neutral this expression must equal zero because the initial-equilibrium use of the resource for other purposes cannot remain unaltered otherwise.

Note that the resource-neutrality requirement corresponds to Equation (6). As discussed after Example 2, resource neutrality then also ensures that the government budget constraints are satisfied at all times. In this sense, the resource-neutrality requirement is fundamental for the neutrality of the regime change.

Coupled with the bank balance sheet restrictions in (9) as well as the market clearing conditions for reserves and the central bank loan, the resource-neutrality requirement reduces to $(\alpha(\zeta^*) + \rho\zeta^* - o(1-\zeta^*))\Delta n^b + \mu\Delta m^g = 0$. Imposing also the household balance sheet restriction in (8) and CBDC market clearing implies the resource-neutrality requirement

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

This parametric condition is generically violated: Except in very special circumstances, a regime change violates resource constraints.

4 Review of Literature

TBC

5 Private Cryptocurrency

We turn next to private cryptocurrencies and their equilibrium implications. One key difference to the CBDC case analyzed before is that a cryptocurrency issuer is a private entity—unlike the government that issues CBDC. This renders it more challenging to preserve the choice sets of agents in the financial sector and implies stricter neutrality conditions. We discuss these conditions and also consider the role of bubbly crypto assets.

5.1 Regime Change

To focus on the cryptocurrency case we abstract from CBDC. But to ease the comparison with the analysis in Section 3 we maintain the formalization in that section and simply change the interpretation of variables indexed by "g." Rather than referring to balance sheet positions or transfers of/to the consolidated government such variables now denote balance sheet positions or transfers of/to the government *and the cryptocurrency issuer*. For example, $\Delta\tau_t^g$ denotes the change of transfer to the government *cum* cryptocurrency issuer and Δm_{t+1}^g denotes the change in the quantity of cryptocurrency (because we abstract from CBDC). With this modified interpretation all market clearing restrictions remain unchanged.

5.2 Profit Motive

The modified interpretation of the model variables suggests a two-step approach for our analysis. In the first step we treat the private cryptocurrency as if it were a form of publicly issued money. Our analysis of Section 3 applies in this case without change. In the second step we ask what additional requirements must be satisfied as a consequence of the fact that the private cryptocurrency is not CBDC and its issuer not the government.

Focusing on this second step immediately makes clear that the profit motive (or related objectives) of the cryptocurrency issuer introduces additional and rather strong restrictions beyond Conditions 1–3. As the discussion in Section 3 has shown the allocation (except for affected balance sheet positions) and price system need not change after CBDC issuance if the central bank lends the appropriate quantity of funds to banks at equivalent terms. This will generally not be the case with a cryptocurrency issuer that has no interest to supply funds below market rates. We conclude that a regime change that involves a cryptocurrency generally violates the restrictions that guarantee neutrality.

Neutrality is easier to guarantee, however, when the issuer is competitive and bears no operating costs and if its instruments are backed by deposits from which they derive their liquidity benefits. Under such circumstances the cryptocurrency is just a veil without significance for the allocation (except for affected balance sheet positions) and the price system and Conditions 1–3 are satisfied. By contrast there is no reason to expect the introduction of a stablecoin to be neutral if the issuer has market power, bears operating costs or generates inherent liquidity benefits.

5.3 Bubbly "Cryptocurrency"

Some "cryptocurrencies" may provide very limited or even no liquidity services. Lacking real dividends these instruments are sometimes characterized as bubbles—speculative stores of value—with minor added liquidity benefits, or even as pure bubbles. We show next that the characterization of cryptocurrencies as bubbles with added liquidity benefits is dubious and discuss thereafter the case of pure bubbles.

Consider a cryptocurrency that provides liquidity services at each date and in each history, i.e., it always contributes to the objective of some household or firm or relaxes a

C constraint beyond the budget constraint. Let $p_t(\epsilon^t)$ denote the price of the cryptocurrency at the beginning of period t, history ϵ^t, expressed in terms of the numeraire. Let $\underline{\chi} > 0$ denote the minimum liquidity contribution of one unit of real balances of the cryptocurrency across histories. Since the price must weakly exceed the fundamental value this implies $p_t \geq \underline{\chi} \sum_{s\geq 0} \mathbb{E}_t[\text{sdf}^*_{t+1} \cdots \text{sdf}^*_{t+s} p_{t+s}]$. Following Tirole (1985) and to establish a contradiction suppose that the price also contains a bubble component, $b_t(\epsilon^t)$ in history ϵ^t. The bubble must pay the required rate of return, $b_t = \mathbb{E}_t[\text{sdf}^*_{t+1} b_{t+1}]$. Moreover, the price must weakly exceed the bubble component such that $\mathbb{E}_t[\text{sdf}^*_{t+1} \cdots \text{sdf}^*_{t+s} p_{t+s}] \geq \mathbb{E}_t[\text{sdf}^*_{t+1} \cdots \text{sdf}^*_{t+s} b_{t+s}]$. This implies that $p_t \geq \underline{\chi} \sum_{s\geq 0} \mathbb{E}_t[\text{sdf}^*_{t+1} \cdots \text{sdf}^*_{t+s} b_{t+s}] = \underline{\chi} \sum_{s\geq 0} b_t$, which is unbounded unless $b_t = 0$. In conclusion the cryptocurrency cannot at the same time provide liquidity services and feature a price bubble. Either it provides liquidity services—the case analyzed so far—or its price reflects a bubble.

Consider, then, the case of a cryptocurrency whose price reflects a bubble but which does not provide liquidity services.[22] As far as budget constraints of households or firms are concerned the bubbly nature of such an instrument does not matter.[23] However, the replacement of a liquid instrument by a bubble does have effects on U and/or C (beyond budget constraints), and Conditions 1 and 2 for households and firms thus may be violated. Moreover, the introduction of the bubble also violates Conditions 1 and 2 for the issuer. Holding prices constant the bubble increases the issuer's net worth and thereby enlarges its choice set. Even if this gain in net worth is taxed away, somebody else's (e.g., the government's) wealth position changes. Neutrality fails and the introduction of the bubble changes prices and the equilibrium allocation beyond affected balance sheet positions.

6 Value of Lender-of-Last-Resort Guarantees

The equivalence relations of Section 3 establish mappings between bank balance sheet positions and interest rates in equilibria with and without deposits. We can use these mappings to construct a measure of the reduction in banks' financing costs due to their ability to issue deposits. In turn, this measure can be interpreted as the value of central bank lender-of-last-resort guarantees if depositors prize the liquidity of deposits because the central bank stands ready to exchange the latter against central bank money.

To a first approximation the reduction in banks' financing costs due to deposits equals the product of deposits outstanding, n^{b*}_{t+1}, and the liquidity premium on deposits, $\chi^{n*}_{t+1} \equiv 1 - R^{n*}_{t+1}/R^{f*}_{t+1}$. Figure 1 plots bounds for this product over the period 1973–2023 based on data in FRED, Hanson et al. (2015), Nagel (2016), Kurlat (2019), Van den Heuvel (2022) and Bianchi and Bigio (2022); Appendix A contains a detailed discussion. Figure 1 shows that banks collected total deposit liquidity premia of between −0.3 and 2.6 percent of annualized GDP; the mean equalled roughly 0.7 percent.

This first approximation overstates the benefits from deposit creation, however, because banks incur costs beyond interest paid to depositors in order to collect the liquidity

[22] The same argument applies for a "CBDC bubble" if the government rather than a private sector entity issues a bubble.

[23] Only the asset return matters, not the composition between dividends and capital gains.

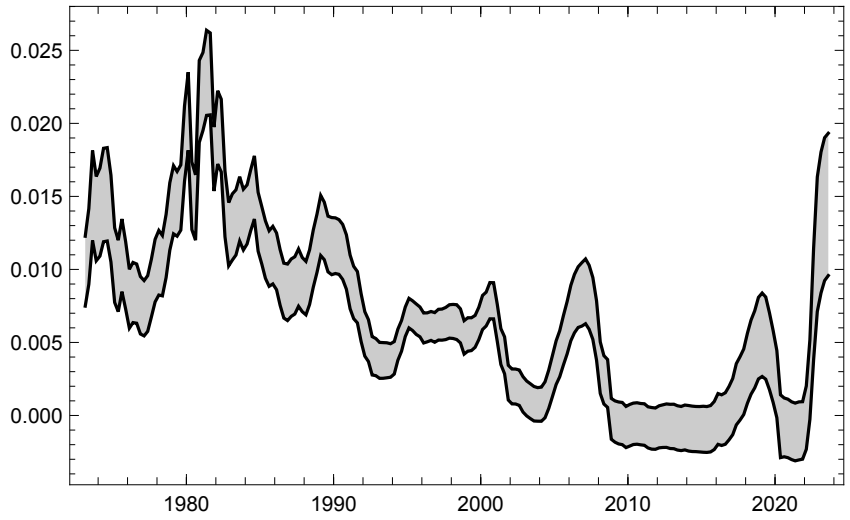

Figure 1: Bounds for deposit-to-GDP ratio times deposit spread, annualized.

premia. Most importantly, they incur operating costs of executing customer payments as well as opportunity costs on the low-yielding reserve holdings that the deposit business requires. A measure of the total costs of bank deposit funding therefore needs to adjust the liquidity premium for these operating and opportunity costs. It also needs to account for the fact that a bank may only use a share $1-\zeta^*$ of deposits to fund profitable investment projects since the remaining share ζ^* is invested in reserves.

Recall from Subsection **??** that the equivalent loan rate $R^{\ell*}_{t+1}$ reflects exactly those factors: It measures the total costs for a bank in a deposit based architecture to fund one dollar of real investment. This implies that the funding costs of a bank whose deposits net of associated reserve holdings are fully replaced by a central bank loan of size $\ell^{b*}_{t+1} = n^{b*}_{t+1}(1-\zeta^*)$ are equal to $\ell^{b*}_{t+1}R^{\ell*}_{t+1}/R^{f*}_{t+1}$ in present value. Compared with the funding costs at market rates, $\ell^{b*}_{t+1}R^{f*}_{t+1}/R^{f*}_{t+1}$, the central bank loan at the equivalent rate—or equivalently, deposit funding—thus reduces bank funding costs by

$$n^{b*}_{t+1}(1-\zeta^*)\frac{R^{f*}_{t+1}-R^{\ell*}_{t+1}}{R^{f*}_{t+1}}. \tag{11}$$

Our objective is to quantify this expression.

Recall also that under the general assumptions of Subsection **??** (and in the absence of CBDC, private cryptocurrencies or a central bank loan) a bank maximizes

$$n^b_{t+1}\left\{-\alpha(\zeta)+\mathbb{E}_t\left[\mathrm{sdf}^*_{t+1}\left((R^{k*}_{t+1}-R^n_{t+1}(n^b_{t+1}))+\zeta(R^{r*}_{t+1}-R^{k*}_{t+1})\right)\right]\right\},$$

which represents the market value of the return on the bank's portfolio (including reserves) net of operating costs. Letting $\chi^{r*}_{t+1} \equiv 1 - R^{r*}_{t+1}/R^{f*}_{t+1}$ denote the liquidity premium on reserves, the bank's ζ and n^b_{t+1} choices, respectively, satisfy

$$\begin{aligned}
\chi^{r*}_{t+1} &= -\alpha'(\zeta^*), \\
\alpha(\zeta^*)-\zeta^*\alpha'(\zeta^*) &= \mathbb{E}_t[\mathrm{sdf}^*_{t+1}(R^{k*}_{t+1}-R^{n*}_{t+1})]-\mathbb{E}_t[\mathrm{sdf}^*_{t+1}]n^{b*}_{t+1}\frac{\partial R^{n*}_{t+1}}{\partial n^b_{t+1}}.
\end{aligned}$$

That is, the liquidity premium on reserves equals the marginal reduction in operating costs and the deposit choice reduces to $\alpha(\zeta^*) - \zeta^*\alpha'(\zeta^*) = \chi^{n*}_{t+1} - \eta R^{n*}_{t+1}/R^{f*}_{t+1}$, where η denotes the elasticity of the deposit rate with respect to n^b_{t+1}.

Suppose that households' liquidity demand is approximately isoelastic, $(n^b_{t+1})^{-\psi} \propto \chi^n_{t+1}$; this is the case, for example, when households have CES preferences over consumption and liquidity services with elasticity of substitution $\psi^{-1} > 1$ (e.g., Niepelt, 2024). Elasticity η then satisfies $\eta R^{n*}_{t+1}/R^{f*}_{t+1} = \psi\chi^{n*}_{t+1}$ such that the second bank optimality condition simplifies to $\chi^{n*}_{t+1}(1-\psi) = \alpha(\zeta^*) - \zeta^*\alpha'(\zeta^*)$; the equivalent central bank loan rate reduces to

$$R^{\ell*}_{t+1} = \frac{R^{n*}_{t+1}}{1-\zeta^*} + \frac{\alpha(\zeta^*)R^{f*}_{t+1} - \zeta^* R^{r*}_{t+1}}{1-\zeta^*} = R^{f*}_{t+1} - \frac{\psi}{1-\zeta^*}(R^{f*}_{t+1} - R^{n*}_{t+1});$$

and, most importantly, the funding cost reduction in (11) collapses to $\psi n^{b*}_{t+1}\chi^{n*}_{t+1}$. We conclude that the funding cost reduction equals the total deposit liquidity premium times the inverse of the elasticity of substitution.

Niepelt (2024) follows Pasqualini (2021) who argues that consistent with findings in Drechsler et al. (2017) or Wang et al. (2020) the markdown in U.S. deposit markets equals 1.5, corresponding to $\psi = 1/3$. Under this assumption and using the total deposit liquidity premium illustrated in Figure 1 the value of the Fed's lender-of-last-resort guarantees for U.S. banks averages roughly a quarter percent of U.S. GDP.

7 Conclusion

The conditions for a change in financial architecture to be neutral are stringent. But in the case of CBDC they are much less stringent than suggested by policy makers who envision dramatic consequences for financial stability, credit, investment and growth. As the examples have shown central banks can go a long way to insulate banks and the asset side of their balance sheets from the consequences of CBDC. And as long as the total social costs of liquidity provision *via* deposits and CBDC are similar and deposits are not "too special," governments are in a position to keep the consequences of CBDC manageable not only for banks but also for society at large.

The conclusions differ for private cryptocurrencies. The conditions for neutral regime change are substantially more stringent for these forms of money unless the issuer is competitive and bears no operating costs and the currency is backed by deposits from which it derives its liquidity benefit. The cryptocurrency is just a veil in this case and its introduction without macroeconomic significance.

Whether societies and central banks would *want* to insulate banks and the macroeconomy from the consequences of CBDC or private cryptocurrencies is a different question. Central banks could choose to raise banks' funding costs—according to our estimate by roughly a quarter percent of GDP—and/or change the allocation in other ways. Indeed, if the total social costs of CBDC or private cryptocurrencies were lower than those of deposits such that a regime change would necessarily be nonneutral then the change would be welfare improving unless policy makers introduced new frictions along the way.

Our analysis does not speak to "microeconomic" or institutional implications of CBDC or private cryptocurrencies; in our setup such implications would be reflected in regime dependent parameter values. It also does not speak to secondary implications of CBDC that are discussed in the policy debate. For example, since the presence of cash gives rise to an effective lower bound on nominal interest rates, which may be binding when prices are rigid, CBDC could empower monetary policy if it were associated with an abolition of cash (Bordo and Levin, 2017).[24] CBDC could enhance the speed and accuracy of government transfer payments if its introduction were associated with an improvement of address and death records. And by making digital payments more attractive, CBDC could weaken the political support for cash.

[24]See, however, Buiter (2009).

A Data

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

Figure 2 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);[25] we refer to this series as "short (Nagel)."

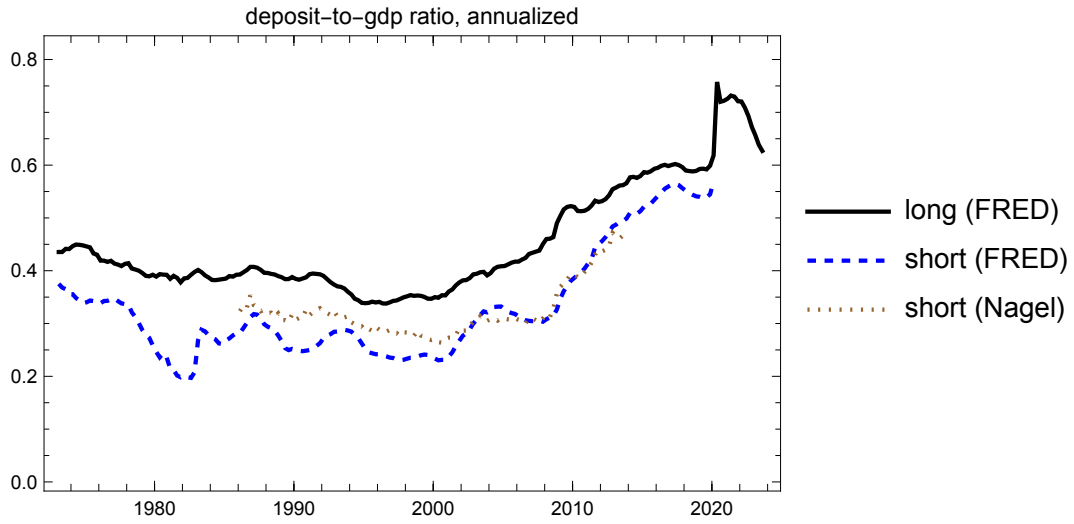

Figure 2: Measures of the deposit-to-GDP ratio.

Figures 3 and 4 illustrate alternative measures of annual gross interest rates that we use to construct measures of deposit liquidity premia. The solid line in Figure 3 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).[26] The solid line in Figure 4 again depicts the FRED series `TB3MS`. The dashed and dotted lines, respectively, depict the benchmark and deposit rates used by Nagel (2016).[27]

[25] 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`.

[26] We thank Pablo Kurlat for providing the data for the benchmark rate and the two spreads.

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

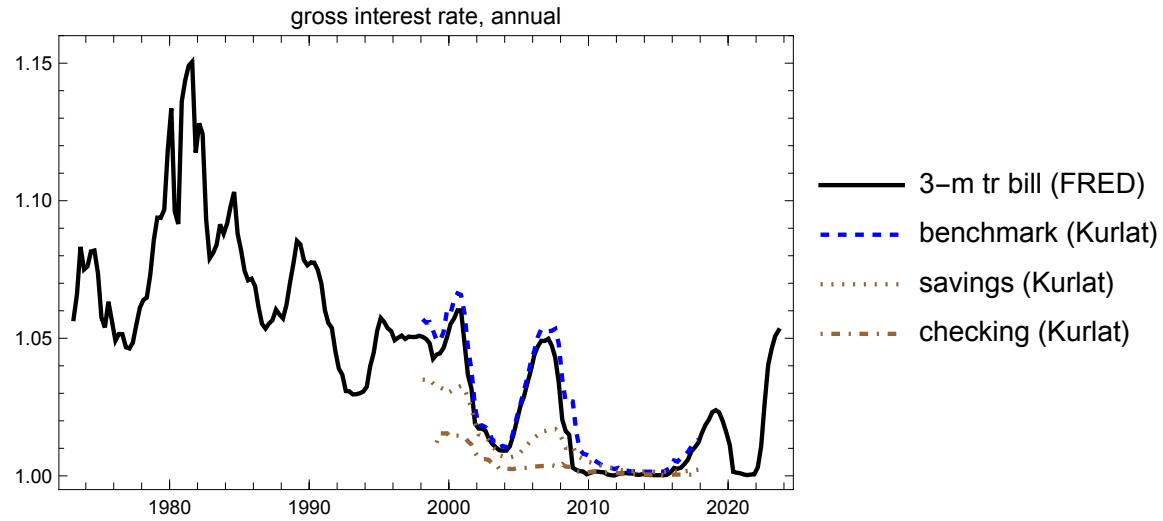

Figure 3: Measures of gross interest rates.

Figure 5 illustrates alternative measures of the annual deposit liquidity premium. The solid line depicts the premium 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 the components of "short (FRED)" as weights. The dashed line depicts the premium that results from the Nagel (2016) data. For comparison, the figure also depicts the average premia 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 6 illustrates alternative measures of the object of interest, the product of the annual deposit liquidity premium and the annualized deposit-to-GDP ratio. The solid line depicts the product computed based on the Kurlat liquidity premium and the "short (FRED)" deposit-to-GDP ratio. The dashed line depicts the product computed based on the Nagel liquidity premium 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 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 liquidity premium according to the Kurlat and Nagel data on `TB3MS` and a constant. Figures 7–10 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 reported in Figure 1 in the main text reflect the products of the predicted series in Figures 7 and 9 on the one hand and Figures 8 and 10 on the other.

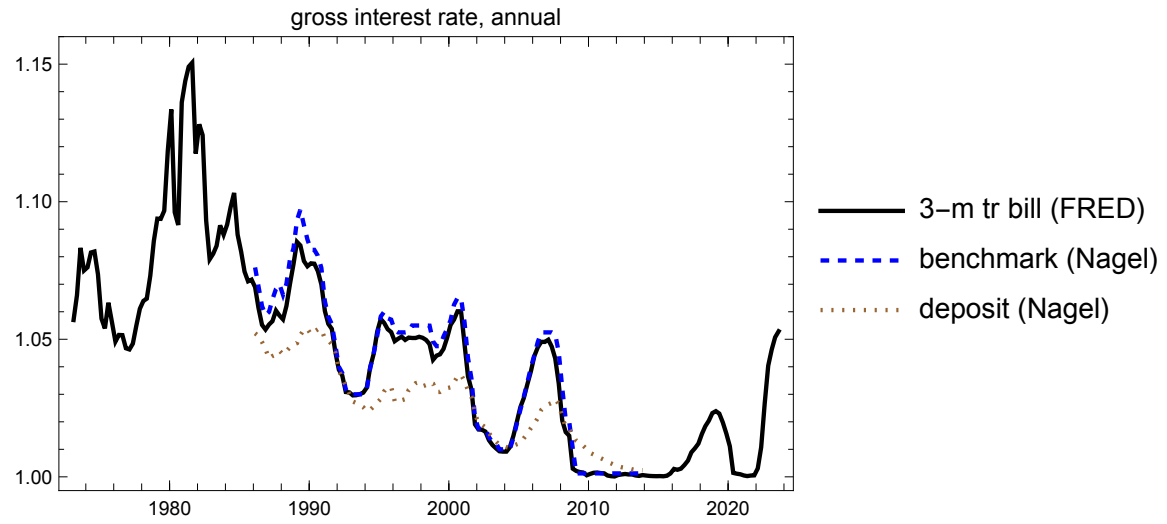

Figure 4: Measures of gross interest rates.

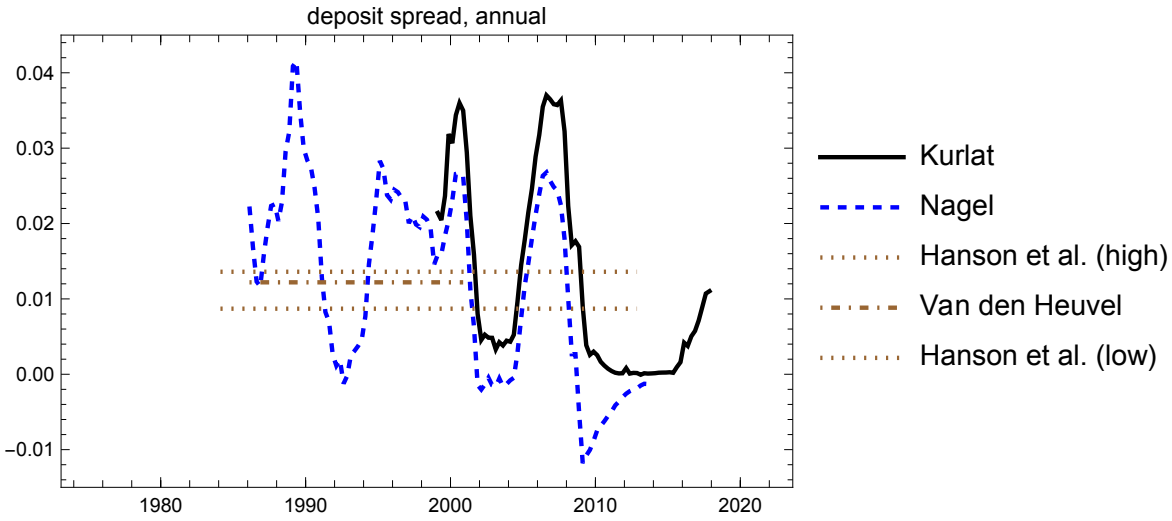

Figure 5: Measures of the deposit spread.

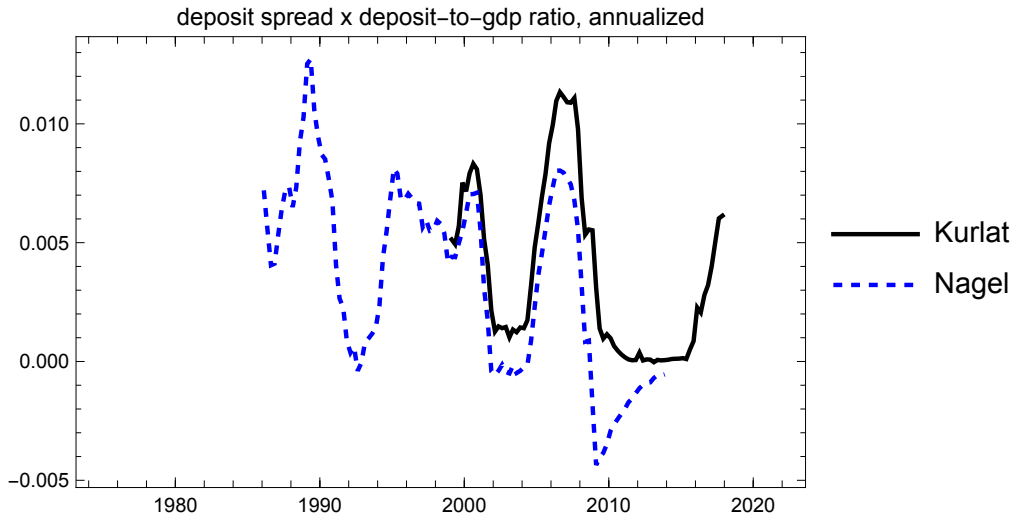

Figure 6: Measures of the deposit spread times the deposit-to-GDP ratio.

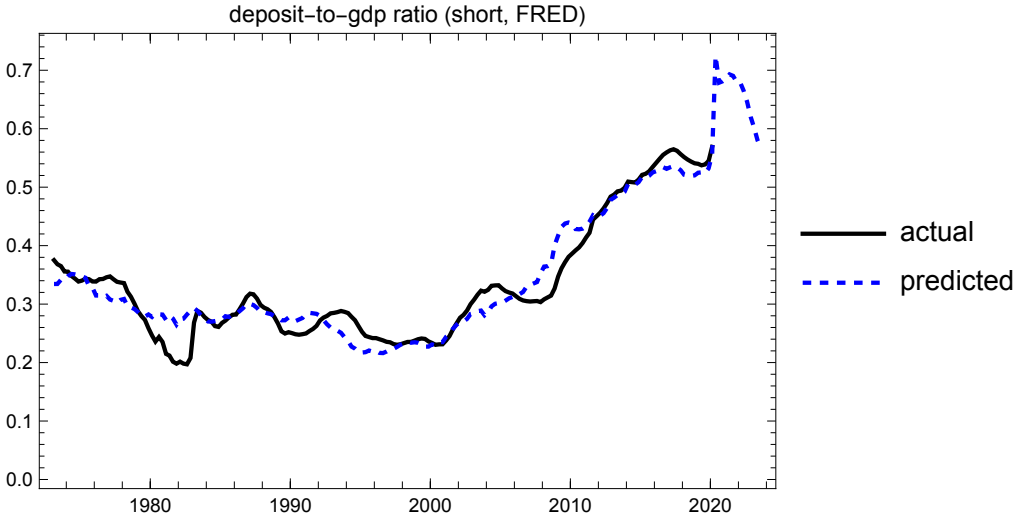

Figure 7: Actual and predicted deposit-to-GDP ratio (short, FRED).

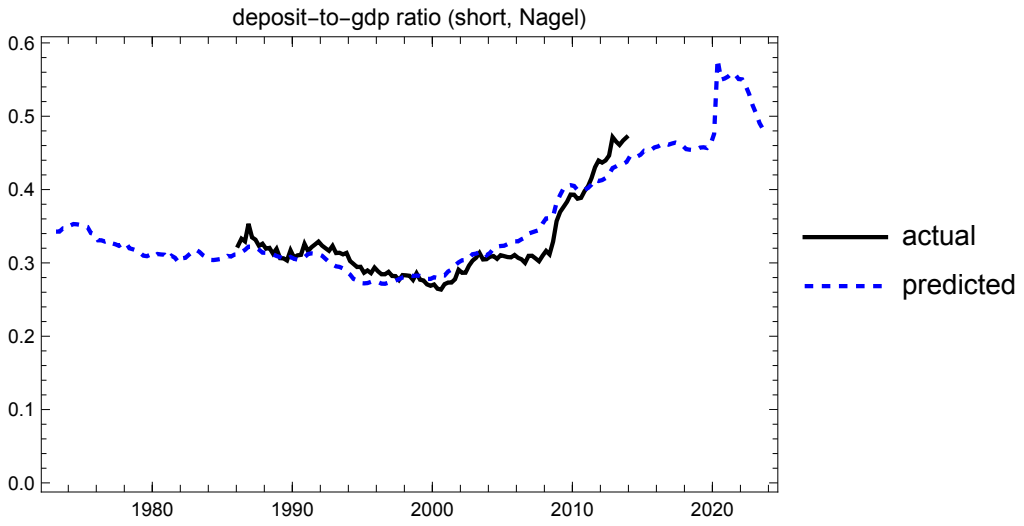

Figure 8: Actual and predicted deposit-to-GDP ratio (short, Nagel).

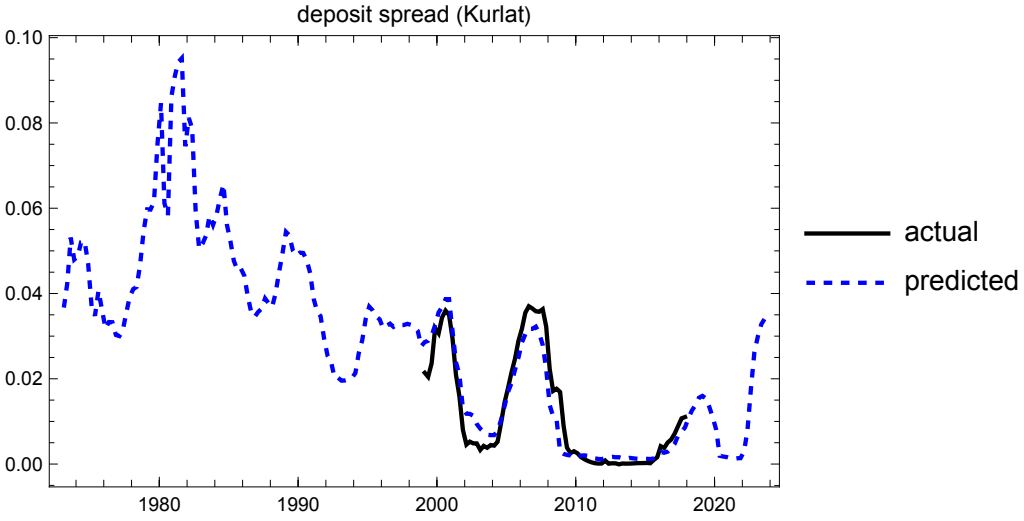

Figure 9: Actual and predicted deposit spread (Kurlat).

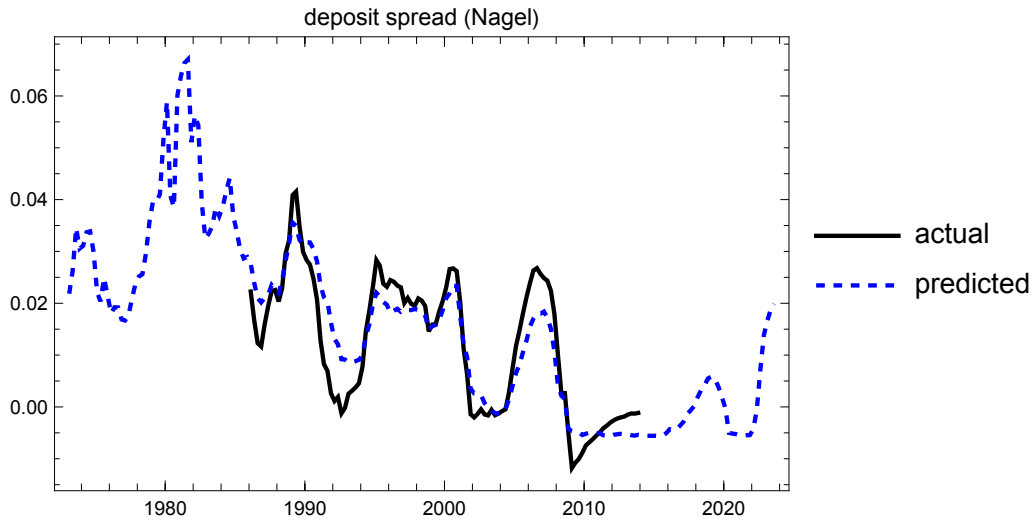

Figure 10: Actual and predicted deposit spread (Nagel).

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