

Supplemental Appendix: Central Bank Digital Currency and Monetary Architecture

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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).

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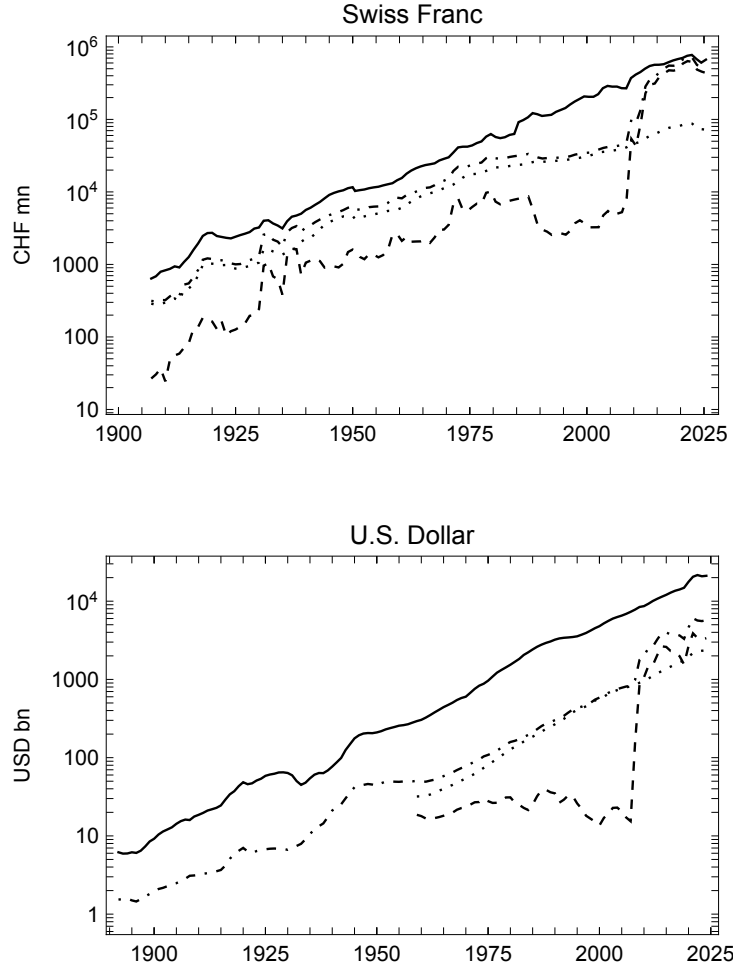


Figure A-1: Public and private money components, Swiss franc and U.S. dollar. The solid lines indicate M1 (Swiss franc) or M2 (U.S. dollar); the dot-dashed lines public money; the dotted lines cash in circulation; and the dashed lines reserves held by commercial banks at the central bank.

A.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).

A.2 Net Interest Income 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. The bounds reflect different data sources, detailed below. The deposit-to-GDP ratio multiplied by the deposit spread represents the interest income depositors forego by holding deposits rather than a risk-free but illiquid asset or, equivalently, the net interest income 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 net interest income. 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 net interest income increases.

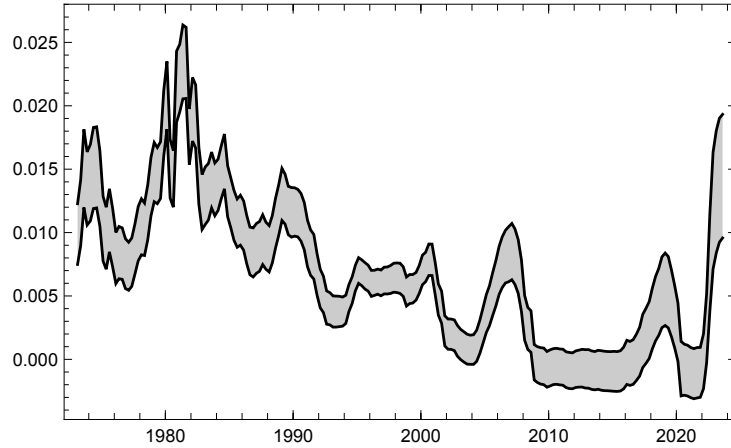


Figure A-2: Bounds for U.S. deposit-to-GDP ratio times deposit spread, based on different data sources. See the text for explanations.

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 `DPSACBW027SB0G` (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);¹ we refer to this series as “short (Nagel).”

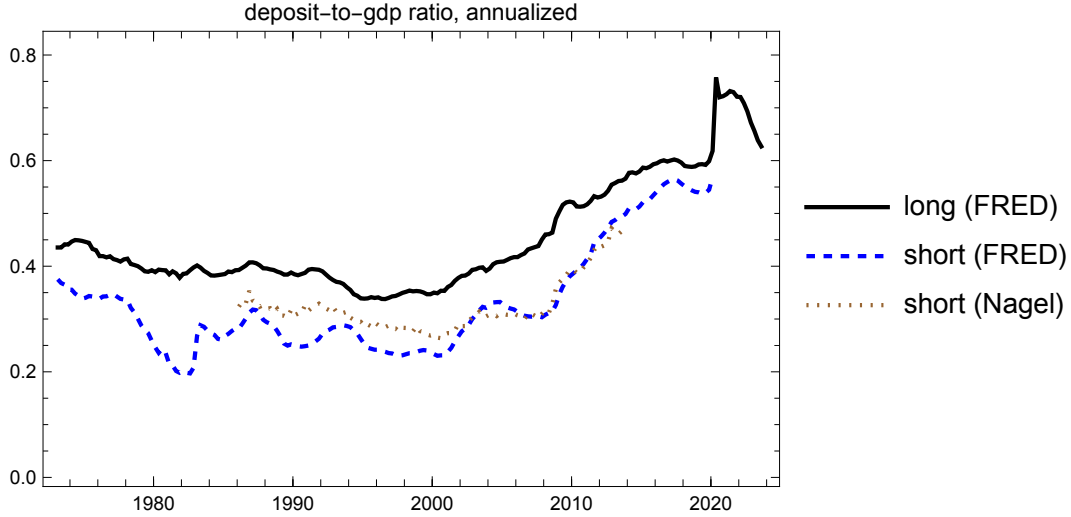


Figure A-3: Measures of the deposit-to-GDP ratio.

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).² 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).³

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 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

¹See <https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/KHXYJ&version=1.1>, file `AggregateDataAndFigures.xlsx`; it represents the (normalized) sum of `savdep`, `timedep100k` and `transdep`.

²We thank Pablo Kurlat for providing the data.

³See file `AggregateDataAndFigures.xlsx`, series `Deposit rate` and `Fed funds rate`.

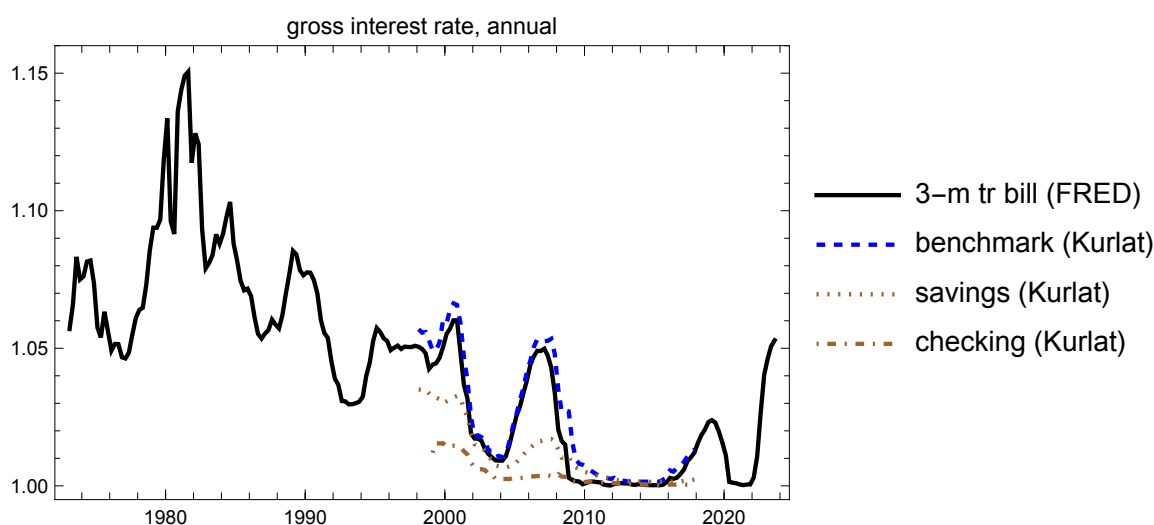


Figure A-4: Measures of gross interest rates.

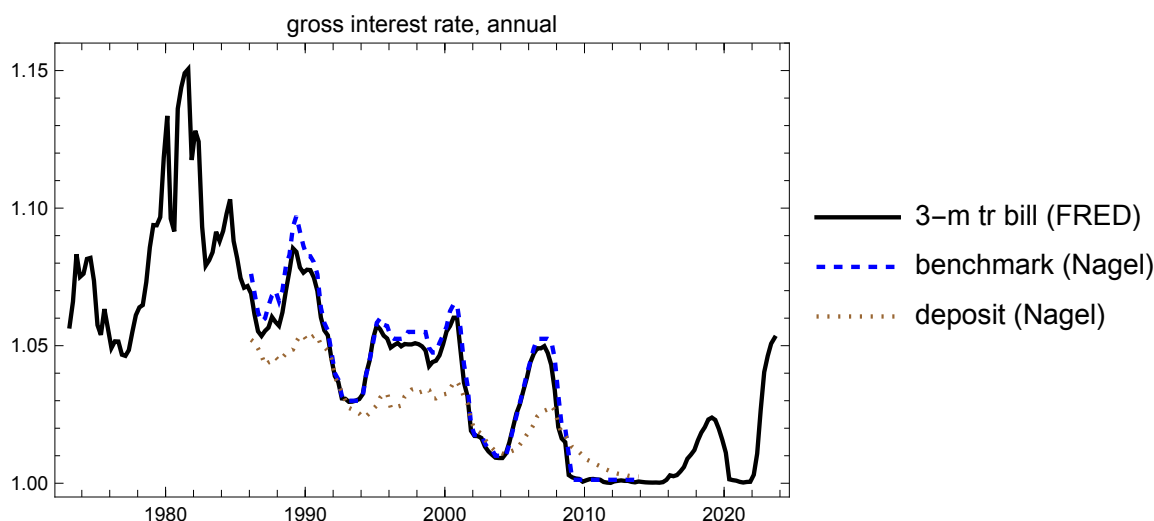


Figure A-5: Measures of gross interest rates.

“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 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

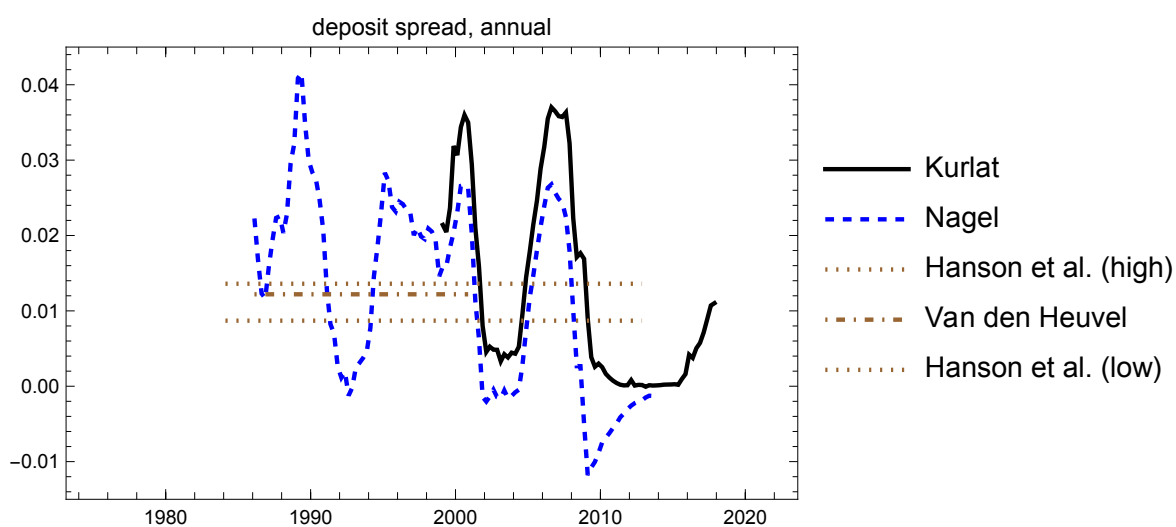


Figure A-6: Measures of the deposit spread.

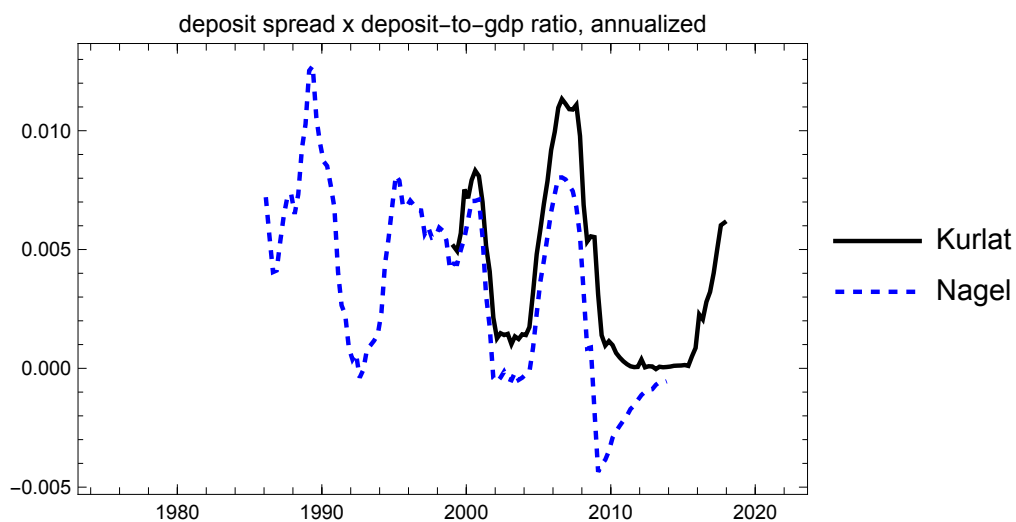


Figure A-7: Measures of the deposit spread times the deposit-to-GDP ratio.

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.

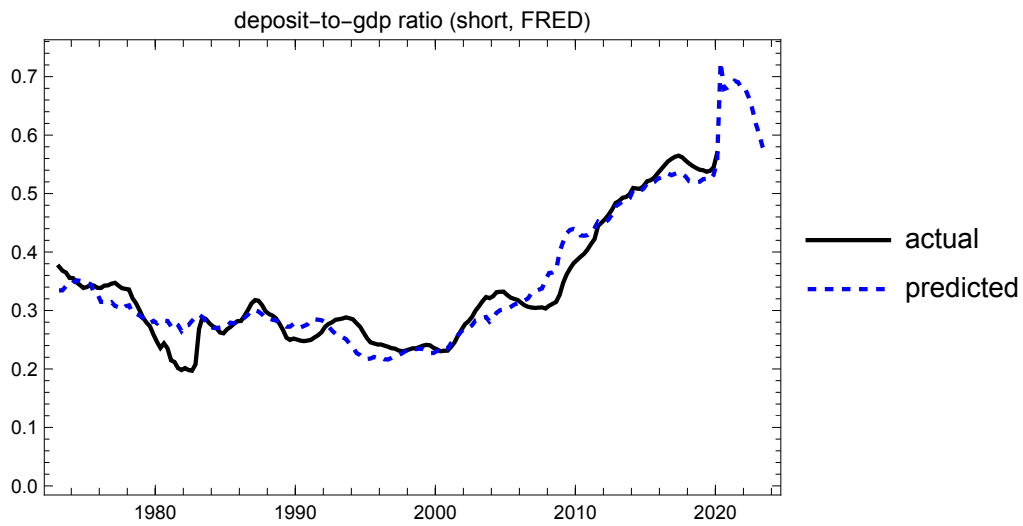


Figure A-8: Actual and predicted deposit-to-GDP ratio (short, FRED).

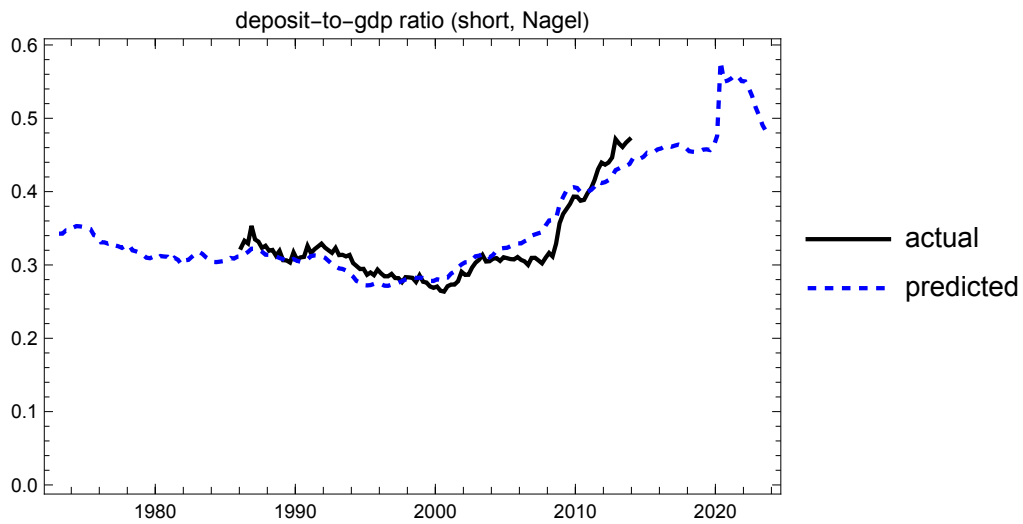


Figure A-9: Actual and predicted deposit-to-GDP ratio (short, Nagel).

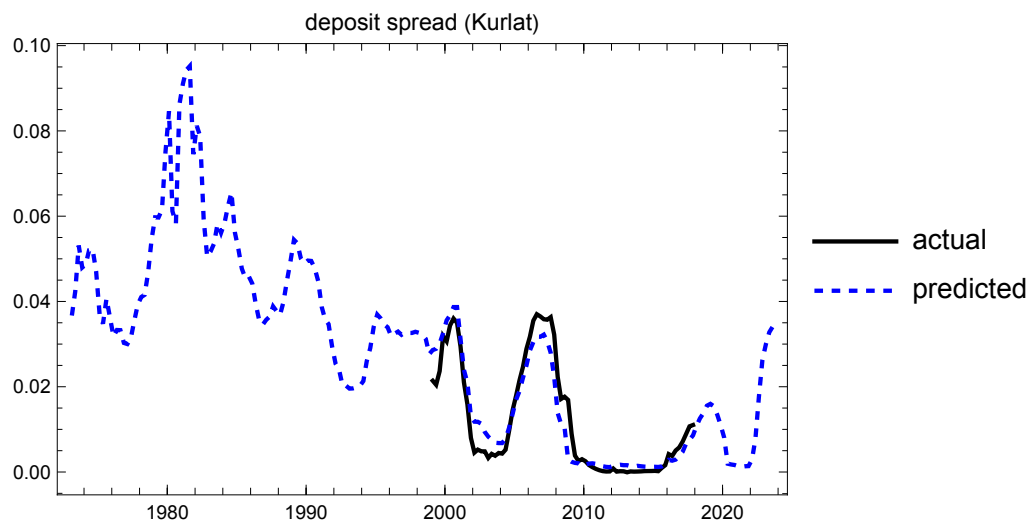


Figure A-10: Actual and predicted deposit spread (Kurlat).

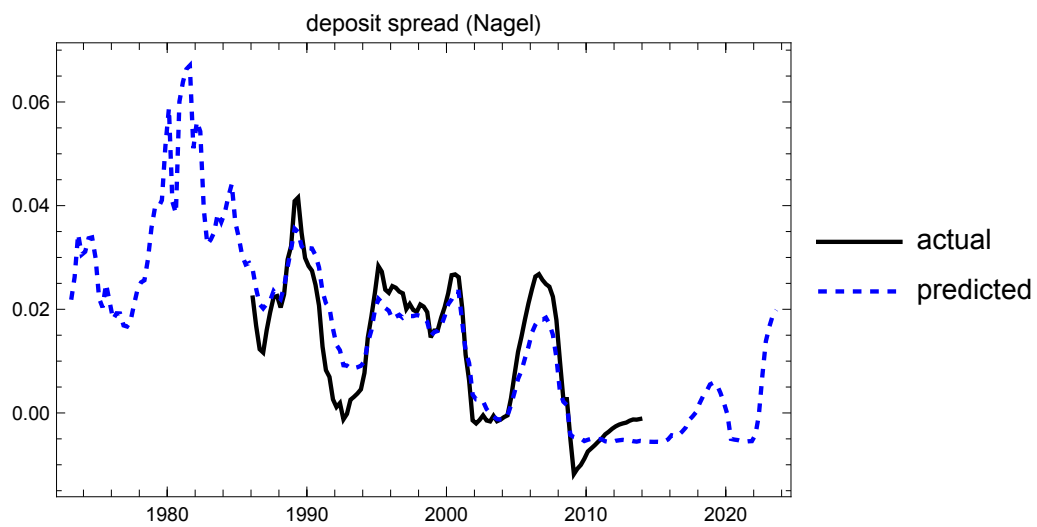


Figure A-11: Actual and predicted deposit spread (Nagel).

B Conceptual Framework: Formal Discussion

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

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

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

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

We denote the objective of agent i in history ϵ^t by $U^i(\cdot, \cdot; \epsilon^t)$, 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 collection $(c^g(\epsilon^t), \{c^i(\epsilon^t)\}_{i \in \mathcal{I}})$, and letting $s^a(\epsilon^t)$ denote the economy's exogenous state in history ϵ^t , we represent the aggregate constraints by

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

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

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

Equilibrium. In history ϵ^t , the economy is characterized by $s^a(\epsilon^t)$, $\mathcal{A}(s^a(\epsilon^t); \epsilon^t)$, and $\{\mathcal{C}^i(\cdot; \epsilon^t), U^i(\cdot, \cdot; \epsilon^t)\}_{i \in \mathcal{I}}$. An equilibrium in history ϵ^t is a policy $c^{g*}(\epsilon^t)$ and a collection of private-sector choices and states, $\{c^{i*}(\epsilon^t), s^{i*}(\epsilon^t)\}_{i \in \mathcal{I}}$, such that⁴

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

⁴Recall the convention to subsume competitive prices under 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, any potential choice that is individually feasible for private-sector agents after the regime change equals a feasible choice prior to the regime change coupled with the proposed adjustment.

- 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

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

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. $\square$

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

$$\sum_{x=n,m} \Delta x^i + \Delta \varphi^i = \Delta \tau^i, \quad (\text{B-2})$$

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

$$\Delta r^b + \Delta \varphi^b = \sum_{x=\ell,n} \Delta x^b + \Delta \tau^b, \quad (\text{B-4})$$

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

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

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

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

where we denote the equilibrium spread on generic asset x by $\sigma^{x*} \equiv 1 - \mathbb{E}[\text{sdf}_+^* R_+^{x*}]$. As with Equations (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

$$\Delta \varphi^g + \Delta \varphi^i + \Delta \varphi^b = 0, \quad (\text{B-8})$$

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 in the main text. 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

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

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.⁵

We conclude that the restrictions

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

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;⁶ with stochastic returns, the time- $(t + 1)$ transfer generally must be stochastic as well.

⁵ $\Delta\tau^i + \mathbb{E}[\text{sdf}_+^* \Delta\tau_+^i] = \Delta n^i \{(1 - \lambda^{-1}) + \mathbb{E}[\text{sdf}_+^* (R_+^{m*}/\lambda - R_+^{n*})]\} = 0$, where the last equality follows from the equilibrium relationship between R_+^{m*} and R_+^{n*} .

⁶The 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 hold. 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.⁷ 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 holds 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.⁸

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 a less than perfectly elastic deposit supply schedule. In the initial equilibrium, this schedule is given by $R_+^{n*}(n^b)$, implying that deposit funding of size n^b results in gross interest payments of $h_+(n^b) \equiv n^b \cdot R_+^{n*}(n^b)$ in the following period. Deposit-related operations—such as processing payments for customers—incur costs denoted by $\varphi^b = \alpha(\zeta)n^b$, where α may decrease in the reserves-to-deposits ratio $\zeta \equiv r^b/n^b$, for instance because liquidity transformation entails operational and stability risks, which increase as the reserve buffer shrinks. The bank chooses the optimal reserve ratio ζ by weighing

⁷Wallace (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.

⁸For a related discussion, see Brunnermeier and Niepelt (2019, p. 35).

the benefit of holding more reserves—lower operational cost—against the cost of a lower return:

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

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 $-R_+^{n*} - (1 - \zeta^*)\beta - (n^b + \ell^b/(1 - \zeta^*)) \partial R_+^{n*} / \partial n^b$.⁹ Indifference thus requires

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

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

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

⁹Note 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.¹⁰ 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.

¹⁰If R_+^* is deterministic, the fourth line reduces to $\Delta\tau_+^b = -\alpha(\zeta^*)\Delta n^b/\mathbb{E}[\text{sdf}_+^*]$.

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