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# A Field Guide to Monetary Policy Implementation Issues in a New World with CBDC, Stablecoin, and Narrow Banks

**James A. Clouse**

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# A Field Guide to Monetary Policy Implementation Issues in a New World with CBDC, Stablecoins, and Narrow Banks

James A. Clouse[1]
Board of Governor of the Federal Reserve System
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## Abstract

This paper develops an analytical framework aimed at shedding light on the implications of the evolution of financial market structure for monetary policy implementation and transmission. The basic model builds on that developed in Chen et. al. (2014) which, in turn, draws inspiration from the pioneering work of Tobin (1969) and Gurley and Shaw (1960). The paper focuses, in particular, on the implications of introducing new types of fixed-rate financial assets in the financial system including retail and wholesale central bank digital currency (CBDC), stablecoins issued by narrow nonbanks, and deposits issued by narrow banks. The analysis also provides a crude way of capturing some of the effects of bank capital and liquidity regulation on financial intermediation and monetary policy implementation. Perhaps the most important conclusion is that the introduction of new fixed-rate assets by the Federal Reserve or by other financial intermediaries can have significant effects on equilibrium interest rates and patterns of financial intermediation and may also affect the potency of monetary policy tools. These effects are most pronounced when new financial assets are close substitutes for existing financial assets.

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[1] The views expressed in this paper are those of the author and do not reflect an official view of the Board of Governors or its staff. The paper has benefitted from the comments and insights of colleagues including Chris Gust, Kyungmin Kim, Romina Ruprecht, Margaret DeBoer, Matthew Malloy, and Don Kim. This paper is dedicated to the memory of Dave Small, a great economist, friend and colleague at the Board, and a truly devoted student of the Federal Reserve and its history.

# 1. Introduction

Monetary policy implementation is not in Kansas anymore. After two of the strongest tornadoes in recorded economic history ripped through the global economy and financial system in 2008 and 2020, central banks around the world were torn from their foundations and catapulted into a new world of large balance sheets, new policy tools, and rapidly evolving technology, regulation, and financial structure. In this new environment, the previously placid and technical realm of monetary policy implementation has become an area of intense interest in which new policy questions abound. How should a central bank employ new tools—administered interest rates on liabilities and asset purchases—to best achieve the desired stance of monetary policy? What are the linkages between regulatory developments affecting the bank and nonbank sectors and monetary policy implementation? And how could new technological and structural developments including the advent of central bank digital currencies (CBDC), stablecoin, and narrow banks affect monetary policy implementation and transmission?

This paper attempts to provide a framework that sheds light on the implications of the evolution of financial market structure for monetary policy implementation and transmission. The basic model extends the framework developed in Chen et. al. (2014) which, in turn, draws inspiration from the pioneering work of Tobin (1969) and Gurley and Shaw (1960). To preview the main results, the framework describes a set of interconnected demand and supply curves for all financial instruments in a competitive model of financial markets with two types of frictions—(i) portfolio allocation costs that determine the extent to which households and financial intermediaries are willing to "reach for yield" in their asset allocation decisions and (ii) balance sheet costs for financial intermediaries that determine the extent to which they are willing to expand their balance sheet to take advantage of potential profit opportunities. In this setup, the Federal Reserve's administered rates exert a powerful influence over the level of other market interest rates and patterns of financial intermediation. Within this framework, the discussion considers the implications of structural changes in the financial sector including the introduction of central bank digital currency (CBDC), stablecoins, and deposits offered by narrow banks. In general, we find that the effects of these structural innovations can be large or small depending on the extent to which new instruments substitute for existing financial instruments and how readily the "supply" of existing financial instruments can adjust. At one extreme, financial innovations that pull demand away from a Federal Reserve liability such as currency may have very little effect on the broader financial system if the Federal Reserve passively adjusts the size and composition of its balance sheet to accommodate the demand for its liabilities. At another extreme, financial innovations resulting in new financial instruments that directly substitute for deposits or nonbank debt may have more widespread repercussions for interest rates and the size and structure of the balance sheets of households and financial intermediaries. Financial innovations of this type also tend to have larger implications for the efficacy of the Federal Reserve's policy tools. Of course, the nature of the results here stem from the structure and assumptions underlying the basic model, and alternative modeling paradigms could well generate qualitatively different results.

The remainder of this paper is organized as follows. Section 2 traces the transition of policy implementation from the "old world" in place prior to the Global Financial Crisis to the "new world" as it exists today. Section 3 describes the basic structure of the model and section 4 provides a discussion of some basic comparative statics exercises. Section 5 considers some implications of the model for policy implementation and transmission. Section 6 considers variations on the basic model that include the

introduction of retail and wholesale CBDC, stablecoins, and deposits offered by narrow banks. Section 7 considers some implications of changes in financial market structure for monetary policy implementation and transmission through the Federal Reserve's balance sheet. Section 8 concludes.

## 2. Transition to the New World

For decades prior to the global financial crisis (GFC) in 2008, the Federal Reserve implemented monetary policy in a "scarce reserves" regime. In that operating framework, the demand for reserves was largely driven by reserve requirements.[2] The Federal Reserve did not have the authority to pay interest on reserves in those years. As a result, banks typically sought to hold only enough reserves to meet their requirement along with a small buffer of "excess" reserves to guard against the cost of a reserve deficiency.[3] The Federal Reserve then conducted open market operations to keep the supply of reserves aligned with the estimated demand for reserves at the intended federal funds rate. Absent any remuneration on required or excess reserves, banks actively sought to minimize the level of transaction accounts and other reservable liabilities, and thereby minimize the "reserve tax." Over the course of the 1990s, the development of retail sweep accounts allowed many depositories to greatly reduce their level of required reserves.[4] As shown by the gray line in Chart 1, by the early 2000s, the level of reserve balances in the system had dropped to very low levels and in mid-2007 averaged around $10 billion in most weeks. Even with this very low level of reserves, the Federal Reserve was able to exert effective control over the level of short-term interest rates. The Open Market Desk conducted frequent operations to keep the aggregate supply of reserves at a level consistent with the target funds rate. Banks relied on intraday credit at the Federal Reserve to facilitate payments during the day and then settled their end of day positions through late-day transactions in the federal funds market. In 2006, after years of deliberations, the Congress passed legislation that provided authority for the Federal Reserve to pay interest on reserves maintained by depository institutions beginning in 2011.

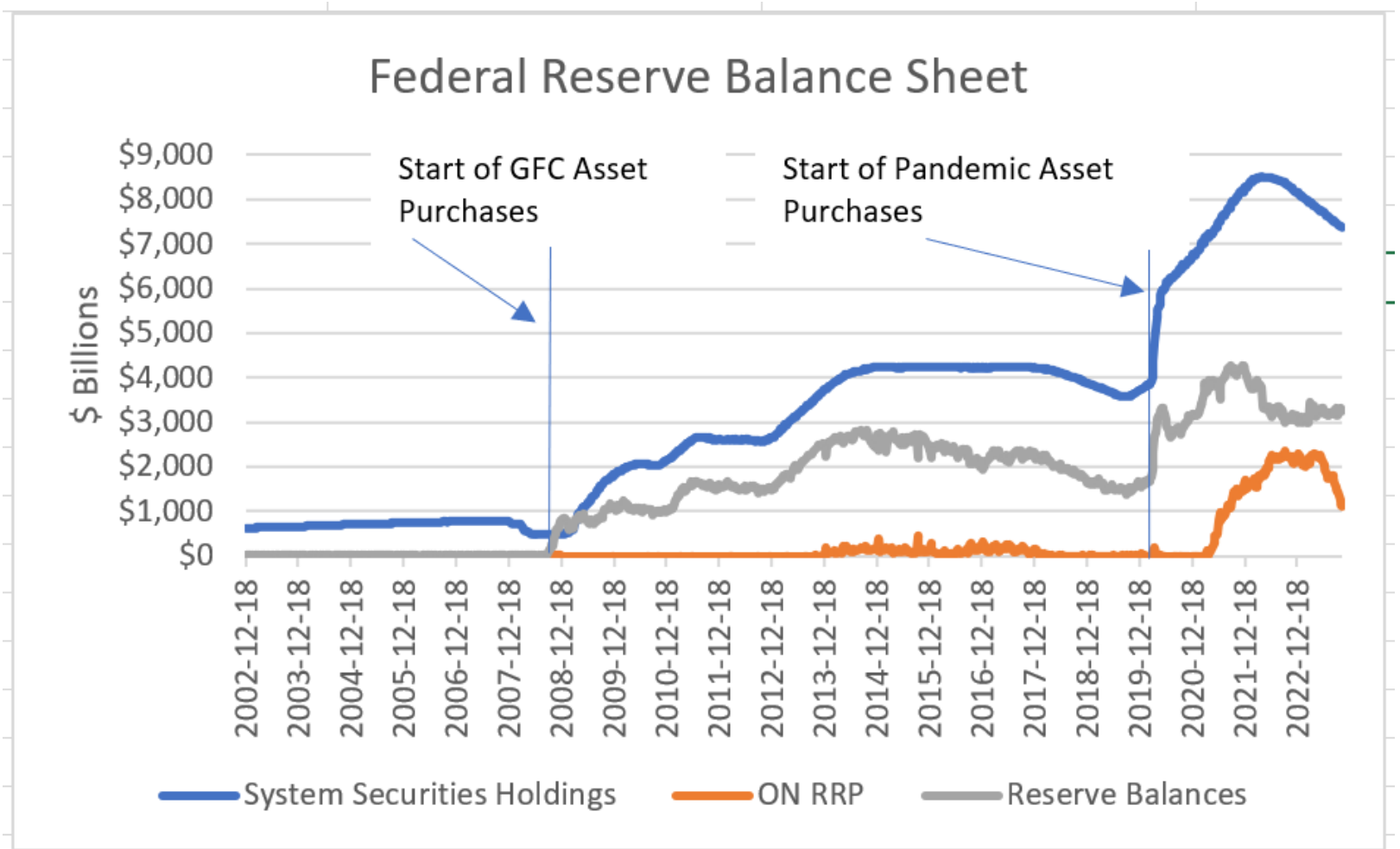
In 2007, funding strains in the banking sector emerged as concerns about the housing sector mounted. To address pressures in term funding markets, the Federal Reserve established the Term Auction Facility (TAF) in late 2007 as well as liquidity swap lines with a group of major central banks. The swap lines allowed foreign central banks to obtain dollar funding that could be used to address funding strains in their jurisdictions that might otherwise amplify the strains in U.S. financial markets. By early 2008, the ground was shifting under the entire U.S. financial system. The Federal Reserve established two emergency lending programs in early 2008 just prior to the failure of Bear Stearns, and many more were established following the collapse of Lehman Brothers in the fall of 2008. Among many other actions taken that year, the Congress accelerated the authority for the Federal Reserve to begin paying interest on

[2] Prior to 1980, only banks that were members of the Federal Reserve System were subject to reserve requirements. The Monetary Control Act of 1980 extended reserve requirements to all depository institutions. The base for reserve requirements was established by statute and included net transaction accounts, nonpersonal time deposits, and net eurocurrency liabilities. The statute also set minimum and maximum reserve requirement ratios for each of these categories of bank liabilities.

[3] Reserves were maintained over a two-week maintenance period. Banks that did not hold reserves sufficient to meet their requirement were subject to a penalty equal to the discount rate plus two percentage points applied to the reserve shortfall. Banks that incurred frequent reserve deficiencies were also subject to "counseling" by their Reserve Bank.

[4] In these arrangements, a large portion of customer's funds would be placed in savings accounts (not subject to reserve requirements) and balances then would be "swept in" to the customer's transaction accounts at regular intervals to cover payments.

Chart 1: Federal Reserve Securities Holdings and Selected Liabilities



reserves, pulling the implementation date forward to the fall of 2008. By December of 2008, the FOMC had cut the federal funds rate to the effective lower bound and launched the first of several programs of large-scale asset purchases aimed at providing additional policy accommodation by putting downward pressure on longer-term interest rates. Asset purchase programs conducted over the period from 2008 to 2014 led to a massive expansion of the Federal Reserve's securities portfolio (blue line in Chart 1) from about $800 billion in mid-2007 to more than $4 trillion by mid-2014. The expansion in the Federal Reserve's assets was accompanied by a corresponding massive increase of reserves in the banking system. Reserve balances in mid-2014 stood at about $2.6 trillion or 260 times the level of reserves, on average, in mid-2007.

Following the GFC, the Congress passed the Dodd-Frank Act (DFA) which, along with parallel efforts by the Basel Committee on Bank Supervision, established new standards for bank capital and liquidity. One particularly important aspect of the new bank regulatory regime was the introduction of new liquidity regulation in the form of a liquidity coverage ratio (LCR) that required banks to maintain so-called high quality liquid assets (HQLA) equal to or greater than an estimate of net outflows over a 30-day period in a stress event; so-called Tier 1 HQLA was limited to Treasury securities and reserves maintained at central banks.[5] Other important elements of the new bank regulatory regime included stronger capital requirements, particularly for global systemically important banks (GSIBs). These developments marked a sea change for bank regulation but also for monetary policy implementation. While the LCR formally treated reserves and Treasury securities as interchangeable for the purpose of determining high quality liquid assets (HQLA), many banks appeared to have a preference to maintain a significant fraction of their HQLA in the form of reserves. Those preferences may stem from the need to demonstrate the ability to "monetize" HQLA under the LCR and other aspects of the regulatory regime including liquidity stress tests. New capital charges also affected the incentives for banks to expand their balance sheets and interacted with aspects of the monetary policy implementation framework. Flush with reserves, most banks had little need to turn to the late-day federal funds market to cover the garden variety types of payments outflows that supported interbank trading in the funds market in the scarce reserve regime. Moreover, with banks earning interest on reserves, banks with excess reserves were content to leave those balances with the Federal Reserve rather than offer them at lower rates to potential borrowers. In this environment, the interbank dimension of the federal funds market withered away. The federal funds market that survived became, in effect, a type of wholesale funding market in which the primary lenders are Federal Home Loan Banks (FHLBs). FHLBs with excess cash had incentives to lend at rates below the interest on reserve balances (IORB) rate because balances maintained by FHLBs at the Federal Reserve are not eligible to earn interest. And some banks, notably branches of foreign banking organizations, found overnight borrowing from the FHLBanks to be a useful part of their overall funding mix, particularly in light of the favorable regulatory treatment accorded to overnight borrowing from FHLBanks under the LCR.[6]

As the Federal Reserve's balance sheet was expanding during the long recovery from the crisis in 2008, the Federal Reserve developed a new tool—the overnight reverse repurchase agreement (ON RRP)

[5] The LCR regulation and calculations are quite complex. For details, see Federal Reserve Board - Federal banking regulators finalize liquidity coverage ratio.

[6] Under the LCR, the runoff rate on overnight federal funds borrowing from the Federal Home Loan Banks is set at 40 percent rather than the 100 percent runoff rate assigned to most forms of unsecured wholesale overnight funding. See LCR40 - Cash inflows and outflows (bis.org) sections 40.40 and 40.42 for details.

facility—to facilitate effective monetary policy implementation in a world with abundant reserves. In many ways, the rate offered at the ON RRP facility operates in a manner similar to the interest rate on reserves for banks. Both rates establish a lower bound on the rate at which financial intermediaries will lend to private counterparties. The ON RRP rate establishes a lower bound on the overnight lending rate for the range of institutions designated as counterparties for ON RRP operations—a group including primary dealers, government sponsored enterprises, and eligible money market mutual funds; the IORB rate sets a lower bound on the rate at which depository institutions are willing to lend in overnight funding markets.

In late 2015, the FOMC lifted the target range for the federal funds rate off the effective lower bound. To implement this change, the IORB and the rate offered on the ON RRP were both increased by 25 basis points. The pass through of these changes to other market rates was immediate and complete. In later years, additional rate increases were similarly implemented through appropriate adjustments in these Federal Reserve administered rates. All of these actions were completed smoothly. The new system of implementing monetary policy through administered rates proved highly effective, even with enormous quantities of reserves in the banking system. Following discussions extending over several years, in 2019, the FOMC formally adopted an "ample reserves" regime as its operating framework.[7] In this operating framework, the FOMC provides a level of reserves sufficient to keep most banks operating on the "flat portion" of their reserve demand curve. The level of reserves would expand gradually over time along with the trend growth in reserve demand, but the Federal Reserve would not need to fine tune the daily levels of reserves as in the period prior to the GFC. Under the ample reserves regime, the key tools for keeping the federal funds rate in the target range established by the FOMC are the interest rate on reserves and the offered rate at the ON RRP facility.

In 2020, the onset of the pandemic and the "dash for cash" spurred a massive wave of selling in the Treasury market, severely disrupting market functioning and threatening to undermine global financial stability. In response, the FOMC purchased enormous volumes of Treasury and agency securities from March through May of that year. Later, the FOMC transitioned to a program of steady, sizable monthly asset purchases that continued through the beginning of March 2022. The net result of these asset purchase programs was another enormous increase in the size of the Federal Reserve's balance sheet and a corresponding enormous increase in its liabilities including reserves and balances placed with the ON RRP facility (orange line in Chart 1).

While designed to support the effective implementation of monetary policy, the advent of IORB and the ON RRP facility created new fixed-rate, risk-free assets potentially available to a wide range of financial institutions. The availability of these new assets, in turn, spawned interest in new business models centered on these assets. The availability of IORB spurred renewed interest in "narrow banking" models which featured specialized depository institutions offering deposits and holding only reserve balances as an asset. Importantly, such specialized depository institutions would not be subject to the same regulations that apply to traditional banking firms and would not be FDIC-insured and so not subject to the FDIC insurance premium assessed on traditional banks. As a result, such narrow banks could operate profitably with very thin net interest margins. Nonbank financial institutions, particularly those associated with "stablecoins," also recognized the potential benefits of gaining access to the Federal

[7] See the press release at https://www.federalreserve.gov/newsevents/pressreleases/monetary20190130c.htm.

Reserve's balance sheet. To that end, various proposals by nonbank financial intermediaries considered the possibility of becoming an ON RRP counterparty or establishing a special purpose money market mutual fund that would meet the eligibility criteria to become an ON RRP counterparty. And layered on top of these developments, central banks including the Federal Reserve have discussed the potential benefits of issuing central bank digital currencies (CBDCs) that could provide access to the Federal Reserve's balance sheet to individuals and other entities in a new way and one that could compete or interact with deposits offered by narrow banks or stablecoins.

This brief synopsis of the extraordinary developments over the period since the GFC sets the backdrop for many of the analytical issues considered in the remainder of the paper. In the "old world," monetary policy implementation was largely "bank centric" with bank reserve requirements and banks' demand for excess reserves playing a central role. In that world, absent any remuneration on reserves, reserve balances were largely a "hot potato," and banks actively sought to minimize the large opportunity cost in holding reserves. In contrast, in the new world, Federal Reserve liabilities are in high demand by both banks and nonbanks seeking safety, liquidity, and risk-free returns comparable to other money market rates. Under the ample reserves operating framework, the Federal Reserve accommodates demand for its liabilities, and its policy tools importantly operate through both banks and nonbanks. And, as discussed in more detail below, the new world of monetary policy implementation is one in which bank regulation, evolving financial structure, and the nature and scale of the Federal Reserve's assets and liabilities are inextricably intertwined and interact with each other.

# 3. Baseline Model with Passive Balance Sheet Management

The baseline model based on Chen et. al. (2014) involves a number of sectors including households, banks, nonbanks, businesses, the government and a foreign sector. Following in the footprints of Tobin (1969), the model derives the demand for financial assets in each sector based on a simple portfolio optimizing framework. The key ingredients of the framework are portfolio "habits" that define baseline target asset and liability allocations for households and financial intermediaries. Households and financial intermediaries may deviate from these portfolio habit allocations but incur portfolio costs in doing so. In addition to portfolio composition costs, financial intermediaries face a cost of expanding the size of their balance sheets.

## Structure of Financial and Nonfinancial Sector Balance Sheets

The model adopts a flow of funds framework by focusing on the balance sheets of the financial and nonfinancial sectors. As shown in figure 1, to keep things manageable, the baseline model limits financial sectors to banks, nonbanks, and the Federal Reserve.

As shown in the upper left panel, households have net worth that they invest in various financial assets including Treasury securities, bank deposits, physical currency, and nonbank debt. Banks invest in Treasury securities, loans, and reserves. These assets are financed by borrowing in the market for deposits. Nonbanks invest in Treasury securities, business loans, and Federal Reserve liabilities. These assets in turn are financed by issuing debt. Businesses hold inventories and other real assets and finance these holdings with bank loans. The Federal Reserve issues currency, reserves, and other liabilities with corresponding assets in the form of Treasury securities. The government sector (not shown) issues securities to finance spending. The implicit asset for the government sector is the present discounted value of future tax revenues. In this structure, the household sector is the net source of wealth in the

# Figure 1: Financial Market Structure in the Baseline Model

**Households**

| Assets | Liabilities |
|---|---|
| Currency | |
| Treasury Securities | |
| Nonbank Debt | |
| Deposits | Net Worth |
| | |

**Banks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Deposits |
| Loans | |
| Reserves | |
| | |
| | |

**Nonbanks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Nonbank Debt |
| Loans | |
| Other Fed Liabilities | |
| | |
| | |

**Business**

| Assets | Liabilities |
|---|---|
| Physical Assets | Loans |
| | |
| | |
| | |
| | |

**Federal Reserve**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Currency |
| | Reserves |
| | Other Liabilities |
| | |
| | |

**Foreign Sector**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Other |
| | |
| | |
| | |
| | |

economy and the only domestic sector that is a net lender. The government and business sectors are net borrowers.

In addition to the financial and nonfinancial sectors noted above, the model includes a foreign sector. The foreign sector holds Treasury securities, and we assume that the foreign sector's demand for Treasury securities is described by a simple demand curve with a structure similar to that derived for households and financial intermediaries. The presence of a foreign sector plays a significant role in the model in allowing domestic sectors to shift between loans and other assets while maintaining equilibrium in the Treasury market.

## Demand and Supply Across Markets

The formal details of the general specification of the model are discussed in the appendix. The basic features of the model described above can be illustrated more concretely in a simplified baseline version of the model. As discussed in the appendix, in this baseline version, we assume the cost functions defining the preferred habitats for households and financial intermediaries take an especially simple form. With this assumption, the household asset demands are all of the form:

$$HHA_i = \alpha_{i,HHA}W + \delta_{i,HHA}(r_i - \bar{r}_{HHA}) = \alpha_{i,HHA}W + \alpha_{i,HHA}\delta_{HHA}(r_i - \bar{r}_{HHA})$$

Here W is the value of household wealth. The shares $\alpha_{i,HHA}$ capture the household habit for a particular asset class $HHA_i$. The term $\delta_{i,HHA}$ is proportional to the inverse of the cost of deviating from the habit and can be thought of as the own-rate interest sensitivity of demand for asset class $HHA_i$. The magnitude of $\delta_{i,HHA}$ for each asset is scaled by the habit for each asset class. As a result, if households hold only a small portion of their portfolio in a particular asset class, the extent to which they are willing to deviate from that habit level is scaled down proportionally. The term $\bar{r}_{HHA}$ for households is the habit-weighted average of the rates on the set of assets held by the household sector in the baseline model—a set that includes Treasury securities, nonbank debt, deposits, and physical currency.

The bank and nonbank optimal asset choices are all of a similar form:

$$BKA_i = \alpha_{i,BKA}S_{BK} + \delta_{i,BKA}(r_i - \bar{r}_{BKA}) = \alpha_{i,BKA}S_{BK} + \alpha_{i,BKA}\delta_{BKA}(r_i - \bar{r}_{BKA}) \quad (1)$$

$$NBA_i = \alpha_{i,NBA}S_{NB} + \delta_{i,NBA}(r_i - \bar{r}_{NBA}) = \alpha_{i,NBA}S_{NB} + \alpha_{i,NBA}\delta_{NBA}(r_i - \bar{r}_{NBA}) \quad (2)$$

Here, $S_{BK}$ and $S_{NB}$ are the optimal scale of banks and nonbanks, respectively. As for the case with households, $\bar{r}_A$ is the habit-weigted average of rates across all assets *specific to a sector*. For banks, $\bar{r}_{BKA}$ is the habit-weighted average of the rates on Treasury securities, loans, and reserves. For nonbanks, $\bar{r}_{NBA}$ is the habit-weighted average of the rates for Treasury securities, loans, and other Federal Reserve liabilities. The terms $\delta_{i,BKA}$ and $\delta_{i,BKA}$ are proportional to the inverse of the cost of deviating from the habit with the scale factor again based on the habit for each asset. These parameters again capture the interest rate sensitivity of the optimal composition of assets for financial intermediaries.

The solutions for the scale of banks and nonbanks (or the quantity of deposits and nonbank debt, respectively) are given by:

$$S_{BK} = \phi(\alpha_{TR}r_{TR} + \alpha_{LN}r_{LN} + \alpha_{rs}r_{RS} - r_{DP})$$

$$S_{BK} = \phi(\alpha_{TR} r_{TR} + \alpha_{LN} r_{LN} + \alpha_{OL} r_{OL} - r_{ND})$$

Where $\phi$ is the inverse of the marginal balance sheet cost. Thus the optimal scale of financial intermediaries is determined by their net interest margin—the expressions inside the parentheses. Here again, the inverse of the marginal balance sheet cost can be regarded as the sensitivity of the optimal scale of the firm to variations in net interest margin.

In the baseline model, we assume banks issue only deposits and nonbanks issue only nonbank debt. In this case, we have:

$$BKL_{DP} = S_{BK}$$

$$NBL_{ND} = S_{NB}$$

The expression for the supply of loans issued by the business sector is described by:

$$l = \mu - a(r_{LN} - r_{LN}^*)$$

Here the intuition is simply that desired investment spending is a function of the gap between the loan rate and the equilibrium loan rate, $r_{LN}^*$. Loan demand is then assumed to be proportional to investment spending.

And the foreign sector demand for Treasury securities is given by:

$$T_F^A = \bar{F} + f(r_{TR} - x)$$

where

$$x = (r_{RS} + r_{OL})/2$$

Here the variable $x$ – the average of the Federal Reserve's administered rates on reserves and other Federal Reserve liabilities – is a proxy for returns that foreign investors could earn on assets other than Treasury securities. The foreign sector demand for Treasury securities just captures the notion that global investors become more interested in investing in Treasury securities when Treasury yields move up relative to other benchmark interest rates.

The total supply of Treasury debt is exogenous and given by:

$$T_G^L = \bar{T}$$

## The Demand for Federal Reserve Liabilities

The demand for reserves and other Federal Reserve liabilities is characterized by equations (1) and (2) above. Although perhaps not immediately apparent, these expressions are closely related to standard formulations of the "demand for reserves." Cutting through some of the notation and simplifying, the demand for reserves can be rewritten from equation (1) as:

$$Reserve\ Demand = \alpha_{RS} S_{BK} - \rho_T(r_{TR} - r_{RS}) - \rho_{LN}(r_{LN} - r_{RS})$$

Consistent with the intuition in many models, the demand for reserves in the baseline model is partly a function of the optimal scale of the bank as captured by the term $\alpha_{RS}S_{BK}$. This scale effect could stem from precautionary motives in connection with uncertainty about deposit levels as in the classic Poole model (1968).[8] Or it could stem from an asset demand for reserves related to the superior safety, liquidity, and return characteristics of reserves as in the "risk-free" asset underlying the capital asset pricing model as in Sharpe (1964). Of course, both of these underlying sources of demand may be present. The model implies two opportunity costs that matter for holding reserves—one represented by the spread between the Treasury rate and the interest rate on reserves and another represented by the spread of the loan rate over the interest rate on reserves. The demand for reserves also depends indirectly on deposit rates through their effect on the scale of the banking firm. The demand for other Federal Reserve liabilities held by nonbanks and the demand for currency held by households can be written in a similar form. Many of the results discussed below turn on the relative strength of scale effects and the substitution effects captured by the opportunity cost terms in the demand functions for Federal Reserve liabilities.

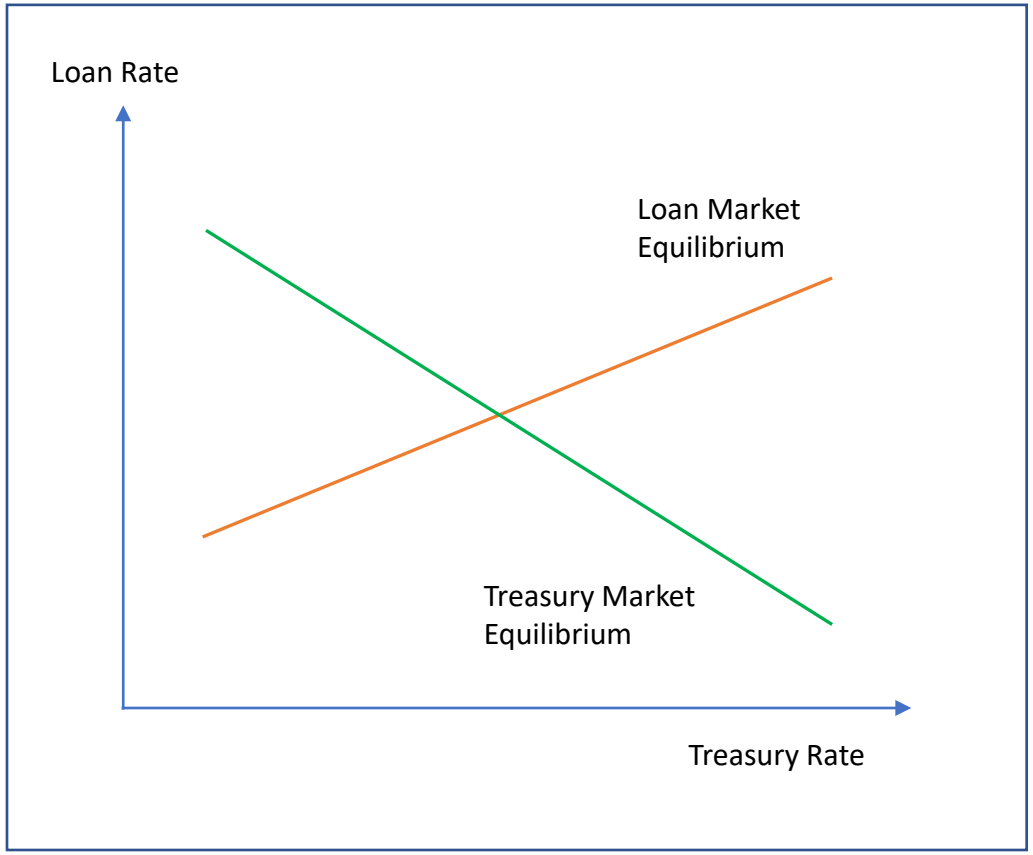
## Equilibrium Rates and Quantities

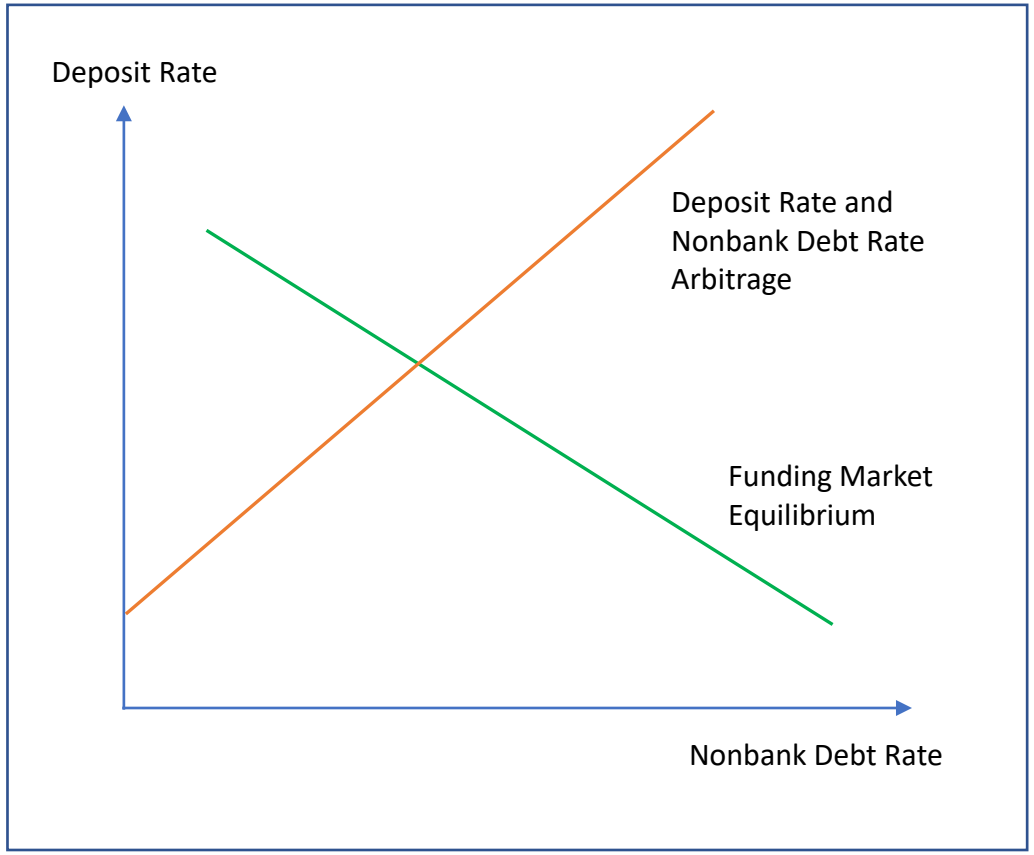
As discussed in the appendix, the solutions to the general model can be expressed in matrix form. The solutions for the baseline version of the model are simple enough to compute analytically as shown in the appendix. As discussed in more detail in the appendix, with similar calibrations for banks and nonbanks, the system of equations describing the equilibrium rates can be boiled down to two equations—one describing the combinations of the loan rate and Treasury rate consistent with equilibrium in the loan market and one describing the combinations of the loan rate and Treasury rate consistent with equilibrium in the Treasury market. As shown by the orange line in the left panel of figure 2, the loan market equilibrium curve is upward sloping—all else equal, a higher Treasury rate implies that loan rates must be higher to leave intermediaries willing to provide any given quantity of loans. The Treasury market equilibrium curve (the green line) is generally downward sloping—all else equal, a lower loan rate induces more borrowing in the loan market requiring higher Treasury rates to induce the additional funding necessary to clear the Treasury market.

With the equilibrium Treasury rate and loan rate in hand, the determination of the equilibrium rates for deposits and nonbank debt can also be described by a simple diagram. With the structure assumed in the baseline model, the equilibrium deposit rate is tightly linked to the equilibrium rate for nonbank debt as shown by the orange line in the right panel of figure 2. The spread between the deposit rate and nonbank debt rate reflects the gap between the administered rate on reserves and the administered rate on other Federal Reserve liabilities and also household's relative demands for deposits versus nonbank debt. The funding market equilibrium relationship, the green line in the diagram, describes the balance between household's desire to invest in deposits and nonbank debt and the supply of deposits and nonbank debt offered by banks and nonbanks. The position of this curve is strongly affected by the weighted average return on assets for banks and nonbanks and also by the rates on assets that compete with deposits and nonbank debt in household portfolios. In the baseline model, these are just the rates on physical currency and Treasury securities.

[8] See also recent studies by Lopez-Salido and Vissing-Jorgenson (2023) and Afonso, Giannone, La Spada and Williams (2023).

# Figure 2: Equilibrium in the Baseline Model



The solutions for the endogenous rates imply corresponding solutions for the equilibrium quantities of all the financial instruments in the model. Because households are assumed to have relatively strong "habits" for their desired holdings of financial assets, household preferences largely drive the relative size of financial intermediaries. In particular, the relative size of bank, nonbank, and Federal Reserve balance sheets is largely driven by the relative size of household demands for deposits, nonbank debt, and physical currency respectively. The composition of assets for banks and nonbanks largely reflects the assumed "habit" composition for these sectors. Households, the foreign sector, and the Federal Reserve end up holding most of the outstanding stock of Treasury securities.

## Aspects of Model Calibration

The model incorporates many parameters so the calibration is necessarily at a high level. The most important feature of the calibration described in the appendix is that optimal asset allocations for households are not highly responsive to changes in interest rates. This stems from the assumption that households have relatively high costs of deviating from their "habit" levels for each asset category. In contrast, financial intermediaries have relatively low costs of deviating from their baseline "habit" allocations across assets. As a result, the composition of assets for financial intermediaries is sensitive to changes in relative rates of return across assets. In addition, financial intermediaries have low balance sheet costs and thus are willing to expand their balance sheet in response to a widening in net interest margins.

The calibration also embeds an assumption that bank substitution effects outweigh balance sheet scale effects in the determination of the optimal desired holdings for any particular asset. For intermediaries, an increase in a market interest rate on one particular asset, holding all other rates constant, has two types of effects. An increase in the market rate on a particular asset class, all else equal, pushes up the return on assets and leads an intermediary to want to expand its balance sheet. The same increase in the market rate on the same particular asset class—all else equal—induces a substitution effect across all assets held by financial intermediaries. So, for example, an increase in the loan rate tends to lead banks to want to expand their balance sheet and also to shift out of other assets and into loans. The calibration assumes that the substitution effects dominate when the substitution and scale effects work in opposite directions. For example, an increase in Treasury rates—all else equal—generates a positive scale effect on loans by increasing the rate of return on bank assets. On the other hand, a change in the rate on Treasury securities relative to loan rates encourages banks to substitute away from loans and toward larger Treasury holdings. We assume parameter settings such that this substitution effect prevails in determining the net effect of an increase in Treasury rates on loans (and vice versa) extended by financial intermediaries.

## General Features of the Model Solutions

The reduced form solutions for the equilibrium rates and quantities (shown in the appendix) capture all of the interactions in the model. Even with the simplified baseline model, these reduced form equations are somewhat complicated. However, some basic features of the model are readily apparent. One key feature is that all asset demands in the model depend on relative rates of return across assets. An implication of this feature is that a given increase in *all* of the Federal Reserve's administered rates (including the notional rate on physical currency) along with an equivalent increase in the equilibrium loan rate generates a corresponding increase in all of the endogenous rates in the model. With all rates in the model rising by equal amounts in this scenario, the relative rates of return among all financial assets

are unchanged. And, as a result, the equilibrium quantities of all financial assets and liabilities are unchanged.

Another general feature of the baseline model stems from the assumption that the Federal Reserve passively accommodates demands for its liabilities. As a result, household substitutions between Treasury securities and physical currency have little effect on interest rates. A shift by households from Treasuries to currency generates corresponding increases in the Federal Reserve's holdings of Treasury securities and the quantity of currency issued. The reverse is true for household shifts from currency to Treasury securities. In that case, the Federal Reserve sheds some of its Treasury securities holdings and reduces the outstanding quantity of currency.

# 4. Comparative Statics in the Baseline Model

This section illustrates some of the key features of the model through a set of comparative statics exercises focusing on the effects of changes in key parameters including administered interest rates, the aggregate supply of Treasury securities, balance sheet costs for financial intermediaries, portfolio substitution costs for households and financial intermediaries, and shifts in household habits across financial assets.

## Effects of Changes in the Administered Rate on Reserves

An increase in the administered rate on reserves directly affects the rate of return on bank assets and generally tends to put upward pressure on market interest rates. As shown in the left panel of figure 3, a change in the rate on reserves moves both the loan market equilibrium curve and the Treasury market equilibrium curve up, resulting in an increase in both loan rates and Treasury rates represented by the movement from the blue dot to the red dot. As shown in the right panel of figure 3, the equilibrium spread between the deposit rate and the nonbank debt rate increases and both rates move up in tandem with the rise in loan rates and Treasury rates. The rise in deposit rates is slightly larger than the rise in nonbank debt rates because the increase in the interest rate on reserves generates a slightly larger increase in the return on bank assets than in the return on nonbank assets.

The top panel of figure 4 provides a schematic of the "impulse response" pattern of a change in the administered rate on reserves and all of the endogenous variables. The first row of this table shows the response coefficients of the equilibrium rates in the model to a 1 basis point rise in the administered rate on reserves. The blue bar for the column corresponding to the change in the interest rate on reserves has a response coefficient of 1 by definition. The response coefficients of the other endogenous rates are shown by the magnitude of the bars (blue is a positive response coefficient, red is a negative response coefficient.) The remaining rows in the table show the response coefficients for the equilibrium holdings of the various financial instruments for each sector. For example, the second row indicates that households respond to an increase in market rates induced by an increase in the interest rate on reserves by shifting into market instruments—Treasury securities and deposits—with slightly higher rates and away from currency with a fixed rate of zero. There is also a small net shift out of nonbank debt reflecting the increase in the returns on other assets relative to the nonbank debt rate. With the interest rate on reserves moving up somewhat more than market rates, the third row shows that banks tend to substitute out of holdings of Treasury securities and loans in favor of holding additional reserves. The scale of the banking sector increases modestly. Conversely, with no change in the rate on other Federal Reserve liabilities, relative rates on assets for nonbanks shift in favor of market instruments. Nonbanks

shift out of other Federal Reserve liabilities and into Treasury securities and loans. The bottom row of the table shows the effect of the change in the rate on reserves on the market totals for each instrument. The market total for loans edges down with the runoff in loans by banks partially offset by the increase in loans at nonbanks. Total reserves in the system increase while other Federal Reserve liabilities held by nonbanks decline.

## Effects of Changes in the Administered Rate on Other Liabilities

The effects of an increase in the administered rate on other Federal Reserve liabilities largely mirror those for an increase in the rate on reserves. As shown in the left panel of figure 5, the increase in the rate on other Fed liabilities again shifts the loan market equilibrium and Treasury market equilibrium lines up, resulting in an increase in both loan rates and Treasury rates. The spread between the deposit rate and the nonbank debt rate narrows and both rates are pulled higher by the rise in loan rates and Treasury rates. The rise in the nonbank debt rate is slightly larger than the increase in the deposit rate because the increase in the rate on other Federal Reserve liabilities results in a slightly larger increase in nonbanks' return on assets than in banks' return on assets.

As shown in figure 6, the change in the administered rate on other liabilities increases the relative return on other Federal Reserve liabilities. As a result, nonbanks substitute away from other assets including Treasury securities and loans in favor of holding other Federal Reserve liabilities. Conversely, with no increase in the interest rate on reserves, relative rates of return on assets for banks shift in favor of market instruments. As a result, banks shift out of reserves and into Treasury securities and loans. Households again shift into investments in market instruments and away from currency resulting in a small reduction in the size of the Federal Reserve's balance sheet. As shown in the bottom row of panel 2 in figure 6, total loans edge down with the runoff of loans at nonbanks partially offset by an increase in loans at banks.

## Effects of a Parallel Shift in the Administered Rates on Reserves and Other Federal Reserve Liabilities

When the administered rates on reserves and other Fed liabilities are raised in parallel—as is often the case when the FOMC chooses to raise the target range for the federal funds rate—market rates move up almost one for one with the change in administered rates. As shown in figure 7, the relative rates of return on assets for banks and nonbanks shift slightly in favor of reserves and other Federal Reserve liabilities. Moreover, the spread between deposit rates and nonbank debt rates is unaffected and the levels of bank and nonbank funding rates move higher with the level of other market interest rates.

As shown in figure 8, the sizable effect of the change in administered rates on the level of market interest rates induces households to shift out of currency, on net, and into other assets including the liabilities of banks and nonbanks. The size of financial intermediaries increases modestly with increased holdings of Treasury securities and Federal Reserve liabilities including both reserves and other liabilities. Total loans decline significantly, reflecting the increase in the loan rate relative to the equilibrium loan rate.

## Effects of Changes in the Administered Rate on Physical Currency

The hypothetical effect of a change in the administered rate on physical currency is shown in figure 9. An increase in this rate shifts the loan market equilibrium curve higher, resulting in a higher loan rate and a lower Treasury rate. As calibrated, the return on assets for banks and nonbanks both increase slightly. As

a result, the funding market equilibrium curve moves out and the deposit rate and nonbank debt rate both move up by the same amount.

With the Federal Reserve passively adjusting the size of its balance sheet to accommodate the increased demand for currency, the increase in the rate on currency effectively generates a higher demand for Treasury securities leading to a lower Treasury rate. As shown in rows 3 and 4 of figure 10, total bank and nonbank assets decline. That decline is registered across all bank and nonbank asset categories. Of note, both banks and nonbanks reduce their credit extension to businesses through the loan market, but only to a modest degree. The size of the Federal Reserve's balance sheet increases but not by as much as the increase in currency.

## Effects of Changes in Treasury Supply

As shown in figure 11, an increase in Treasury supply causes the Treasury market equilibrium curve to shift out, pulling both loan rates and Treasury rates higher. In funding markets, the increase in bank and nonbank returns on assets pushes out the funding market equilibrium line, resulting in equal increases in both deposit rates and nonbank debt rates.

As shown in figure 12, the increase in Treasury rates leads households to shift out of currency, deposits and nonbank debt in favor of Treasury securities. The pullback from deposits and nonbank debt contributes to the upward pressure on deposit rates and nonbank debt rates. Higher market interest rates lead banks and nonbanks to substitute out of Federal Reserve liabilities in favor of holding additional Treasury securities. Both banks and nonbanks also substitute out of loans to a modest extent. On net, the size of bank and nonbank balance sheets declines modestly while the Federal Reserve's balance sheet declines substantially. Much of the increase in the supply of Treasury securities is absorbed by the foreign sector.

## Shifts in Household Preferences from Currency to Treasury Securities

As discussed above, shifts in household preferences from currency to Treasury securities (or vice versa) have almost no effect on equilibrium rates. This type of shift has only a minimal effect on the equilibrium curves shown in figures 13. As discussed above and shown in figure 14, as households shift from currency to Treasury securities, the Federal Reserve sheds Treasury securities in exactly the amount acquired by households. With only minor changes in equilibrium interest rates, the effects on bank or nonbank balance sheets are likewise minimal. As shown in figure 14, households end up with an increase in Treasury holdings matched by a corresponding reduction in currency. The balance sheets of all other sectors are little changed.

## Shift in Household Preferences Away from Deposits Toward Safe Assets

Another type of experiment of interest is one in which households shift away from bank deposits in favor of safe assets such as physical currency or Treasury securities. The net effects of a shift out of deposits into either currency or Treasury securities are identical. As shown in figure 15, the shift pushes up the loan market equilibrium line, resulting in higher loan rates. The shift also boosts the net demand for Treasury securities, pushing Treasury yields down. As calibrated in the model, the changes in Treasury yields and loan rates result in a net increase in the return on assets for banks and nonbanks. The funding market equilibrium shifts outward, and the equilibrium spread between deposit rates and nonbank debt rates widens.

As shown in figure 16, the size of the banking sector declines somewhat with corresponding reductions in all bank asset categories. The scale of nonbanks is largely unaffected by this type of shock but the increase in loan rates and modest decline in the Treasury rate induces nonbanks to shift out of Treasury securities and other Federal Reserve liabilities and into loans. The increase in loans at nonbanks attenuates the overall decline in loans shown in the bottom row.

## Increase in Intermediary Balance Sheet Costs

As shown in the left panel of figure 17, an increase in intermediary balance sheet costs tends to flatten the loan market equilibrium curve but also pushes the entire curve higher. The net effect of the shift and slope changes results in a slightly higher loan rate and a slightly lower Treasury rate. The effects of an increase in balance sheet costs are much more pronounced in funding markets. The higher balance sheet cost drives a larger wedge between rates on assets held by intermediaries and the equilibrium rates on their liabilities. As noted in the right panel, the funding market equilibrium line shifts inward, and the deposit rate spread relative to the nonbank debt rate narrows a bit. The latter effect stems from the fact that a key factor driving a difference between the deposit rate and nonbank debt rate—the spread between the interest rate on reserves and the interest rate offered on other Federal Reserve liabilities—is not as important when banks and nonbanks become less willing to expand their balance sheets.

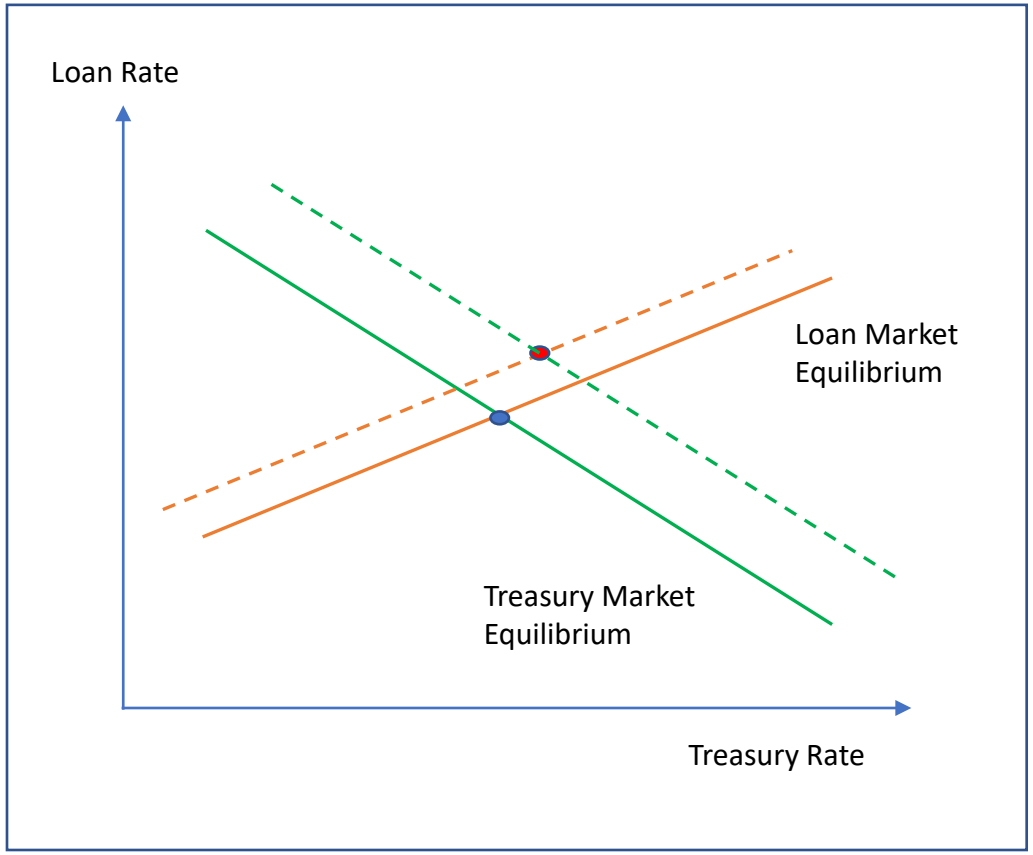
As shown in figure 18, the sizable decline in rates offered on deposits and nonbank debt leads households to shift into alternative assets including Treasury securities and physical currency. However, households are relatively insensitive to interest rate movements, so the magnitude of these shifts is rather small. Banks and nonbanks then experience small runoffs in their funding that, in turn, is reflected in small corresponding declines in their assets that are spread across all asset categories. The Federal Reserve's balance sheet increases modestly with the household shift into currency outweighing the small declines in bank and nonbank holdings of reserves and other Federal Reserve liabilities, respectively.

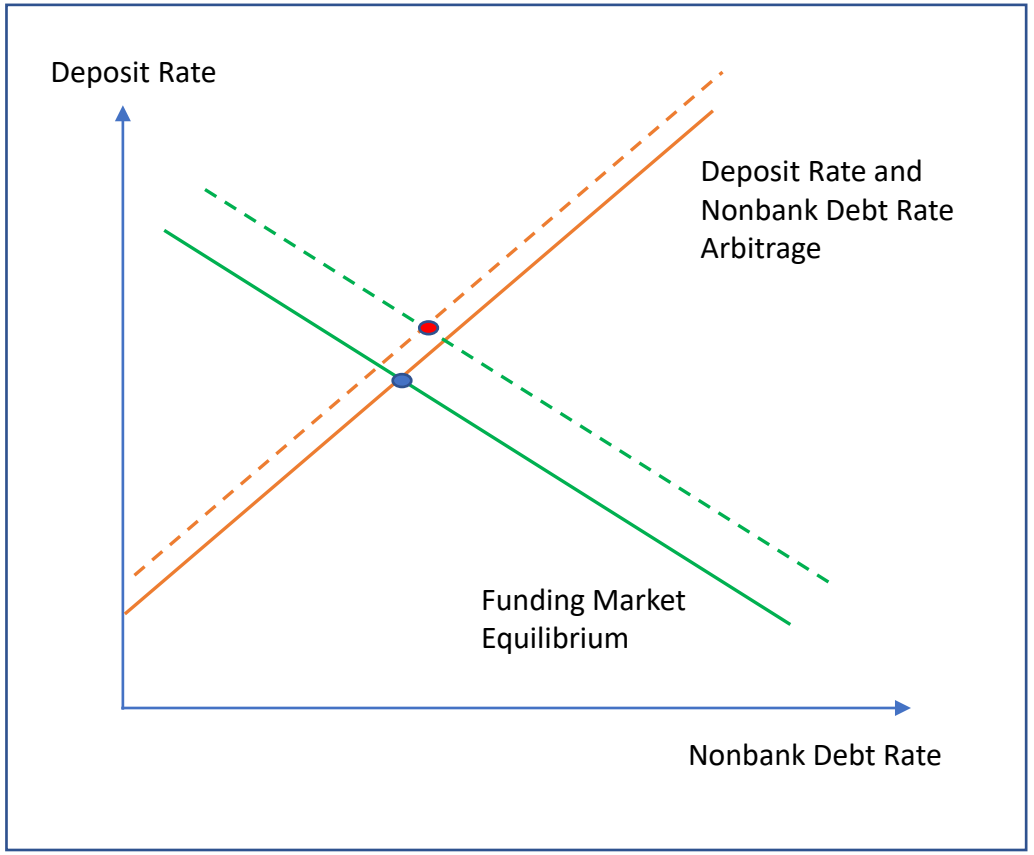
## Increase in Household Costs of Substitution Across Assets

The presence of costs capturing the willingness of households to substitute across alternative assets is another important aspect of the model. As shown in figure 19, an increase in this cost for households makes them less willing to shift out of currency in favor of market instruments with higher yields. The interest rate effects of this change are very small. The pull back in funding provided by households to financial intermediaries puts a bit of upward pressure on deposit rates and nonbank debt rates. That effect is reflected in the outward shift of the funding market equilibrium line in the right panel. Higher intermediary funding costs, in turn, result in an inward shift in the loan market equilibrium line in the left panel with a resulting slight increase in the equilibrium loan rate and decline in Treasury rates.

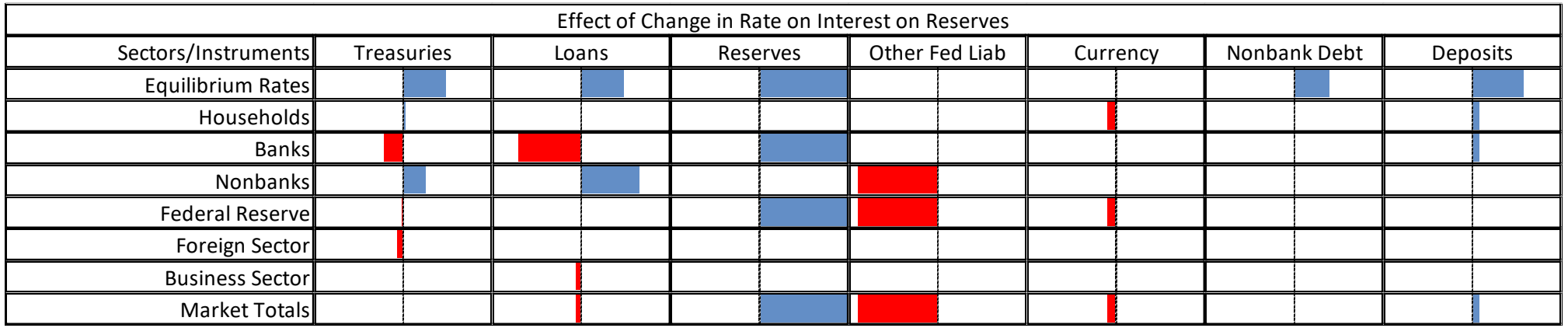
As noted in figure 20, these changes in rates are accompanied by shifts in households and financial sector balance sheets. Households shift into currency and away from Treasury securities, deposits and nonbank debt. The size of financial intermediary balance sheets declines with corresponding declines in their holdings of Treasury securities, loans, and Federal Reserve liabilities. The increase in currency is larger than the combined outflows from reserves and other Federal Reserve liabilities, resulting in a modest increase in the size of the Federal Reserve's balance sheet.

# Figure 3: Response to Increase in Interest Rate on Reserves

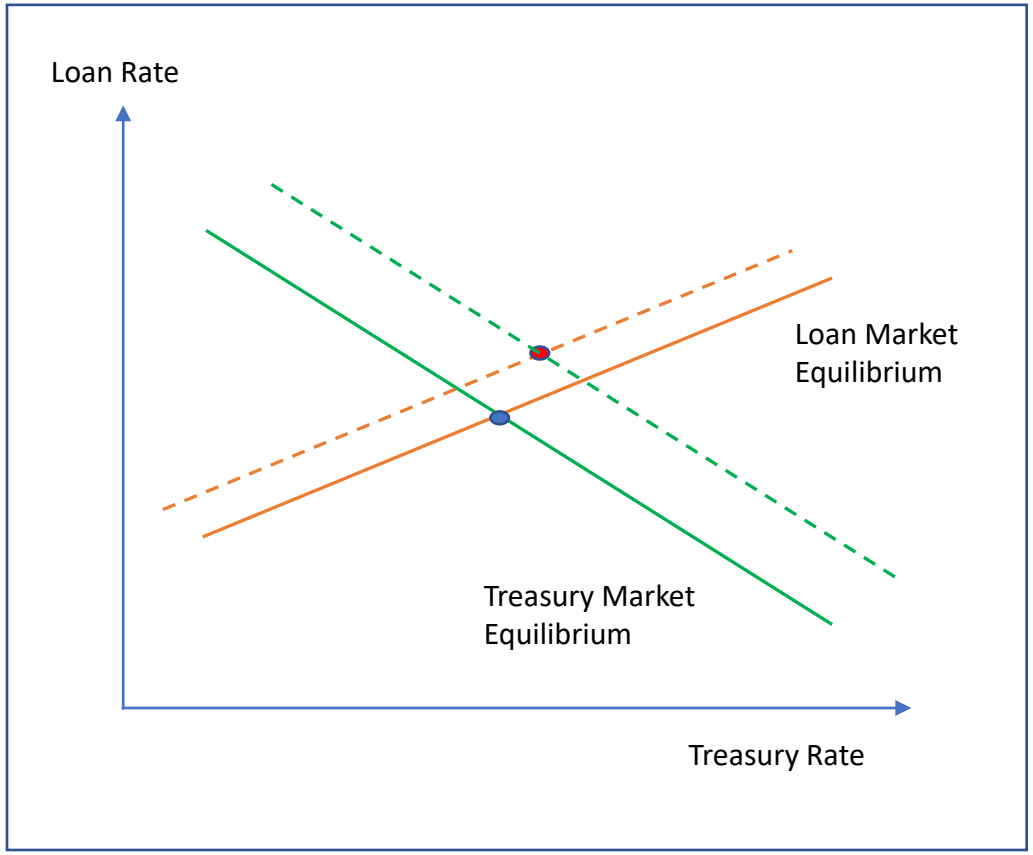


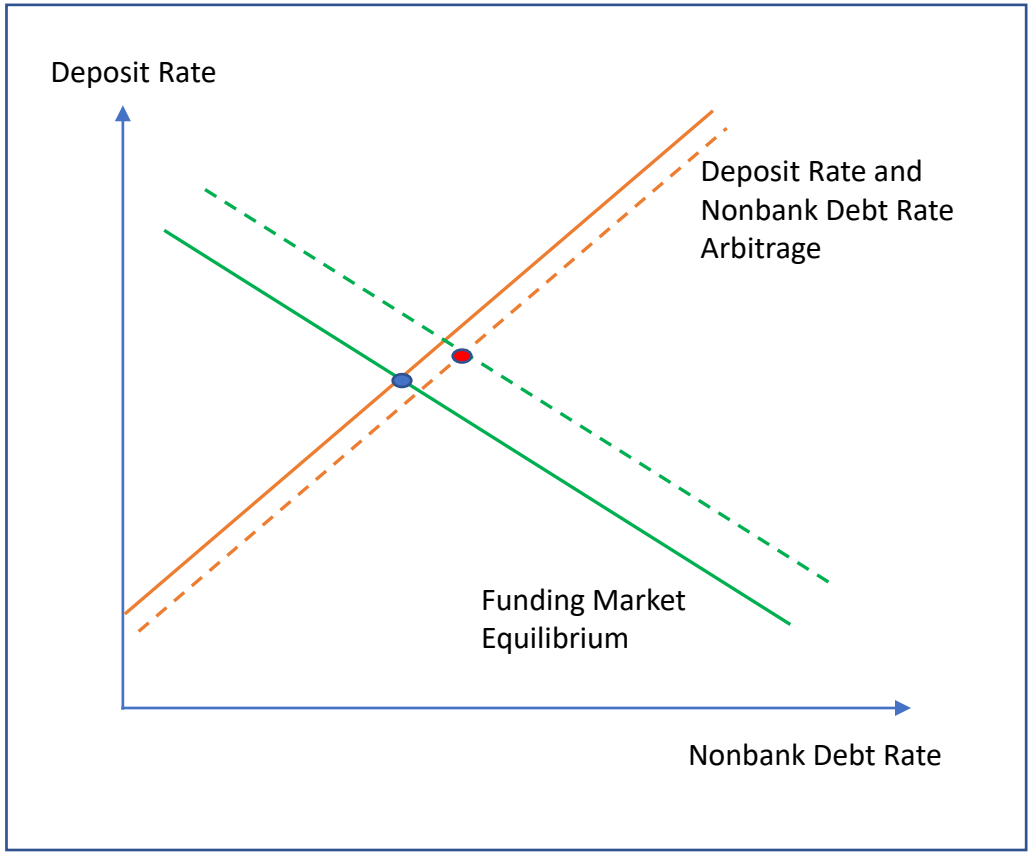



# Figure 4: Portfolio Effects of Increase in Interest Rate on Reserves

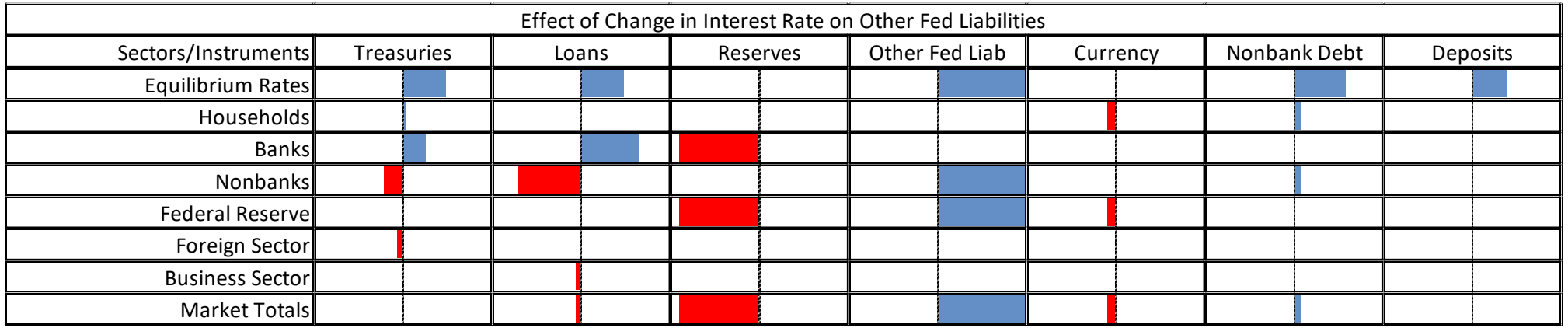


# Figure 5: Response to Increase in Interest Rate on Other Liabilities

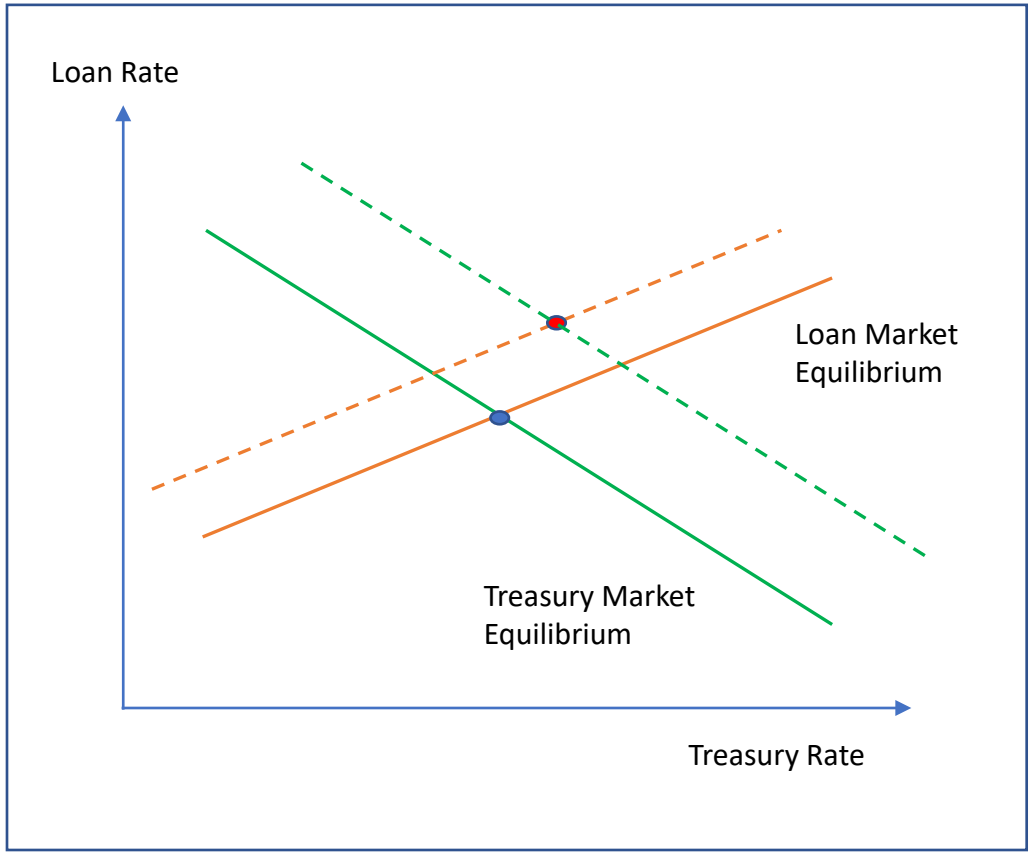


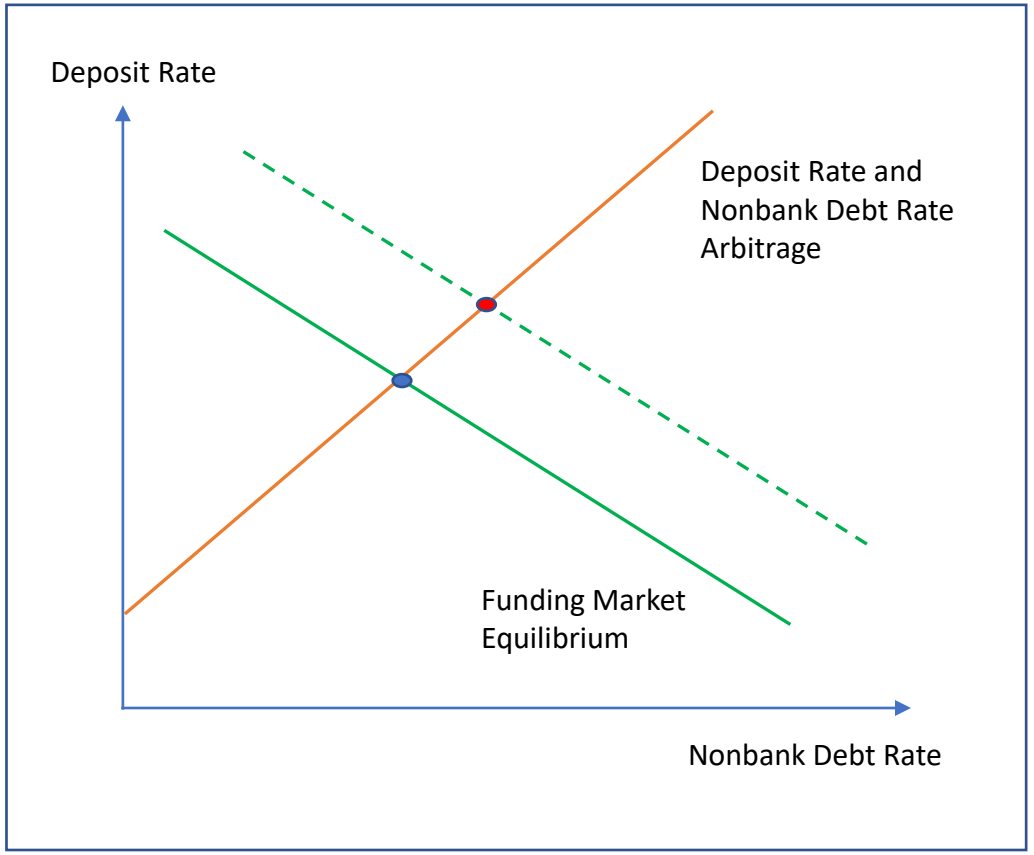



# Figure 6: Portfolio Effects of Increase in Rate on Other Fed Liabilities

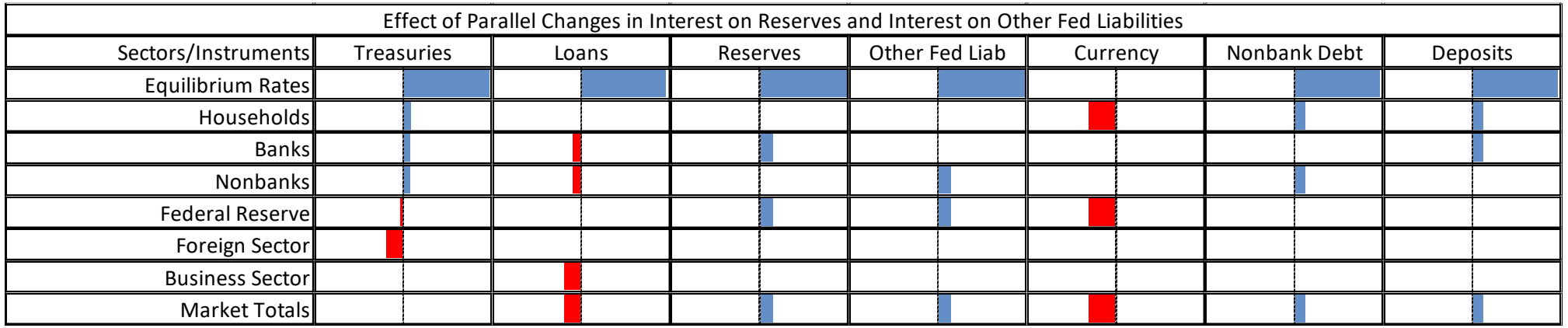


# Figure 7: Response to Parallel Increase in Rates on Reserves and Other Federal Reserve Liabilities

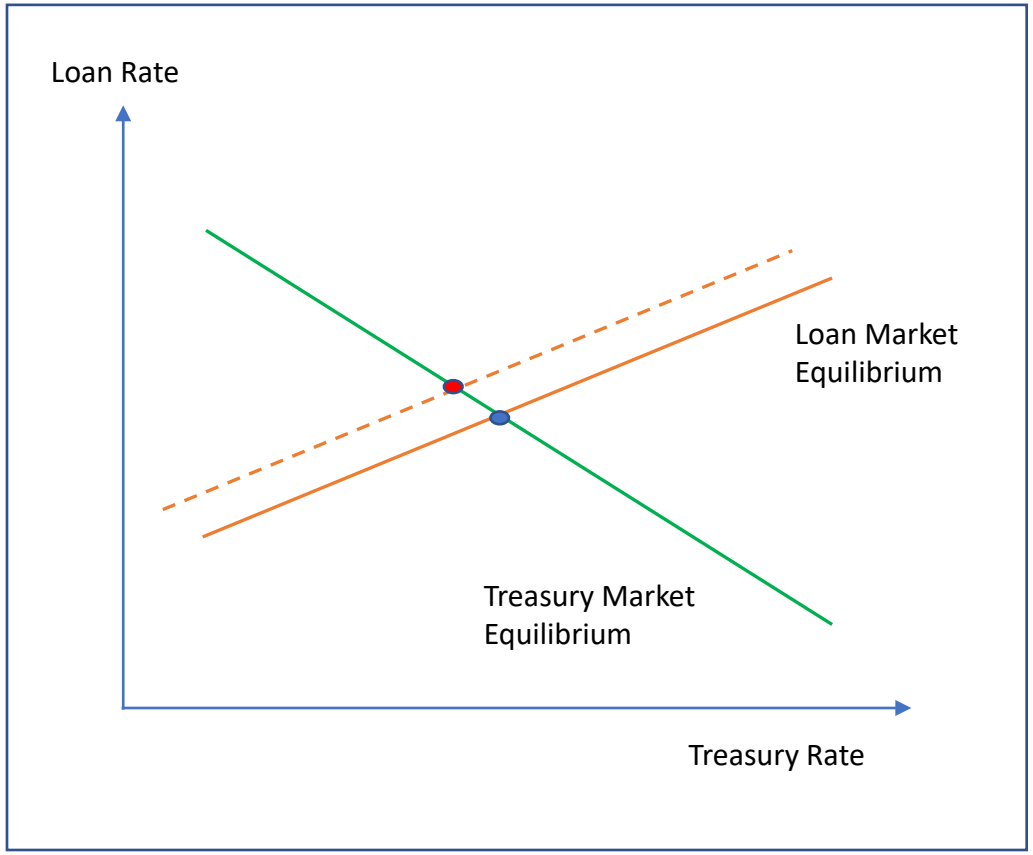


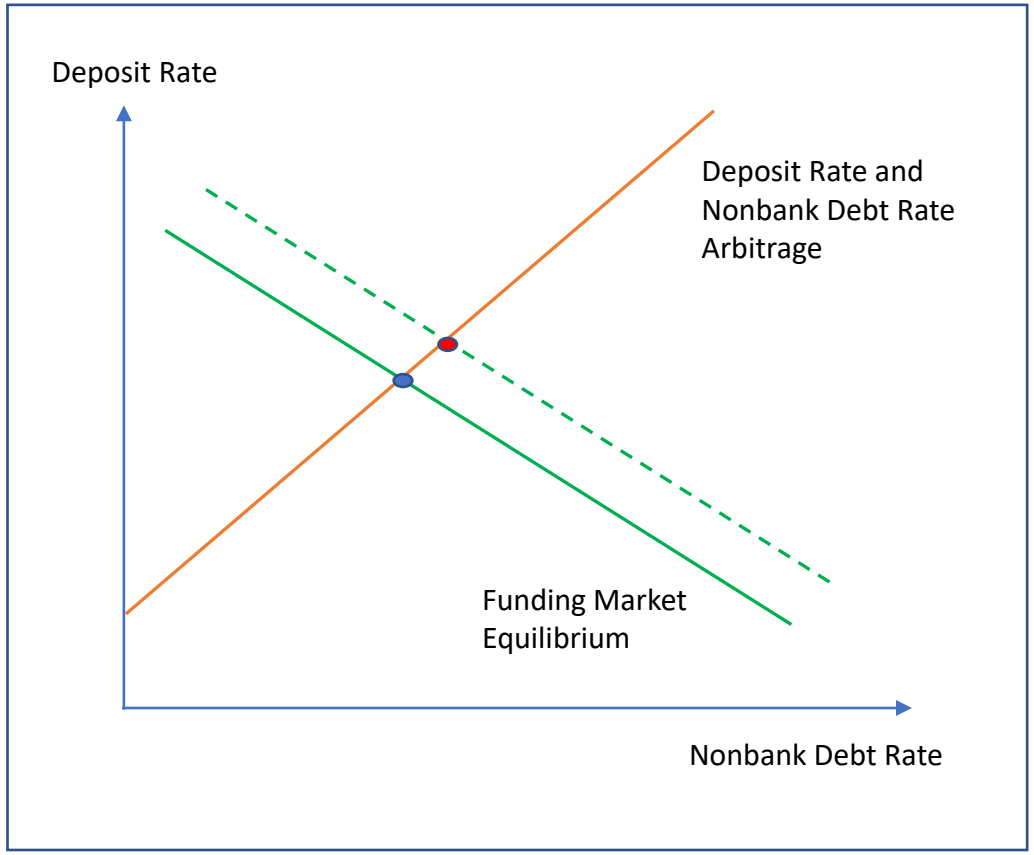



# Figure 8: Portfolio Effects of Parallel Change in Interest on Reserves and Other Fed Liabilities

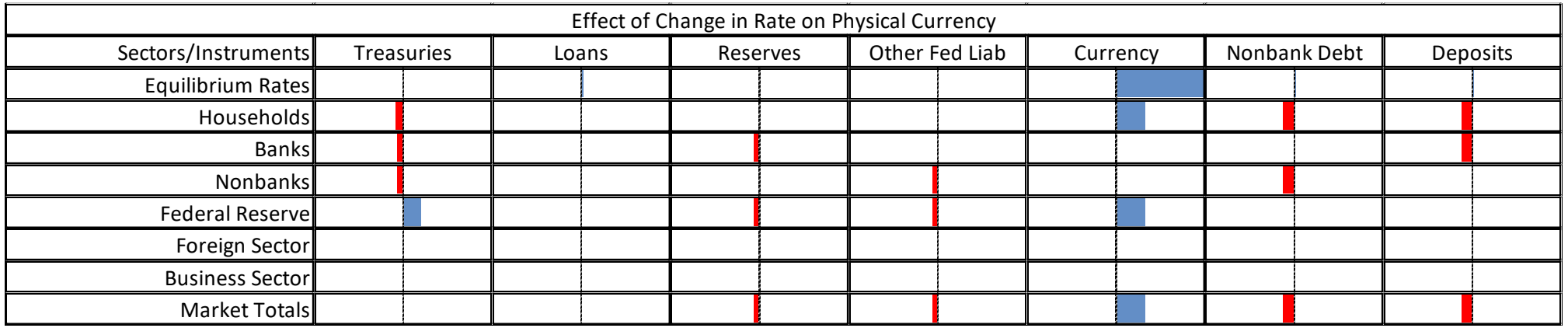


# Figure 9: Response to Increase in Interest Rate on Physical Currency

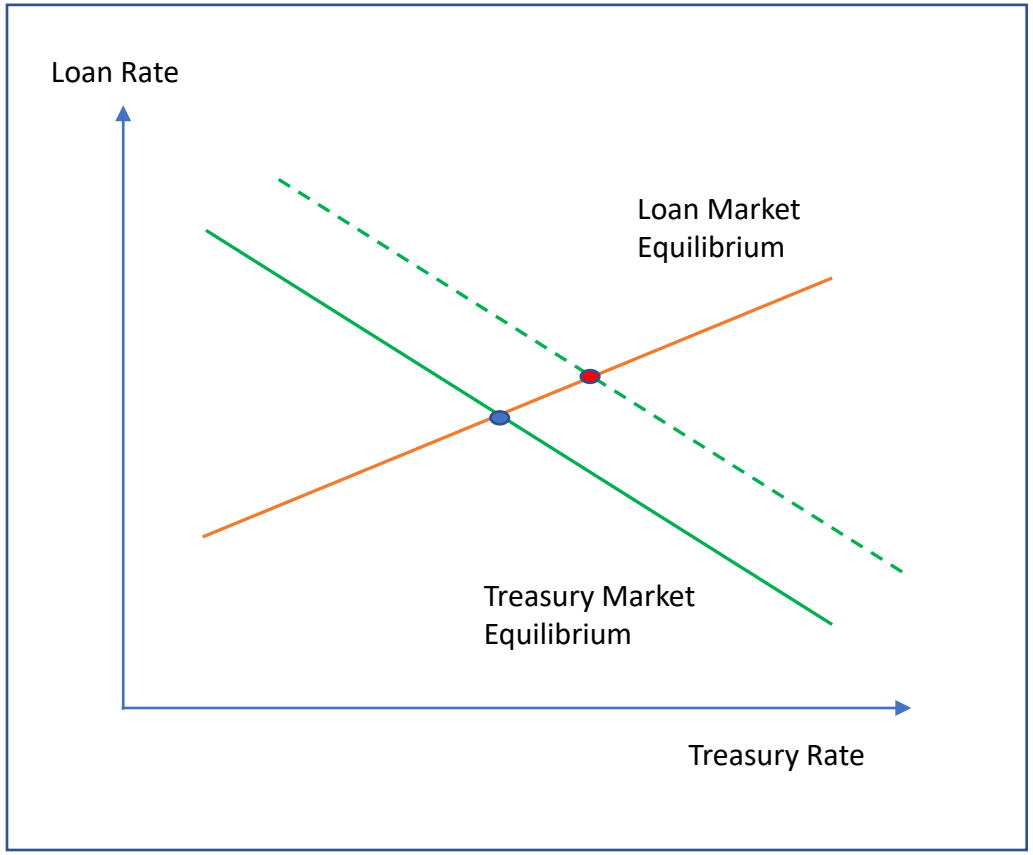


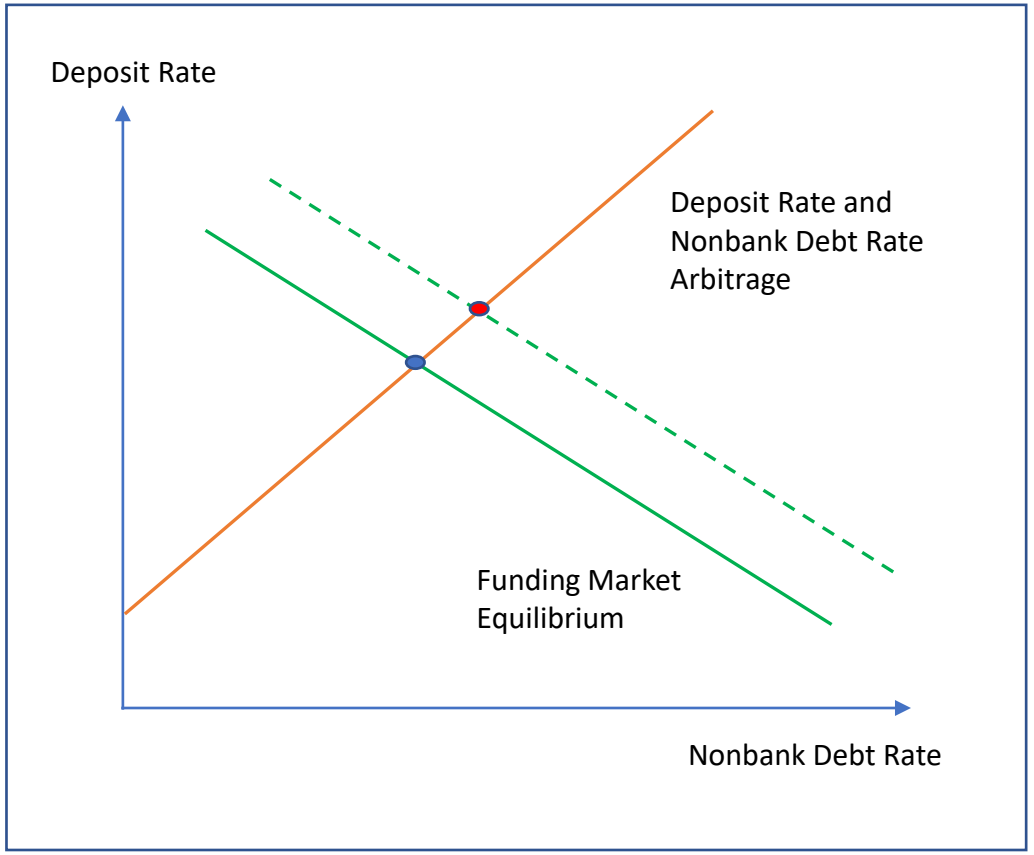



# Figure 10: Effect of Change in Rate on Physical Currency



# Figure 11: Response to Increase in Treasury Supply



# Figure 12: Effect of Change in Aggregate Supply of Treasury Debt

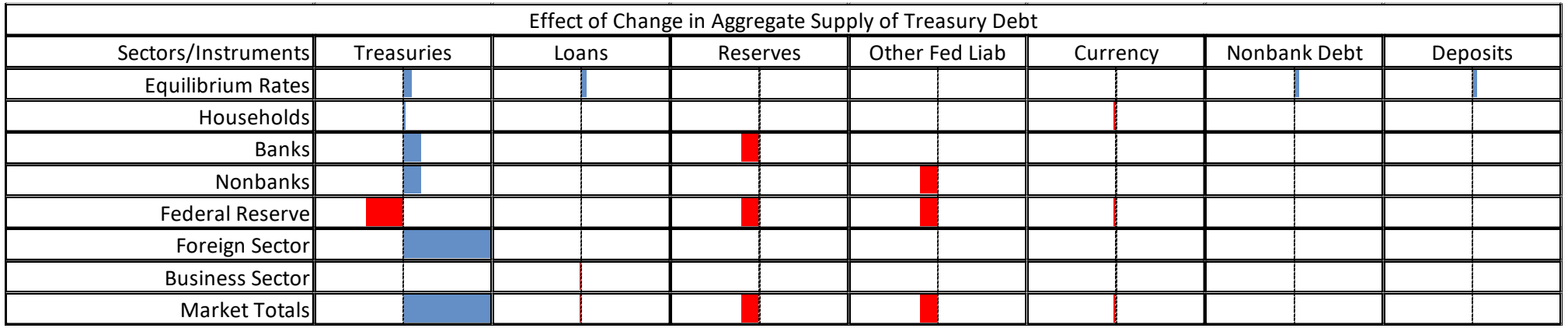
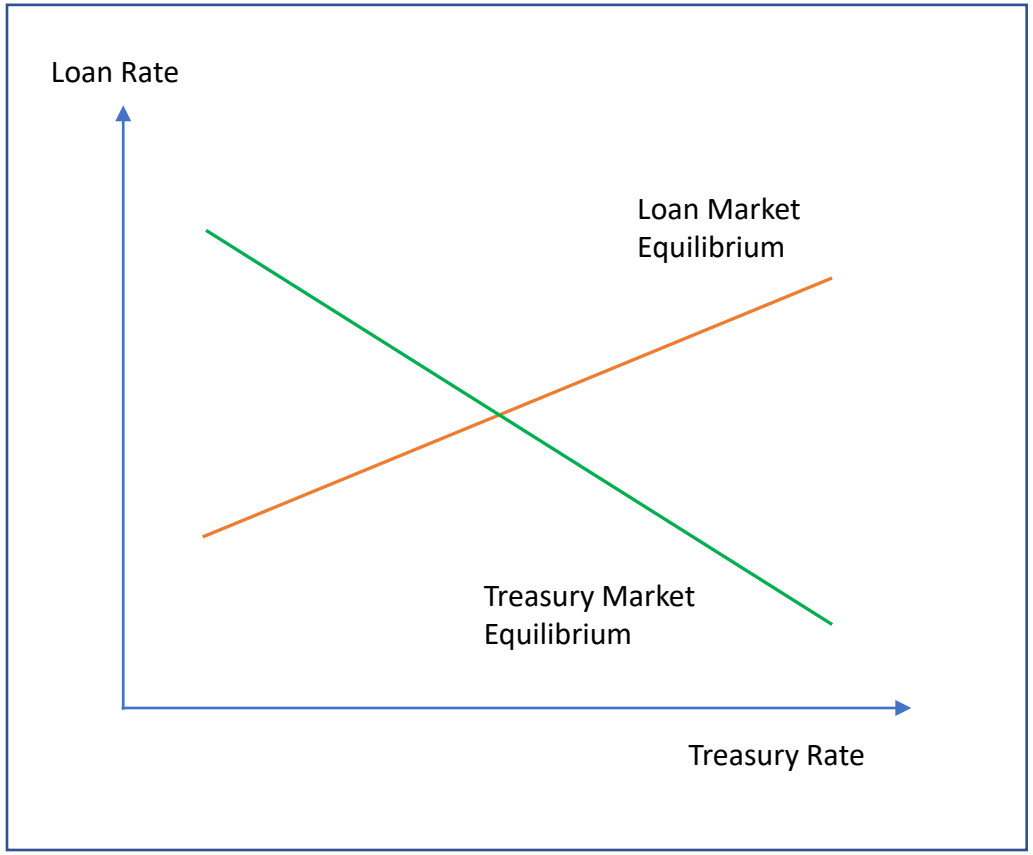
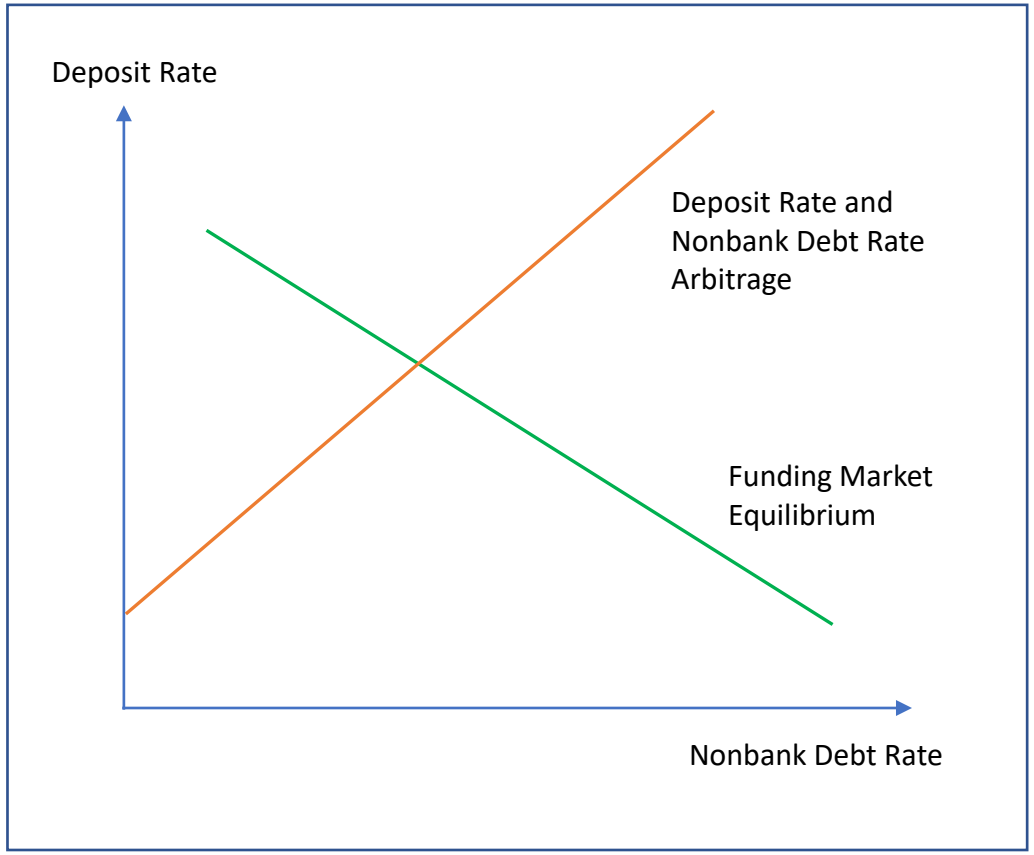


Figure 13: Shift in Household Preferences from Currency to Treasury Securities



# Figure 14: Effect of Increase in Household Shift from Currency to Treasury Securities

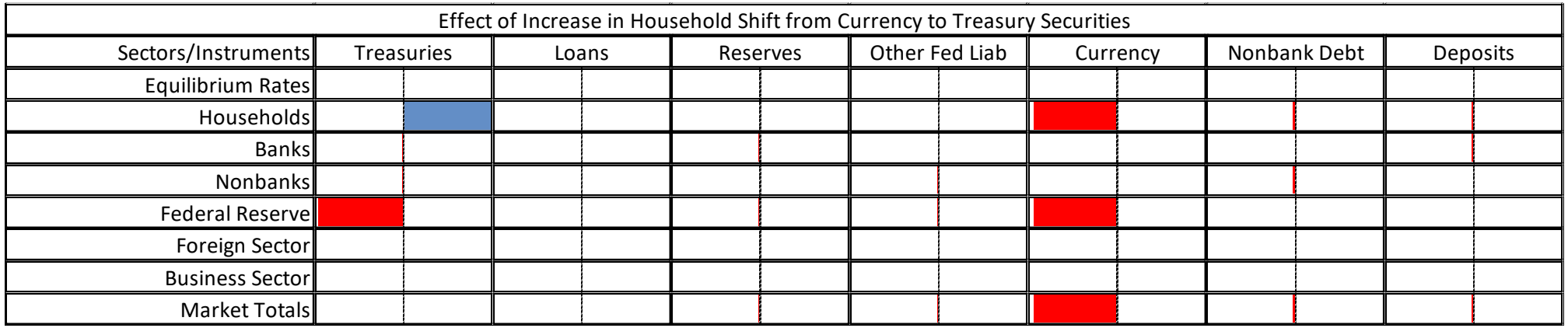
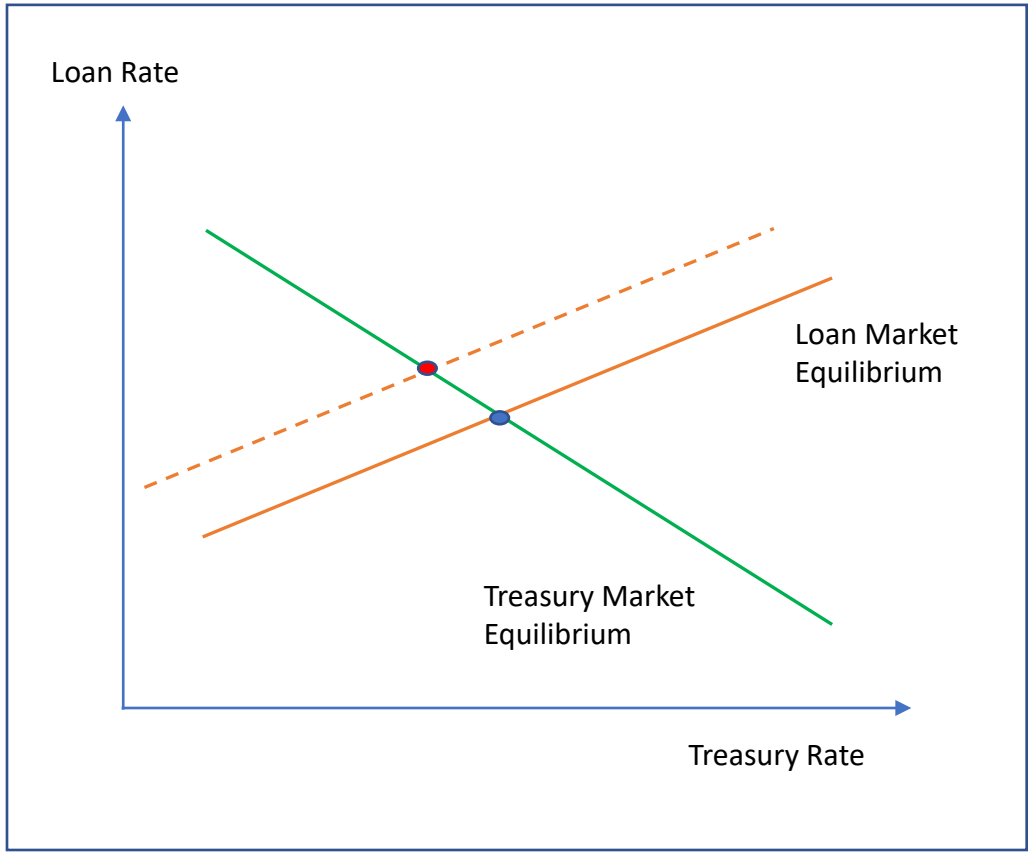
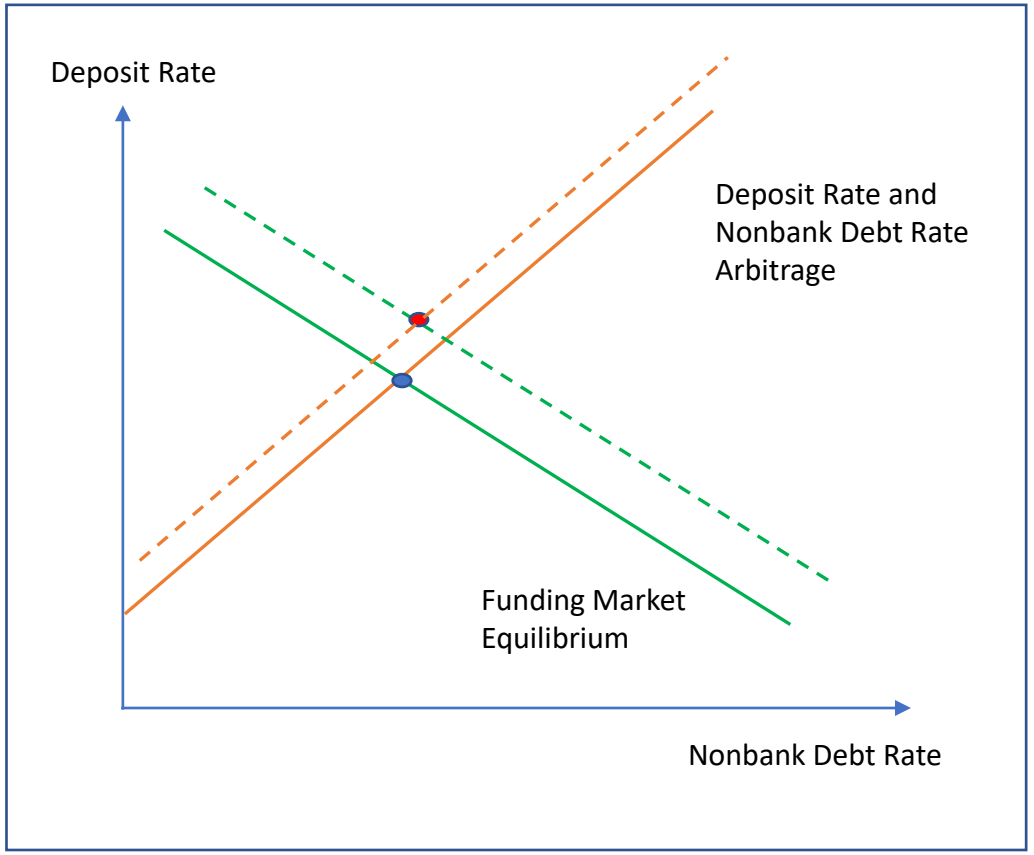
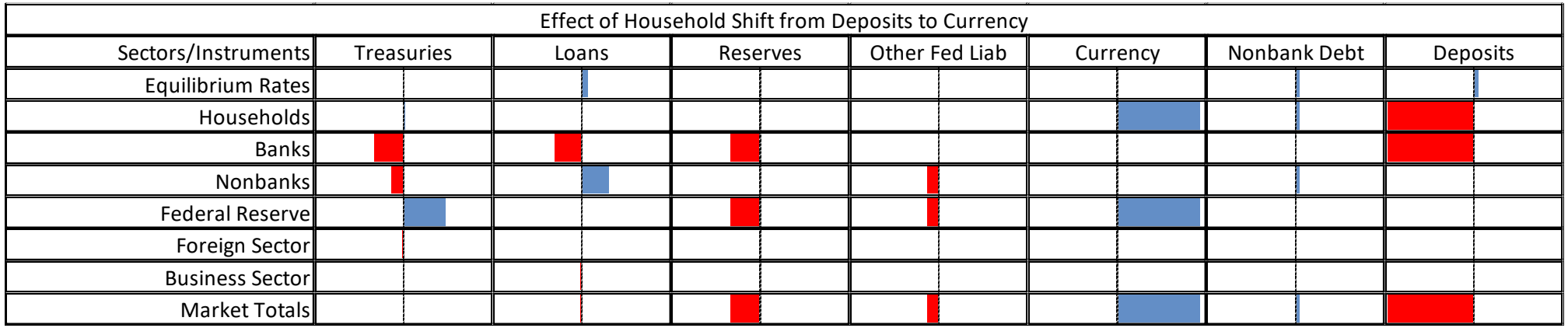


Figure 15: Response to Shift in Household Habits Away from Deposits Toward Currency

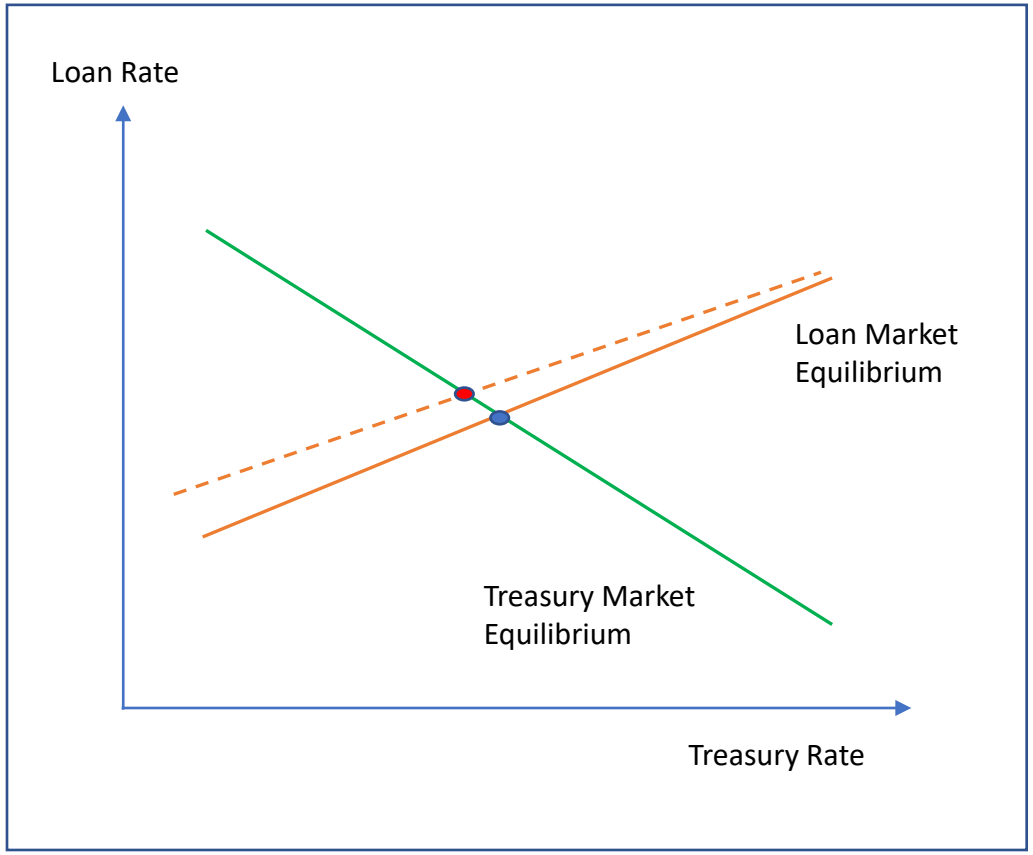


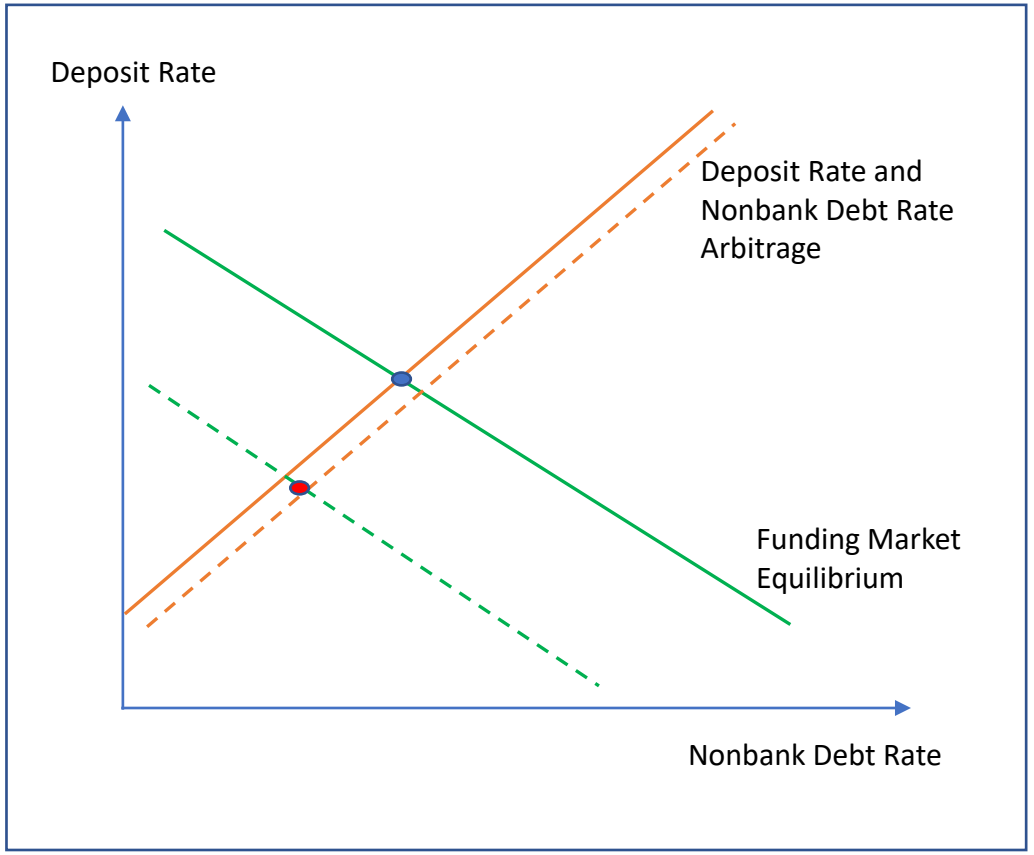



# Figure 16: Effect of Household Shift from Deposits to Currency

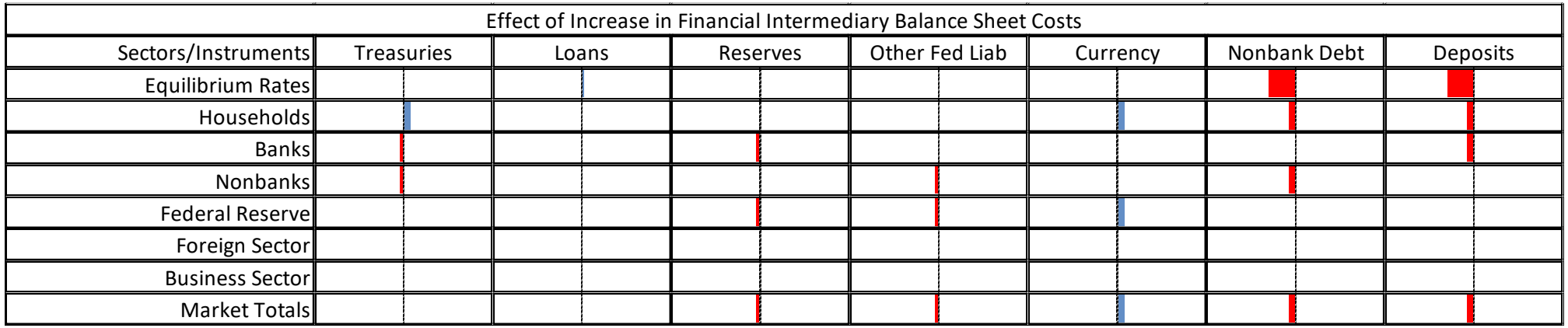


# Figure 17: Response to Increase in Balance Sheet Costs

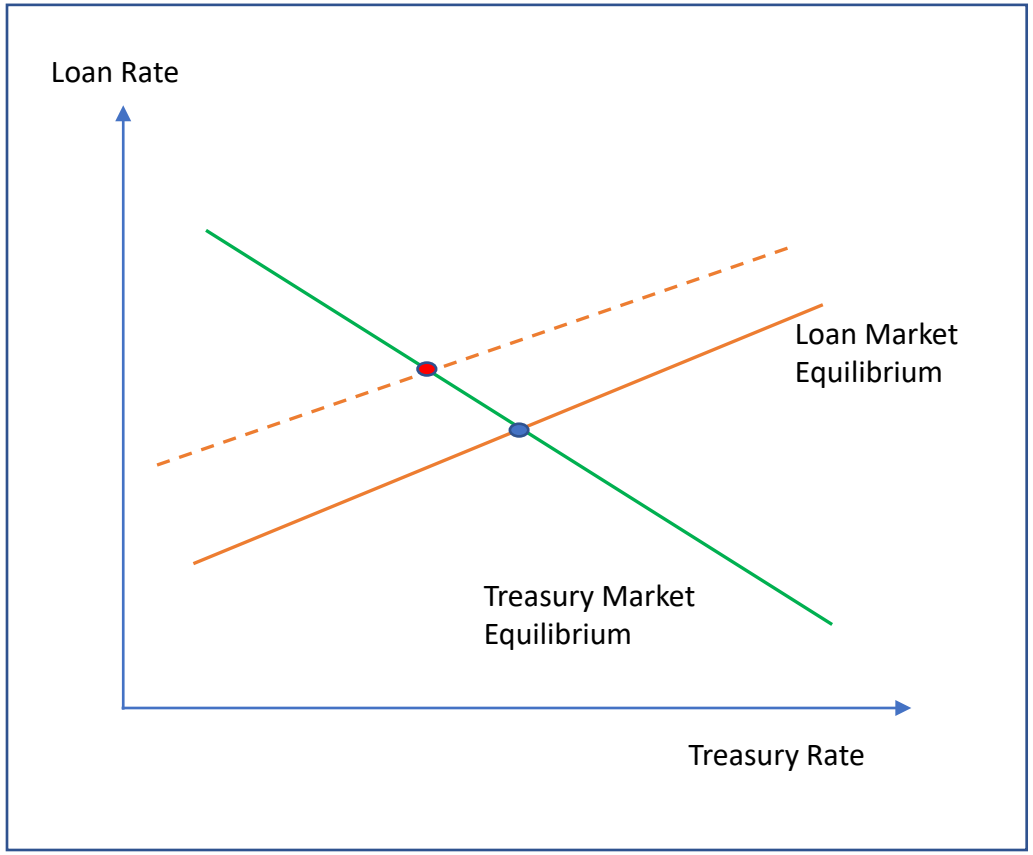


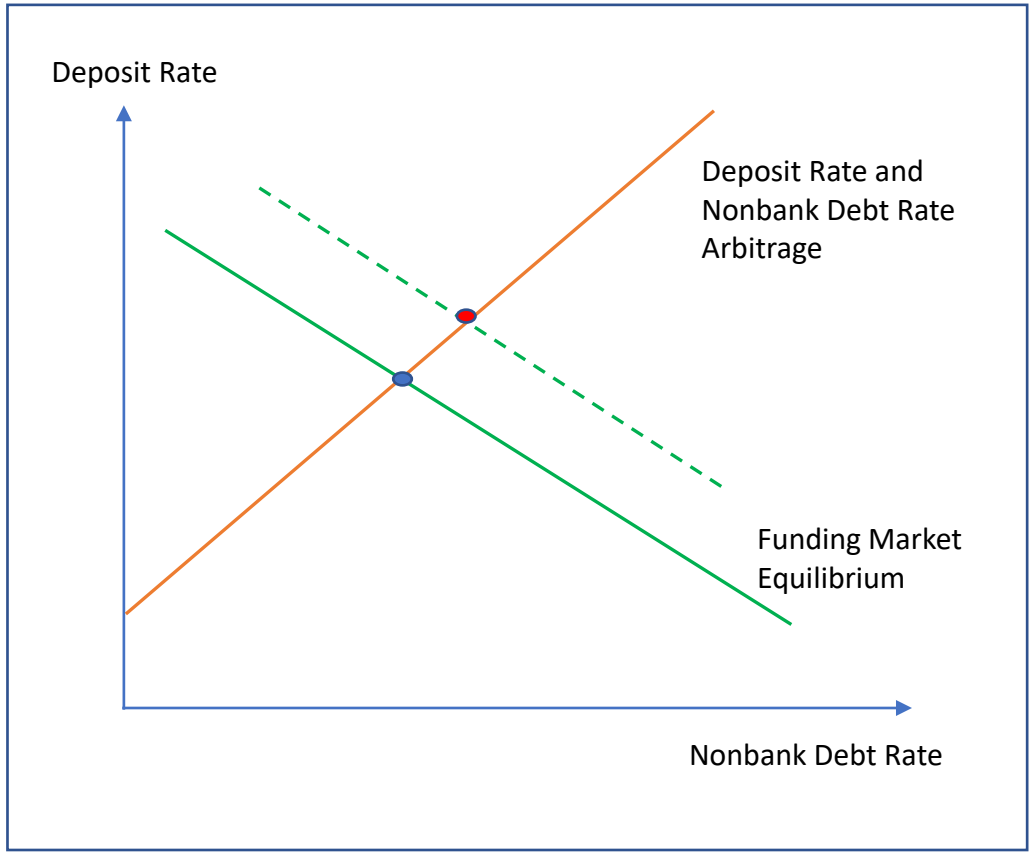



# Figure 18: Effect of Increase in Financial Intermediary Balance Sheet Costs



# Figure 19: Response to Increased Cost of  Deviating from Habit for Households

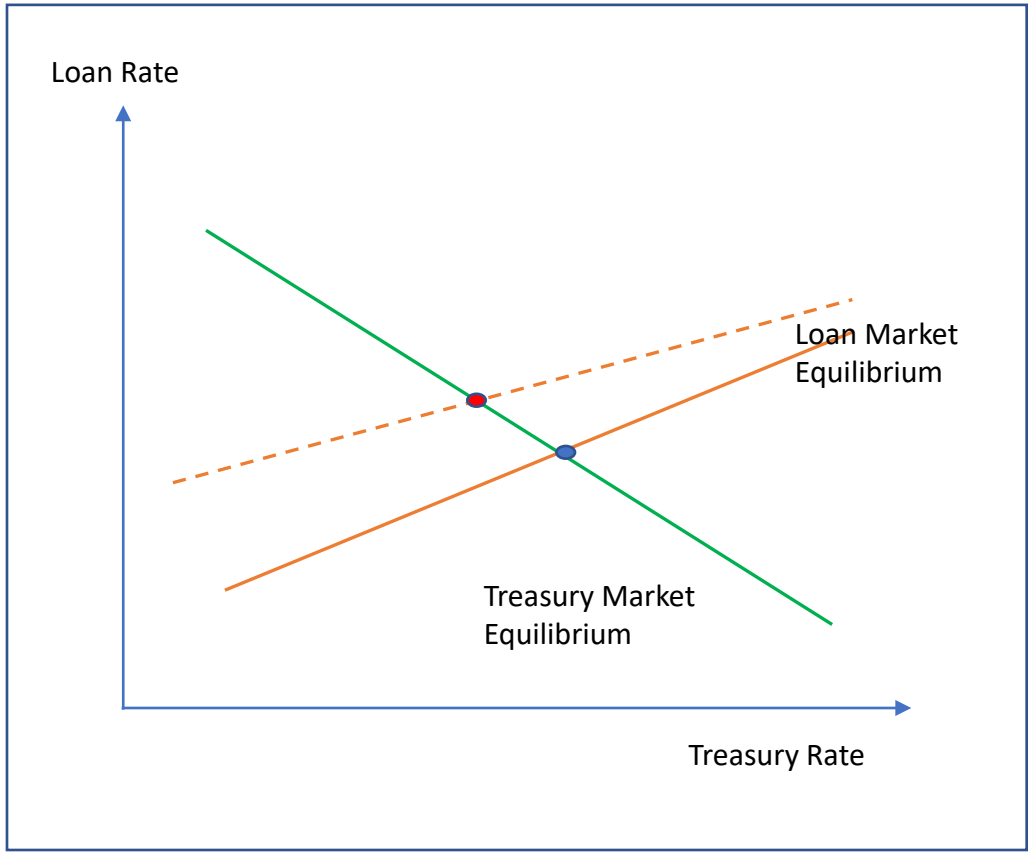


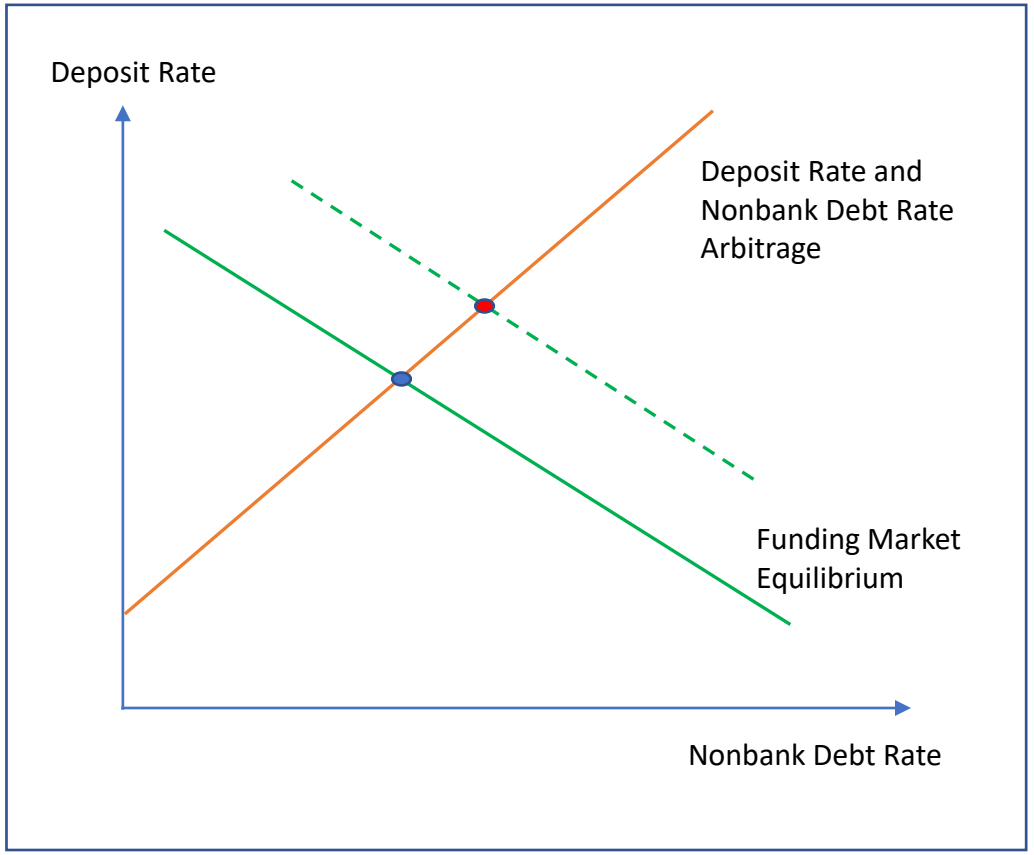



# Figure 20: Effect of Increase in Household Substitution Costs

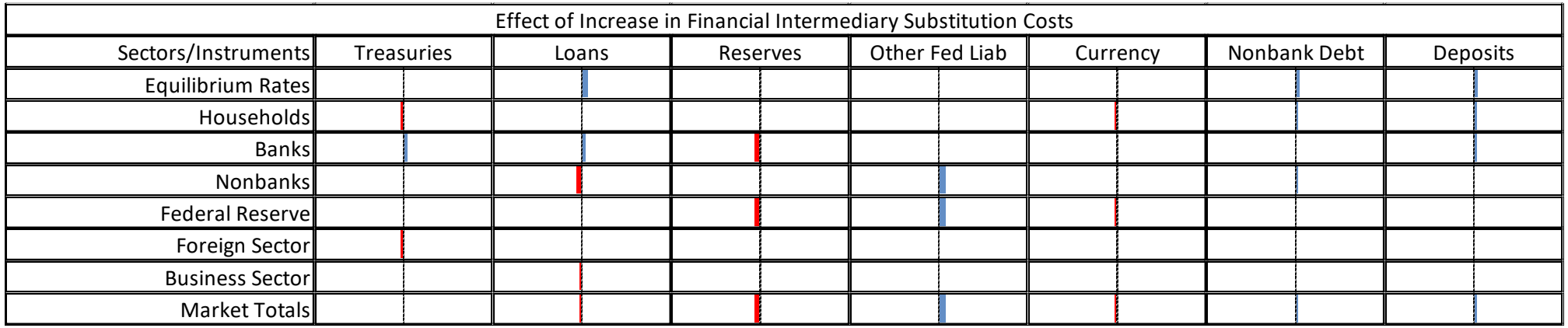
| Effect of Increase in Household Substitution Costs | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sectors/Instruments | Treasuries | | Loans | | Reserves | | Other Fed Liab | | Currency | | Nonbank Debt | | Deposits | |
| Equilibrium Rates | | | | | | | | | | | | | | |
| Households | | | | | | | | | | | | | | |
| Banks | | | | | | | | | | | | | | |
| Nonbanks | | | | | | | | | | | | | | |
| Federal Reserve | | | | | | | | | | | | | | |
| Foreign Sector | | | | | | | | | | | | | | |
| Business Sector | | | | | | | | | | | | | | |
| Market Totals | | | | | | | | | | | | | | |

# Figure 21: Response to Increased Cost of Deviating from Habit for Intermediaries



# Figure 22: Effect of Increase in Financial Intermediary Substitution Costs



### Increase in Financial Intermediary Costs to Substitute Across Assets

Figure 21 illustrates the case of an increase in the portfolio habit costs for financial intermediaries and a corresponding decline in their willingness to substitute across assets. The decline in the willingness to substitute across assets results in an inward shift in the loan equilibrium line and a corresponding increase in loan rates and decline in Treasury yields. These changes result in an outward shift in the funding market equilibrium line and associated increases in bank and nonbank debt rates.

As shown in figure 22, these changes in rates ripple through the portfolio allocations of households and financial intermediaries. In light of the low rate on other Federal Reserve liabilities, nonbanks start from a position with a higher share of assets in the form of loans. The increase in substitution costs thus leads to a shift out of loans and into other Federal Reserve liabilities. The increase in loan rates, however, leads banks to shift into loans to some extent. On net, the aggregate quantity of loans declines but more lending is extended through the banking sector.

## 5. Selected Policy Issues

The discussion below examines selected policy issues from the perspective of the baseline model including: (i) the effects of widening the spread between the Federal Reserve's administered rates; (ii) some aspects of the choice of interest rate targets, (iii) the potential effects of regulatory developments affecting bank leverage and liquidity, and (iv) factors affecting the pass through of the Federal Reserve's administered rates to market interest rates.

### The Spread Between Administered Rates

The Federal Reserve has typically operated with a small spread between the administered rates on reserves and overnight reverse repurchase agreements. In part, that configuration was motivated by a desire to manage the size of the ON RRP facility and to preserve significant trading volumes in the federal funds market.[9] The baseline model employed here does not incorporate a federal funds market but the results shed some light on the effects of changes in that spread between administered rates on equilibrium rates and patterns of intermediation.[10] As noted in figure 23, the effects of a mean preserving spread between the administered rates on reserves and other Federal Reserve liabilities leaves the level of Treasury rates and loan rates unchanged. The equilibrium deposit rate increases modestly while the rate on nonbank debt declines. As shown in figure 24, households shift their portfolios from nonbank debt to deposits. Banks observing an increase in the rate on deposits with no corresponding increase in loan rates and Treasury rates shift their portfolios away from Treasury securities and loans and choose to hold more reserves. Nonbanks do the reverse. With the rate on other Federal Reserve liabilities declining relative to Treasury rates and loan rates, nonbanks shift out of Federal Reserve liabilities and into higher yielding instruments. On net, there are no changes in the quantity of Treasury securities and loans held by financial intermediaries, but nonbanks account for a larger portion of total credit provided to nonfinancial

[9] See the minutes of the July 2014 FOMC meeting, The Fed - Monetary Policy: (federalreserve.gov).

[10] Introducing a federal funds market in the model is straightforward but significantly complicates the analytical results presented in the appendix. Incorporating a funds market involves allowing for another liability for banks and another asset for nonbanks. With this structure, as one would expect, the volume of borrowing and lending in the market is strongly affected by the spread between the administered rates.

sectors. The size of the Federal Reserve's balance sheet is unaffected by this change, but the composition of its liabilities shifts from other Federal Reserve liabilities to a larger share of reserves.

## Interest Rate Targets in the Baseline Model

Another basic question concerns the implications of interest rate stabilization by the central bank. As noted above, the administered rates on reserves and other Federal Reserve liabilities have a strong influence on the level of interest rates in the model. As a result, the Federal Reserve can adjust the level of these rates in tandem to offset the effects of the exogenous shocks on a particular rate chosen as the "policy rate."

As noted in the appendix, the equilibrium solutions for all of the endogenous rates are of the form:

$$r_i = a_{i,CU} \cdot r_{CU} + a_{i,RS} \cdot r_{RS} + a_{i,OL} \cdot r_{OL} + a_{i,r^*_{LN}} \cdot r^*_{LN} + \sum_k b_{i,k} x_k$$

If the central bank keeps the spread between the interest rate on reserves and the interest rate on other Federal Reserve liabilities fixed at some level, $s$, this can be expressed as:

$$r_i = \left(a_{i,RS} + a_{i,OL}\right) \cdot r_{RS} - a_{i,OL} \cdot s + a_{i,CU} \cdot r_{CU} + a_{i,r^*_{LN}} \cdot r^*_{LN} + \sum_k b_{i,k} x_k$$

And the level of the interest rate on reserves necessary to peg the level of the endogenous rate, $r_i$, at a target level, $r_{target}$ , is then given by:

$$r_{rs} = \frac{1}{(a_{i,RS} + a_{i,OL})} (r_{target} + a_{i,OL} \cdot s - a_{i,CU} \cdot r_{CU} - a_{i,r^*_{LN}} \cdot r^*_{LN} - \sum_k b_{i,k} x_k) \qquad (3)$$

A rule of this type for setting the administered rate eliminates all variability in the targeted rate, $r_i$. However, the effect on other rates may depend on the source of shocks and other factors. For example, if the central bank followed the rule above to target $r_i$, the equilibrium expression for other endogenous rates would be given by:

$$r_j = a_{j,CU} \cdot r_{CU} + a_{j,r^*_{ln}} \cdot r^*_{LN} + \left(a_{j,RS} + a_{j,OL}\right) \cdot r_{rs} - a_{j,OL} \cdot s + \sum_k b_{j,k} x_k$$

Using the expression for the policy setting of the interest rate on reserves given in equation (3), the full coefficients on exogenous variables, $x_k$,in this expression would be:

$$\hat{b}_{j,k} = b_{j,k} - (a_{j,RS} + a_{j,OL}) \cdot b_{i,k} / \left(a_{i,RS} + a_{i,OL}\right)$$

And the magnitude of this new coefficient on the exogenous variable may be greater or smaller than the initial coefficient. In fact, when the exogenous factor pushes endogenous rates in opposite directions, stabilizing one rate will tend to amplify the volatility of the other endogenous variable in response to that shock.

As an example of this effect, figure 25, shows the effect of following a rule stabilizing the loan rate versus the Treasury rate in response to an exogenous shock to Treasury supply. As noted above, an exogenous increase in Treasury supply drives both the loan rate and Treasury rate higher, shown by the movement from the black dot to the yellow dot. By adjusting the administered rates in tandem, the central bank can achieve any desired equilibrium along the blue line. If the central bank eased policy to stabilize the loan

rate, it would stop at a point shown by the red dot. At that point, the Treasury rate would still be somewhat above its initial level. If the central bank wished to stabilize the Treasury rate, it would need to ease policy enough to reach the blue dot. At that point, the loan rate would be well below its initial equilibrium.

## Effects of Regulatory Changes

Following the Global Financial Crisis, banking regulators put in place a range of new requirements focused on strengthening bank capital and liquidity. Important elements of the revised regulatory framework included higher minimum capital ratios based on the total size of bank assets—the so-called leverage ratio—and requirements to hold liquid assets as a function of a bank's potential liquidity exposures from deposit runoffs and other sources.

The model developed above can capture the effects of these regulations in a crude way. Some aspects of liquidity requirements could be viewed as a shift in bank "habits" from loans to safe asset such as Treasury securities and reserves coupled with stronger incentives to stay close to those new habit levels. Similarly, one could think of increases in bank leverage ratio requirements as corresponding to an increase in the parameter governing "bank balance sheet costs" in the baseline model.

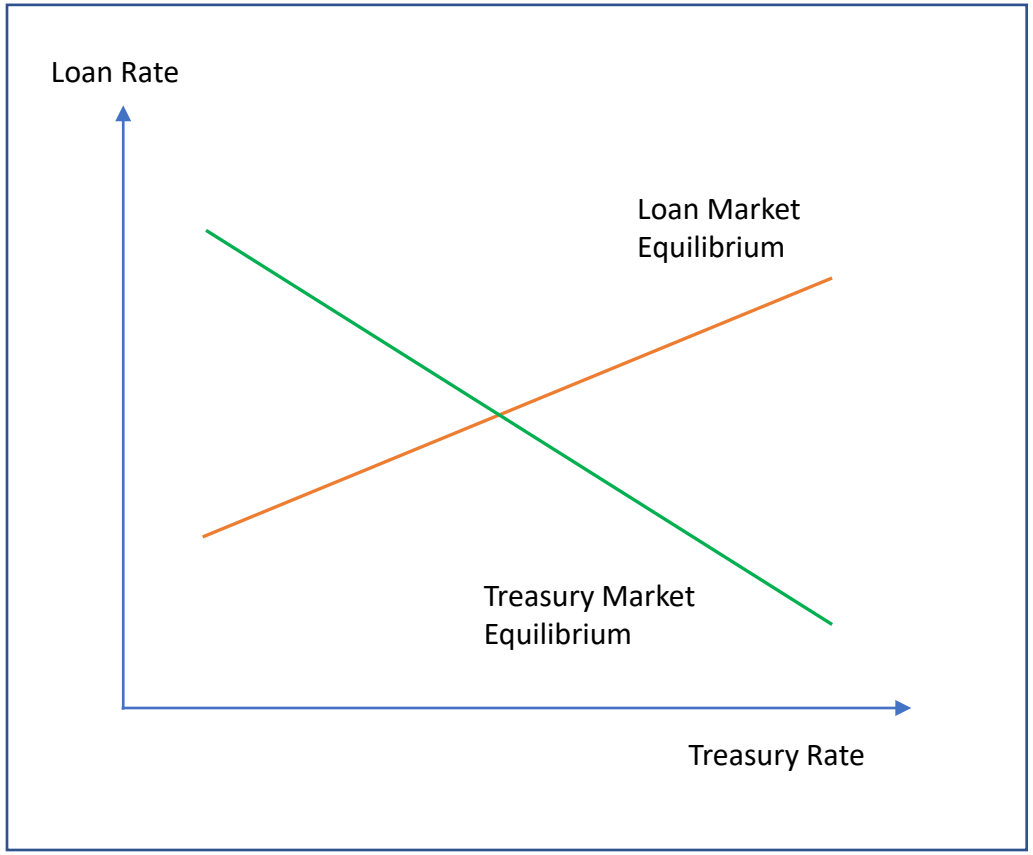
Figures 26 and 27 display the impulse response patterns for changes in parameters along these lines. In the case of a liquidity requirement applied to banks, the results point to a shift in bank portfolios away from bank loans and toward reserves and Treasury securities. The portfolio allocation for nonbanks largely mirrors those of banks; nonbanks shift into loans and away from Treasuries and other Federal Reserve liabilities. The net effect is a modest reduction in total loans outstanding with more credit to businesses extended by nonbanks and also a less liquid nonbank sector.

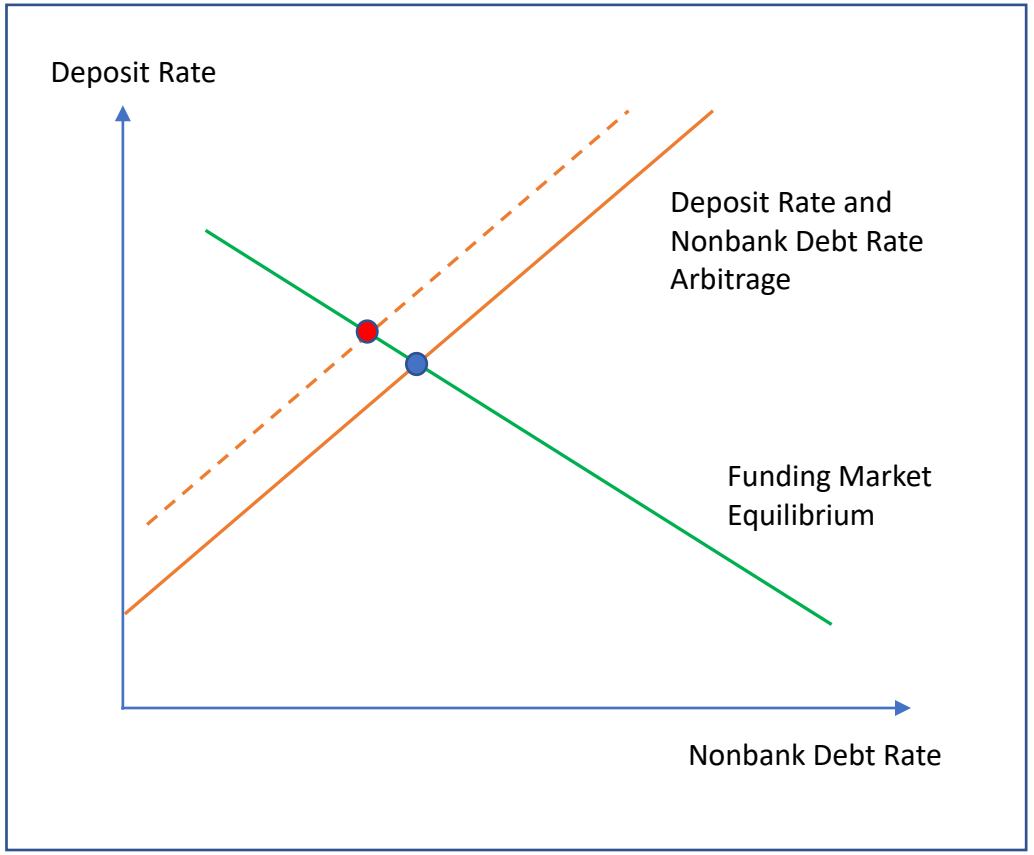
Figure 27 displays the results for an increase in balance sheet costs for the banking sector. An increase in bank balance sheet costs drives up loan rates and puts downward pressure on deposit rates and the size of bank balance sheets. Households shift their portfolios toward nonbank debt. The nonbank sector expands and again shifts into loans and away from holding of Treasury securities and other Federal Reserve liabilities.

At a 60,000 foot level, this interpretation touches on many of the themes in common narratives around the evolution of bank balance sheets in response to changes in regulation over recent years. Consistent with the model results, the strengthening of bank capital requirements and liquidity regulations make the banking system safer. But in a point often emphasized by banks and evident in the model results, those gains may come at the expense of increased costs of intermediation in the banking sector and a reduction in the safety and liquidity of the nonbank sector. Similarly, in the model, additional safety afforded by new liquidity regulations for banks weighs on bank net interest margins and contributes to a sizable increase in the demand for reserves in the banking system.

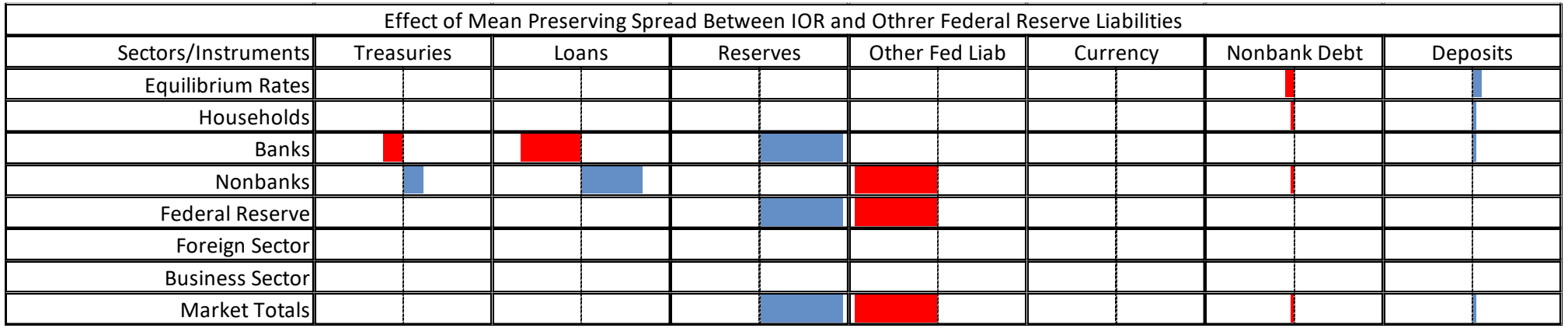
Regulations that primarily affect banks also have an influence on the relative importance of the Federal Reserve's administered rates. In the model, increases in bank capital requirements and liquidity requirements tend to diminish the effect of the interest rate on reserves in influencing market interest rates while boosting the effect of the interest rate offered on other/ Federal Reserve liabilities.

# Figure 23: Mean Preserving Spread Between Administered Rates

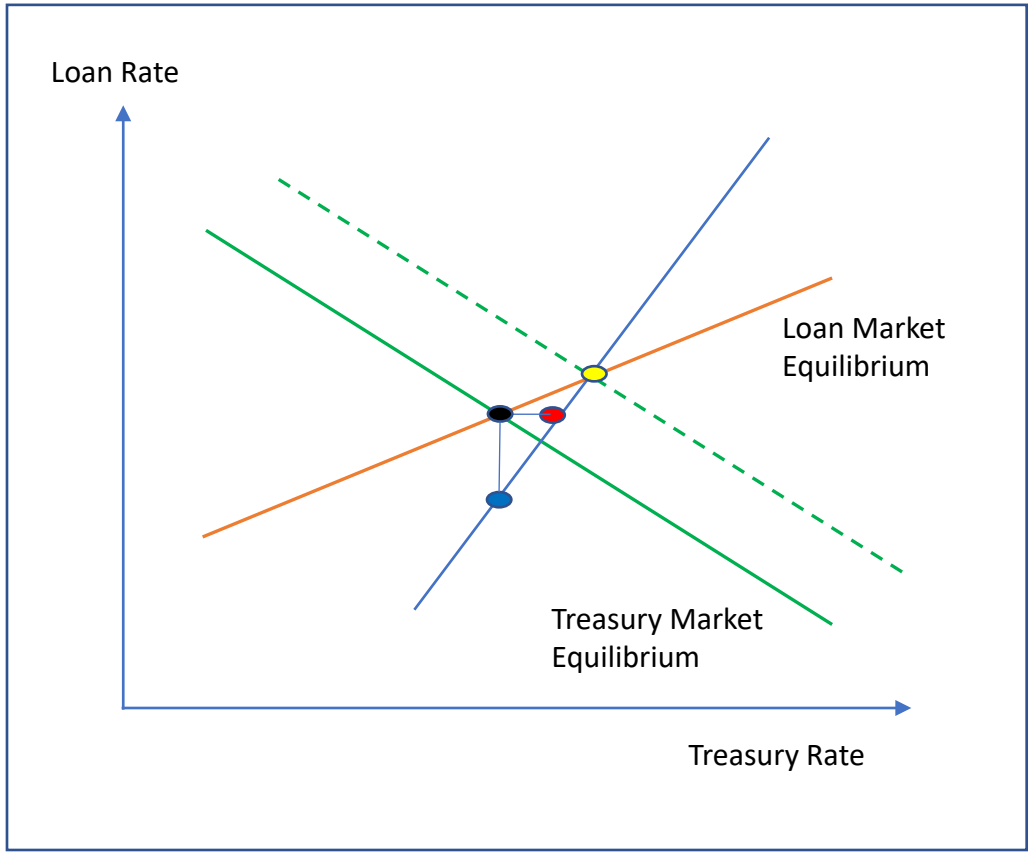


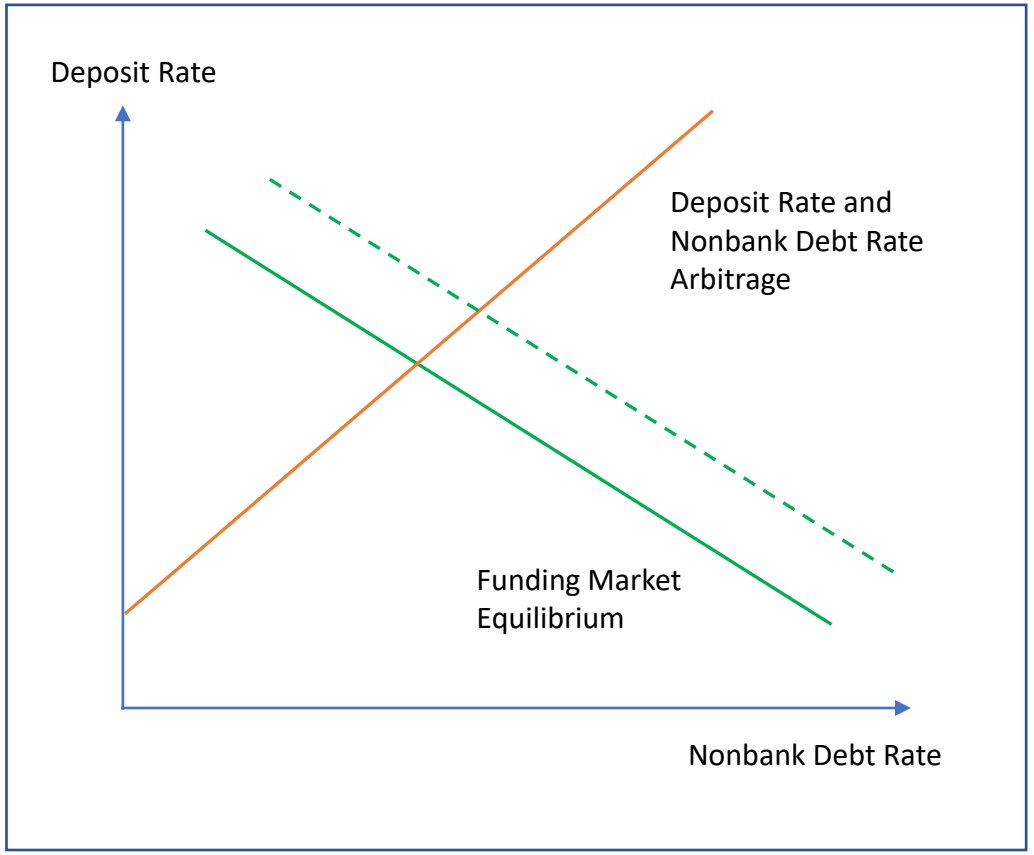



# Figure 24: Effect of Mean Preserving Spread of IOR and Other Federal Reserve Liabilities Rate

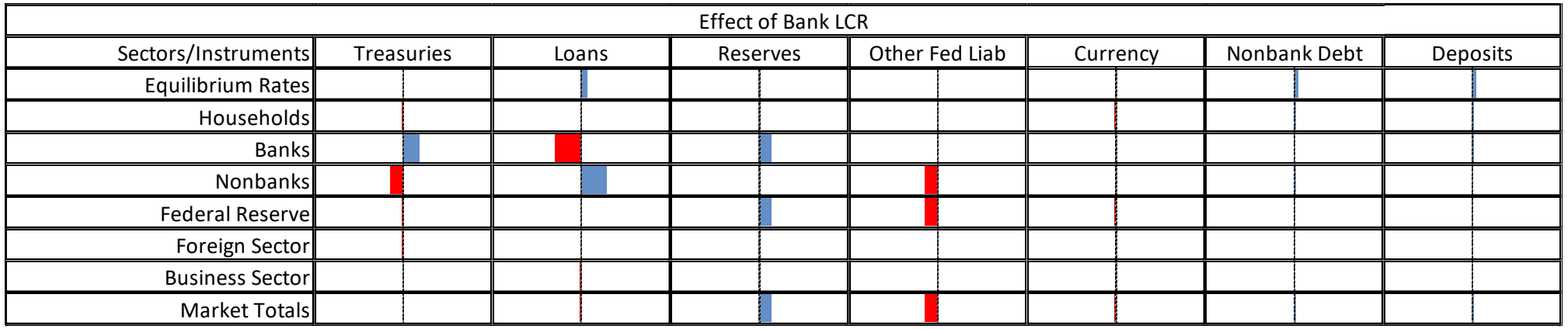


# Figure 25: Alternative Rate Targets



# Figures 26 and 27: Effect of Increase in Bank LCR and Effect of Increase in Bank Leverage Ratio



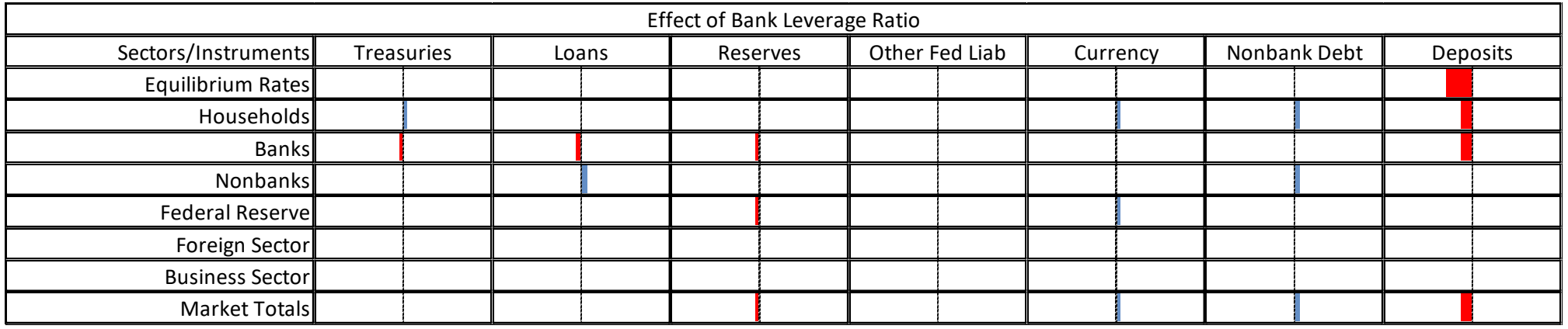



Figure 28: Pass Through Coefficient in Baseline Model

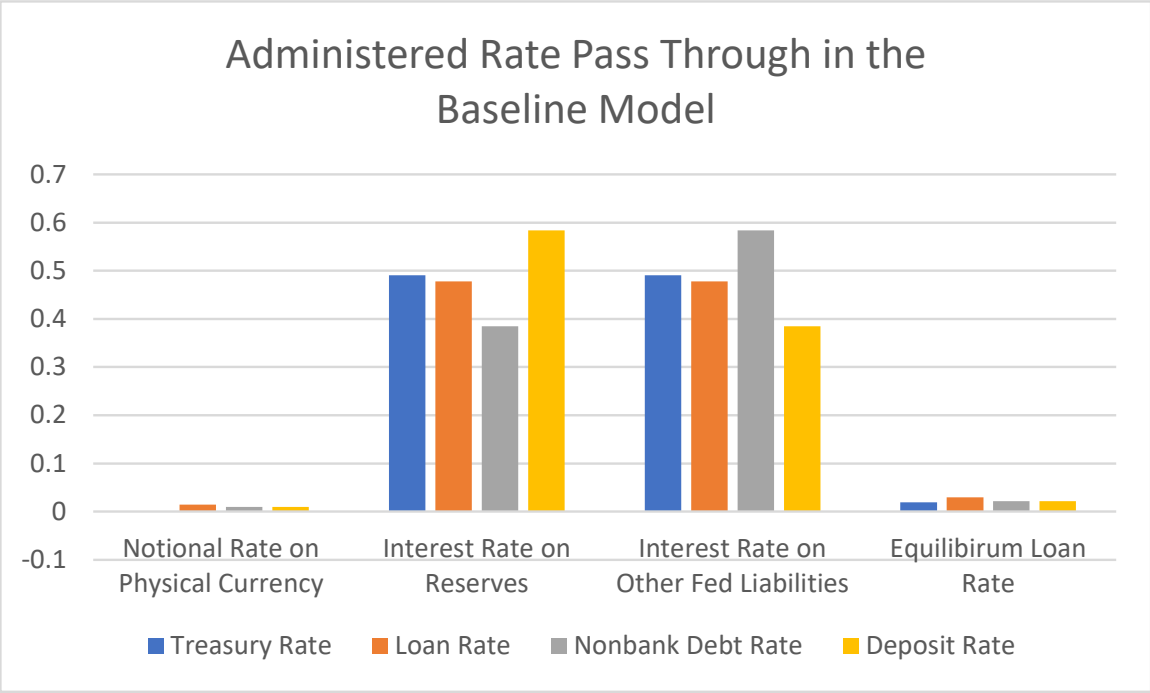
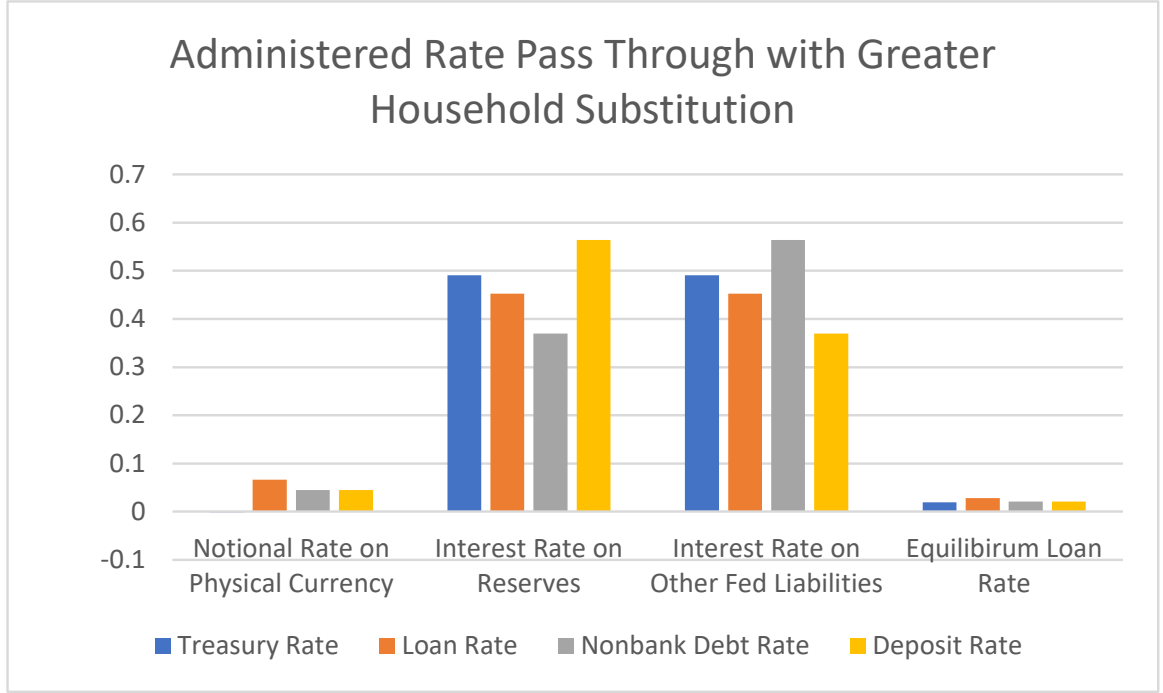



Figure 29: Pass Through Coefficients with Greater Household Substitution



As a final note, the significant downward pressure on deposit rates in the case of an increase in the bank leverage ratio requirement opens up a wider spread between the interest rate offered on Federal Reserve liabilities and deposit rates. As discussed in more detail below, that wider spread in turn may create opportunities for new types of financial entities with a different cost structure than traditional banks and nonbanks to develop profitable business models if they are able to hold reserves or invest in other Federal Reserve liabilities.

### Pass-Through Effects of Administered Rates in the Baseline Model

As discussed in the appendix, the Federal Reserve's administered rates and the equilibrium loan rate together determine a "base" level for each of the endogenous rates. The base level for each equilibrium rate is of the form:

$$r_i = a_{i,CU} \cdot r_{CU} + a_{i,RS} \cdot r_{RS} + a_{i,OL} \cdot r_{OL} + a_{i,r^*_{LN}} \cdot r^*_{LN}$$

The coefficients, $a_{i,CU},\ a_{i,RS},\ a_{i,OL},\ and\ a_{i,r^*_{LN}}$ sum to 1. Figure 28 plots these pass-through coefficients from the baseline model for all of the endogenous rates. Not surprisingly, the interest on reserves rate—the second cluster of bars--has an outsized effect on the deposit rate (yellow bar) while the interest rate on other Federal Reserve liabilities—third cluster of bars--has an outsized effect on the nonbank debt rate (gray bar). These two administered rates are about equally important for the loan rate and the Treasury rate (blue and orange bars). Also of note, the pass-through coefficients for the interest on reserves rate and the interest rate on other Federal Reserve liabilities are much larger than those for the notional rate on physical currency or the equilibrium loan rate. The muted effect of the equilibrium loan rate on endogenous rates stems from the assumed low interest sensitivity of business loan demand. Similarly, the very muted effect of the notional administered rate on physical currency also stems from the assumed very low interest sensitivity of household demands for financial assets.

Figure 29 shows how the pass-through coefficients change in connection with an increase in the willingness of households to substitute across financial assets. In this case, the pass-through coefficient for the rate on physical currency is notably higher while the pass-through coefficients for the other rates decline somewhat. With more scope to substitute across financial assets, the notional rate offered on physical currency matters more in the determination of endogenous rates. With the notional rate on currency set at zero, households are more willing to shift out of currency in favor of alternative assets, putting downward pressure on other interest rates. A marginal increase in the notional rate on currency would put marginally more upward pressure on interest rates. Conversely, a marginal increase in the Federal Reserve's other administered rates has a somewhat smaller effect that in the baseline because the upward pressure on market rates is damped somewhat by the greater substitution out of currency. This theme of the potential for increased household substitution across financial assets also figures in the discussion below of the introduction of new financial assets such as CBDC or stablecoin.

## 6. Variations on the Baseline Model

This section considers three variations on the baseline model with the aim of exploring the potential implications of alternative financial market structures and instruments. The first variation considers a version of the model that incorporates both a retail and wholesale central bank digital currency. Retail and wholesale CBDC are distinguished primarily by the range of entities entitled to invest in these instruments. In the model, only households invest in retail CBDC while banks and nonbank financial

institutions may invest in wholesale CBDC.[11] A second variation considers the introduction of so-called stablecoins in the model. Stablecoins are issued by narrow nonbank institutions and held only by households. A third variation on the model considers the role of so-called narrow banks that issue deposits and hold assets only in the form of reserves.

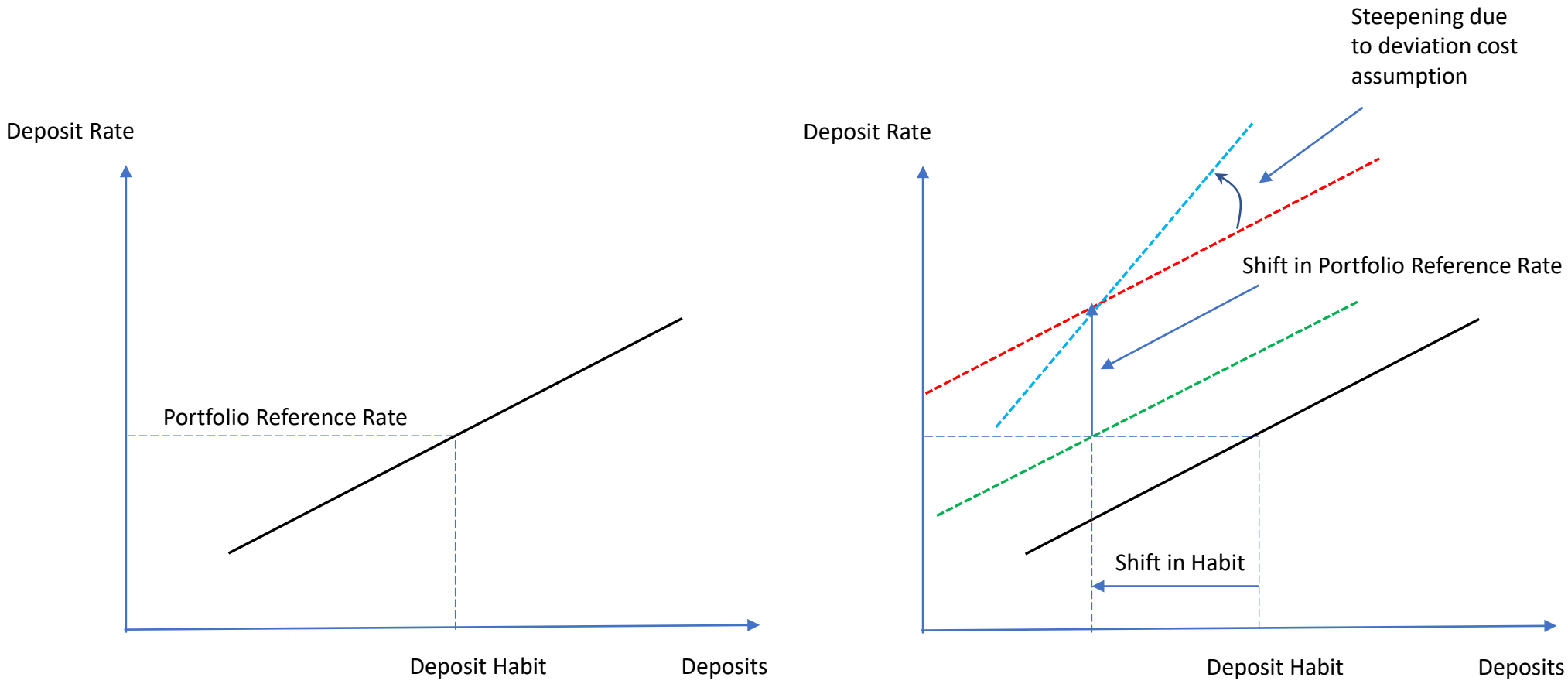
## The Effects of Introducing New Financial Assets

The first two variations on the baseline model introduce new financial assets to either households, financial intermediaries, or both. The introduction of new financial assets in the choice sets for households and financial intermediaries is conceptually different than the comparative statics exercises discussed above. Those exercises involved marginal changes in parameters of a given structural model. In contrast, the introduction of new financial assets involves a discrete change in the preferences of households and financial intermediaries. Some of the effects of introducing new financial assets into the model can be viewed as different types of "substitution effects." One type of effect might be termed "habit substitution" reflecting a change in the desired habit share of household or intermediary portfolios. For example, the introduction of retail CBDC may entail a decline in the habit for, say, physical currency reflecting the new habit for retail CBDC. One might think of this type of substitution as arising from the nonpecuniary aspects of different financial assets or their implicit flow of "services" apart from interest payments. Another type of effect stems from the influence of a new asset on the portfolio "reference" rate that households and financial intermediaries use as a benchmark in their portfolio allocation decisions. Yet another type of substitution effect arises from the potential for households and intermediaries to move away from the habit share of one asset in favor of another in light of changes in relative interest rates. Given our assumptions about the nature of habit deviation costs, the response of demand for a financial asset to any given deviation of the own rate for that asset relative to the portfolio benchmark rate may also change.

As an example, figure 30 presents a graphical representation of these types of substitution effects in connection with the introduction of a new interest-bearing asset available to households on the household demand for deposits. As shown in the left panel, the initial household deposit curve is upward sloping with the deposit rate plotted on the vertical axis. When the deposit rate is equal to the portfolio reference rate, household demand for deposits is exactly equal to the habit level of deposits. The right panel shows the hypothetical effects of introducing a new interest-bearing asset on this deposit curve. If the new financial asset attracts a habit level of demand that comes at the expense of deposits, the new habit level of deposits will decline as shown by the shift from the black line to the green line. If the new financial asset bears interest, the portfolio reference rate may also change. The chart shows the effect when the portfolio reference rate increases from the green line to the red line. Finally, based on our assumptions regarding habit deviation costs, the slope of the deposit line will steepen if the deposit habit level

[11] There are many different concepts of "wholesale CBDC." Similar to the view adopted in this paper, some concepts for a wholesale CBDC involve a new liability issued by the central bank to facilitate payments, perhaps in connection with securities settlement or cross border transactions (see Project Helvetia Phase II (2022), BIS Innovation Hub and Project mBridge (2022), BIS Innovation Hub for detailed discussions of prototypes for this concept of wholesale CBDC). Alternative conceptions of a wholesale CBDC involve developing ways to better integrate existing payment and settlement systems to facilitate more efficient transactions. See Durfee, et. al. (2023), Green (2023) and Panetta (2022) for a discussion of various perspectives on wholesale CBDC.

## Figure 30: Effects of Introducing New Financial Assets



declines, shown by the rotation from the red line to the blue line. All of these types of substitution effects play an important role in the model.

## The Case with Retail and Wholesale CBDC

This section examines aspects of an extension of the baseline model to include a retail and wholesale central bank digital currency denoted by R_CBDC and W_CBDC, respectively. The financial structure underlying this version of the model is shown in figure 31. The R_CBDC is held only by households and represents a new financial asset available as an investment vehicle with a corresponding new liability of the Federal Reserve. Households are assumed to have a "habit" for R_CBDC similar to that assumed for other financial assets. And the introduction of R_CBDC in the model also entails a new administered rate for a Federal Reserve liability, $r_{R\_CBDC}$, that we assume is set at zero to match the assumed rate on physical currency. We assume the habit for R_CBDC initially comes entirely at the expense of the habit for physical currency.

This version of the model also incorporates a wholesale CBDC and a corresponding new administered rate, $r_{W\_CBDC}$. Wholesale CBDC is assumed to be available for banks and nonbanks but is not part of the portfolio choice set for households. Because banks and nonbanks are relatively interest rate sensitive, we assume the rate on W_CBDC is set at a level comparable to that on reserves or other Federal Reserve liabilities held by financial intermediaries.

The general properties of this variation of the model are the same as those for the baseline model. An equal increase in all of the Federal Reserve's administered rates—the notional rate on physical currency along with the rates on retail CBDC, reserves, other Federal Reserve liabilities, and wholesale CBDC—along with the equilibrium loan rate results in a one for one pass through to all market interest rates. All interest rate spreads in this scenario are again unaffected so the equilibrium quantities are also unaffected by such a change.

Equilibrium in the extended model depends importantly on assumptions about the shift in "habits" by households and financial intermediaries. In general, if the portfolio habit for retail or wholesale CBDC comes at the expense of the habit for another Federal Reserve liability or Treasury securities, the equilibrium in the model is essentially unchanged relative to the baseline model. This result stems from the assumption that the Federal Reserve passively accommodates all demand for its liabilities.

The analysis here is closely related to a rapidly growing literature on CBDC. Infante et. al. (2022) provide an excellent survey of the literature. Recent work includes important papers by Chiu et. al. (2023), Andolfatti (2021), Keister and Sanches (2023), and Williamson (2022) among others. Much of the work in these papers has focused on the implications of central bank digital currencies on banks and bank lending. Gust, Kim and Ruprecht (2023) provide an excellent discussion of the potential implications of retail CBDC for monetary policy implementation. Malloy et. al. (2023) use a variety of empirical methods to develop a range of estimates of the potential demand for retail CBDC. Panetta (2022), Durfee et. al. (2023), and Green (2023) discuss issues associated with wholesale CBDC.

## Comparative Statics in the Extended Model with CBDC

Many of the comparative statics results for the extended model with retail and wholesale CBDC largely parallel those for the baseline model. The discussion below focuses on specific issues related to the

administered rates on retail and wholesale CBDC and also the implications of shifts in habits associated with retail CBDC.

### *Effects of An Increase in the Rate on R_CBDC*

Similar to the case of an increase in the hypothetical rate on physical currency in the baseline model, an increase in the rate offered on retail CBDC induces upward pressure on rates. As shown in figure 32, an increase in the R_CBDC rate shifts the loan market equilibrium curve upward, resulting in an increase in loan rates and a decline in Treasury rates. The change also shifts the funding market equilibrium line outward, resulting in equal increases in the deposit rate and nonbank debt rate.

As shown in figure 33, the increase in the R_CBDC rate leads households to shift out of other assets and into R_CBDC. The resulting decline in funding available for intermediaries in the deposit and nonbank debt markets leads banks and nonbanks to scale back their assets with the decline spread across all asset classes. There is a slight negative effect on the aggregate quantity of loans. On the Federal Reserve's balance sheet, reserves, wholesale CBDC, other Federal Reserve liabilities, and currency all decline while retail CBDC increases. On net, the size of the Federal Reserve's balance sheet increases.

## Effects of a Shift in Household Preferences from Deposits to R_CBDC

Also of interest are the effects in the case of a shift in household preferences from deposits to R_CBDC. As shown in figure 34, the changes in this case are similar to those in the baseline model in considering the effects of a shift from deposits to physical currency. The shift in household habits away from deposits moves the loan market equilibrium curve to the left, pushing up loan rates. The funding market equilibrium line (right panel) shifts outward, and the deposit-nonbank debt arbitrage line shifts up leading to an increase in deposit rates relative to the nonbank debt rate.

As shown in figure 35, this shift generates an increase in the Federal Reserve's balance sheet accompanied by a slight decline in Treasury yields. Bank balance sheets decline on net as do bank holdings of loans, reserves, and W_CBDC with the scale effect of the shift again outweighing the substitution effect of a decline in Treasury yields relative to the Federal Reserve's administered rates. The effect of the shift in funding away from banks drives an increase in loan rates and an overall decline in the level of loans. However, much of the decline in lending at banks is offset by an increase in lending by nonbanks. Nonbank financial intermediaries see the increase in loan rates and reduce their holdings of Treasury securities, other Federal Reserve liabilities, and wholesale CBDC in favor of extending additional business loans. In addition, they also draw in funding in the form of nonbank debt with the scale of the nonbank sector increasing slightly.

Figure 35 displays the effects of a *marginal* shift in household habits from deposits to R_CBDC. The rate effects of this type of shift can be sizable depending on the magnitude of the shift in household portfolio allocations. For example, in the calibrated extended model, we assume the initial household habit for physical currency (20 percent) is split evenly between physical currency and R_CBDC so that the new habits for each are 10 percent. If we assume instead that the habit for R_CBDC comes at the expense of deposits, the deposit habit would fall from 30 percent to 20 percent. The left panel of figure 36 displays equilibrium rates for the baseline model, the extended baseline model with CBDC, and the extended baseline model with the habit for R_CBDC coming at the expense of deposits. As noted above, there is essentially no difference between the blue and orange bars given that the Federal Reserve accommodates any shift between physical currency and R_CBDC. However, when the habit for R_CBDC comes at the

expense of deposits (gray bars), the interest rate outcomes are much different. The loan rate, in particular, moves up about 70 basis points and both the deposit rate and nonbank debt rate move considerably higher as well. The right panel shows the corresponding changes in the Federal Reserve's balance sheet. In moving from the baseline model to the extended baseline model (blue bars to orange bars), there is no change in the size of the Federal Reserve's balance sheet. Declines in physical currency, reserves, and other Federal Reserve liabilities "make room" for the holdings of R_CBDC and W_CBDC. When the R_CBDC habit comes at the expense of deposits (gray bars), there is a modest associated runoff of reserves, other Federal Reserve liabilities and W_CBDC as banks and nonbanks scale back the size of their balance sheets. However, the total size of the Federal Reserve's balance sheet increases significantly.

### *Effects of an Increase in the W_CBDC Rate*

As modeled here, wholesale CBDC is held by both banks and nonbanks. As a result, an increase in the W_CBDC rate directly affects both bank and nonbank asset allocations. The interest rate effects of an increase in the W_CBDC rate are shown in figure 37 and are similar to those for the case of a parallel increase in the interest rate on reserves and interest rate on other Federal Reserve liabilities in the baseline model. As shown in the left panel, the increase in the W_CBDC rate shifts the loan market equilibrium curve up and to the left and also pulls up the Treasury market equilibrium curve. The latter effect stems from the assumption that the W_CBDC rate becomes part of the "benchmark" rate in the foreign sector Treasury demand curve. The net effect is an increase in both the Treasury rate and loan rate. And those increases lead to increased demand for funding by banks and nonbanks—illustrated by the outward shift in the funding market equilibrium line in the right panel— resulting in increases in the deposit and nonbank debt rates.

Bank and nonbank balance sheets expand as households are drawn out of currency, R_CBDC, and Treasury securities. However, as shown in the top panel of figure 38, banks and nonbanks are able to substitute between reserves or other Federal Reserve liabilities and W_CBDC. Given the sensitivities of intermediaries to changes in relative rates of return, the substitution effects of an increase in the W_CBDC rate are pronounced on the asset side of bank and nonbank balance sheets.

The bottom two panels of figure 38 show the effects of increases in the interest rate on reserves and the interest rate on other Federal Reserve liabilities, respectively. The patterns displayed in these charts are similar to those reported above for the baseline model. One feature to note, however, is that the magnitude of the rate effects and quantity effects in the case of a marginal change in the W_CBDC rate is somewhat larger than the magnitude of the effects shown for the interest on reserves rate or rate on other Federal Reserve liabilities. The relatively large effect of a change in the W_CBDC rate stems from the assumption that both banks and nonbanks are able to invest in W_CBDC. Thus, the "reach" of a marginal change in the W_CBDC rate in directly affecting portfolio allocations of financial intermediaries is larger than for the Federal Reserve's other administered rates. This effect is shown more clearly in figure 39. The left panel of bars reports the response of endogenous rates to changes in the interest rate on reserves and other Federal Reserve liabilities in the baseline model. The right panel reports comparable coefficients in the extended model with wholesale CBDC. As shown by the gray bars, the marginal effect of a change in the W_CBDC rate is larger than that for other administered rates. The marginal effects for all of the individual administered rates are smaller than those in the baseline model. However, the sum of the coefficients (shown by the yellow bars) is identical to the sum of the coefficients for the administered

rates in the baseline model. As a result, policy responses that involve parallel adjustments of all three administered rates in the extended model generate the same changes in endogenous rates that accompany parallel adjustments in the two core administered rates in the baseline model.

## Discussion: Implications for Policy Implementation

The extended model incorporating retail and wholesale CBDC points to some significant potential implications for policy implementation. Perhaps most notably, the interest rate offered on wholesale CBDC becomes another very important policy rate that would likely need to be moved in tandem with the interest rates on reserves and the interest rate on other Federal Reserve liabilities in achieving any desired level of short-term interest rates. Indeed, as modeled here, wholesale CBDC would be available to banks and nonbanks alike, and the independent influence of the W_CBDC rate on market rates is larger than the corresponding individual effects of the Federal Reserve's other administered rates.

Another issue would be the appropriate setting of the W_CBDC rate relative to the Federal Reserve's other administered rates. In the model, the W_CBDC rate is set exactly in the middle of the range between the interest rate on reserves and the interest rate on other Federal Reserve liabilities. Setting the W_CBDC rate at the lower end of this range would likely imply that W_CBDC would be mostly held by nonbanks and could interact strongly with the demand for other Federal Reserve liabilities. Setting the W_CBDC rate at the top end of the range could imply that nonbanks would pull back from other investments (such as lending in the federal funds market) in favor of holding W_CBDC.

The potential impact of the advent of retail CBDC in the loan market also raises some important questions. As discussed above, in the case when the household habit for retail CBDC comes at the expense of deposits, funding costs for intermediaries move higher and the equilibrium loan rate moves higher as well with a corresponding decline in borrowing by businesses. To the extent that the increase cost of credit to businesses works against the macroeconomic objectives the Federal Reserve is seeking to achieve, the Federal Reserve could take countervailing policy actions by reducing its policy rate (and adjusting the administered rates on reserves, other Federal Reserve liabilities, and wholesale CBDC appropriately). That would largely return the financial system to its initial equilibrium but with a lower level of the Federal Reserve's policy rate. The lower level of the policy rate, in turn, would imply less scope for policy to respond to other adverse shocks that could weigh on the economy. In effect, the introduction of a retail CBDC that attracts funding from deposits would push down the equilibrium level of the Federal Reserve's policy rate. That decline, in turn, would bring the zero lower bound on interest rates into play more often in the event of future adverse shocks to the economy.

As many have noted, one possible counter to the concern about retail CBDC and the zero lower bound is that retail CBDC might make it more feasible for the Federal Reserve to implement negative interest rates. In the model, implementing a negative rate on retail CBDC would lead households to substitute away from retail CBDC in favor of physical currency, deposits and nonbank debt. That shift would move the equilibrium market funding line in, pulling down deposit rates and nonbank debt rates. And the equilibrium loan line would shift to the right, resulting in a decline in the equilibrium loan rate and a small increase in aggregate loans. However, as parameterized, the model results suggest these effects would be minor. For example, if the retail CBDC rate is reduced from 0 to -100 basis points, the level of interest rates would drop by only about a basis point. That result stems from the assumption that households are generally quite insensitive to interest rates in their portfolio decisions and particularly for

# Figure 31: Financial Market Structure in Model with CBDC

**Households**

| Assets | Liabilities |
|---|---|
| Currency | |
| Treasury Securities | |
| Nonbank Debt | |
| Deposits | |
| Retail CBDC | Net Worth |

**Banks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Deposits |
| Loans | |
| Reserves | |
| Wholesale CBDC | |
| | |

**Nonbanks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Nonbank Debt |
| Loans | |
| Other Fed Liabilities | |
| Wholesale CBDC | |
| | |

**Business**

| Assets | Liabilities |
|---|---|
| Real Assets | Loans |
| | |
| | |
| | |
| | |

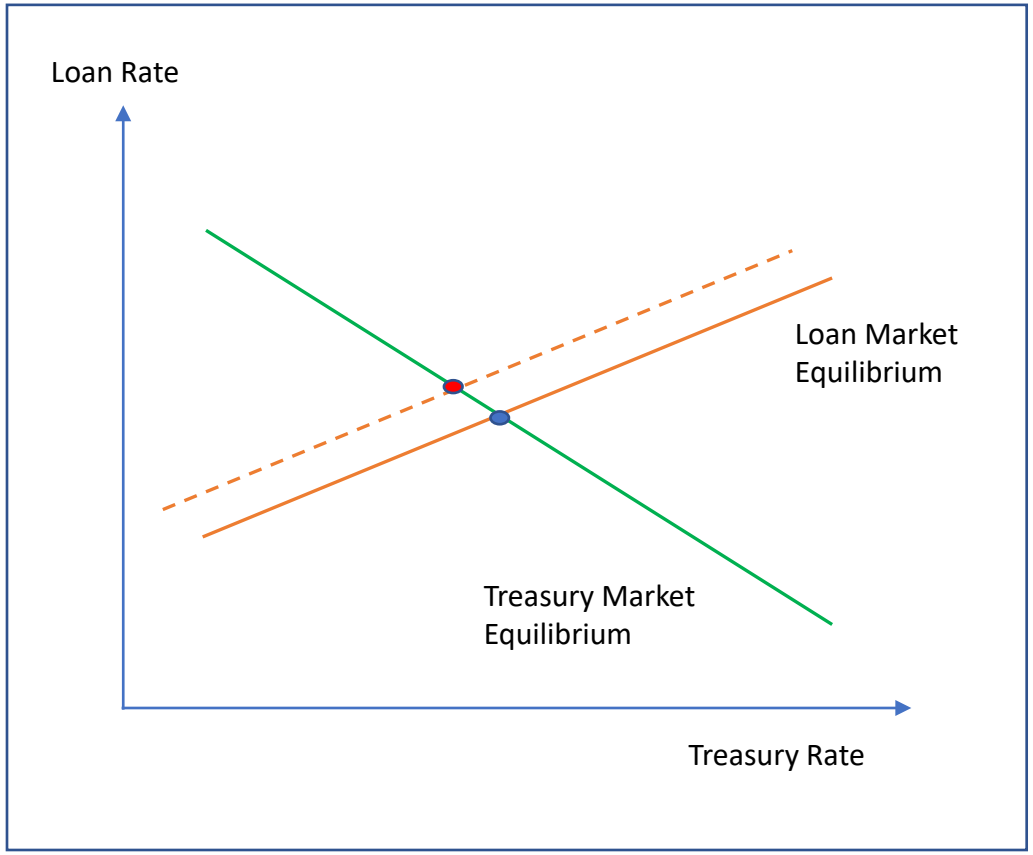
**Federal Reserve**

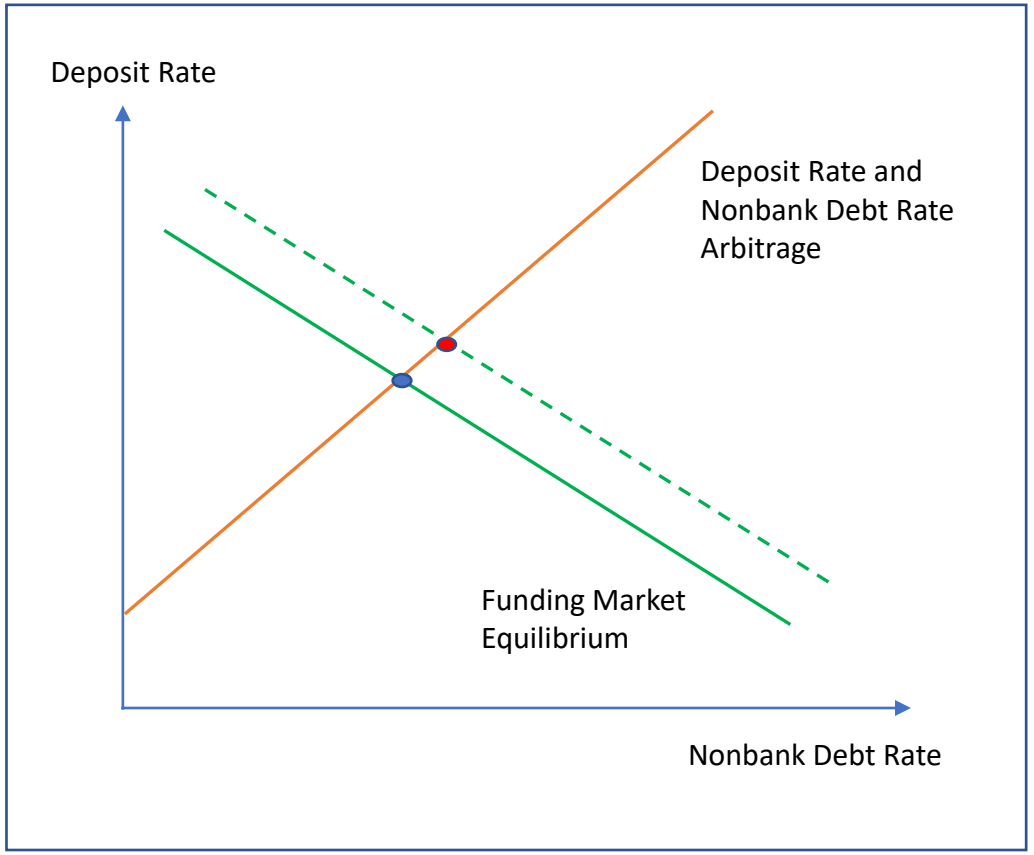
| Assets | Liabilities |
|---|---|
| Treasury Securities | Currency |
| | Reserves |
| | Other Liabilities |
| | Retail CBDC |
| | Wholesale CBDC |

**Foreign Sector**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Other |
| | |
| | |
| | |
| | |

# Figure 32: Response to Increase in Interest Rate on R_CBDC



# Figure 33: Effect of Increase in Retail CBDC Rate

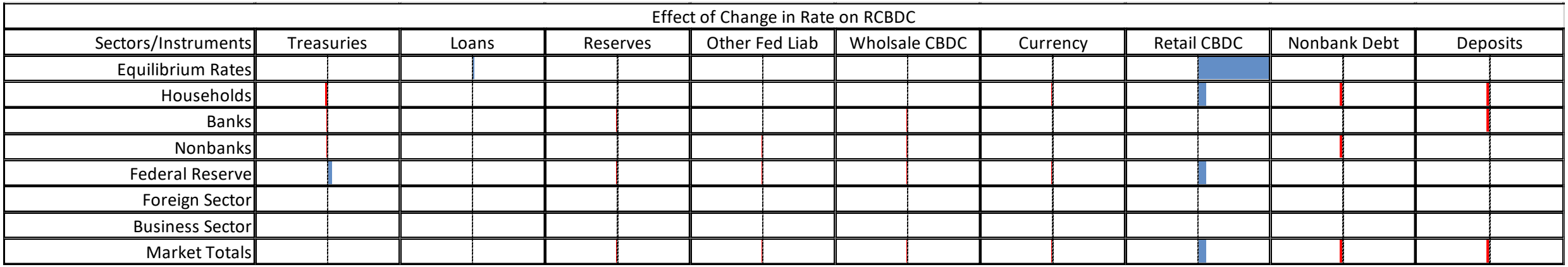
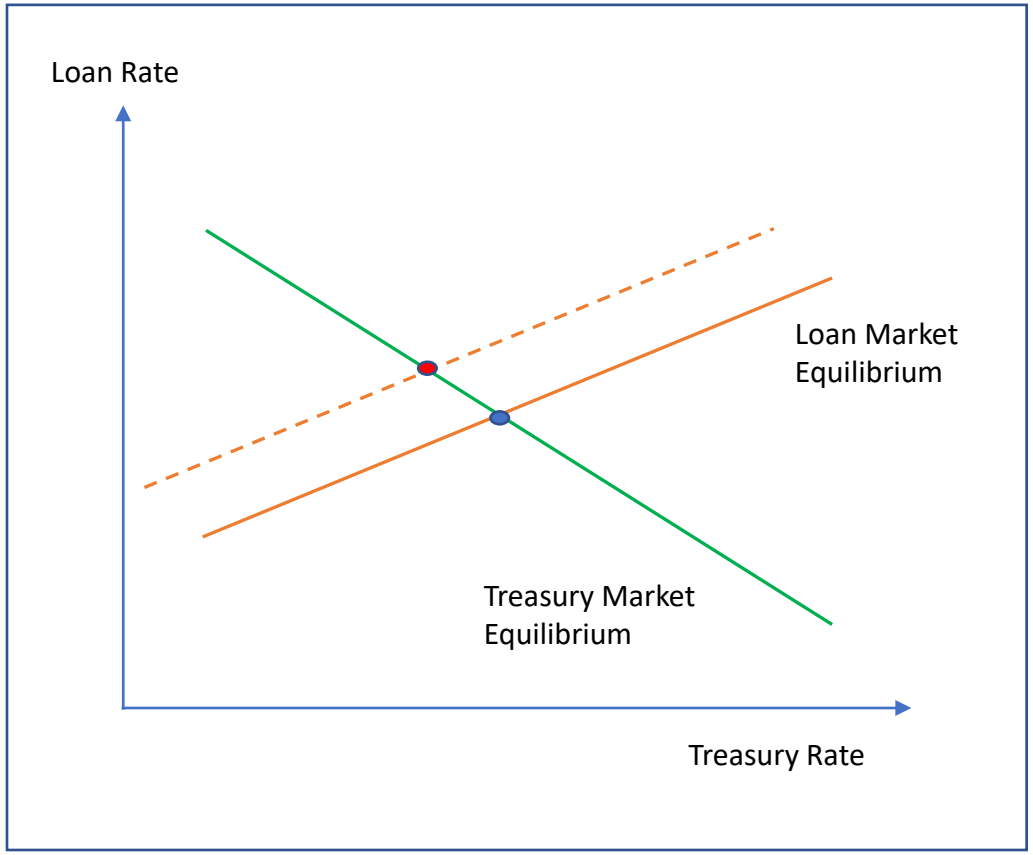
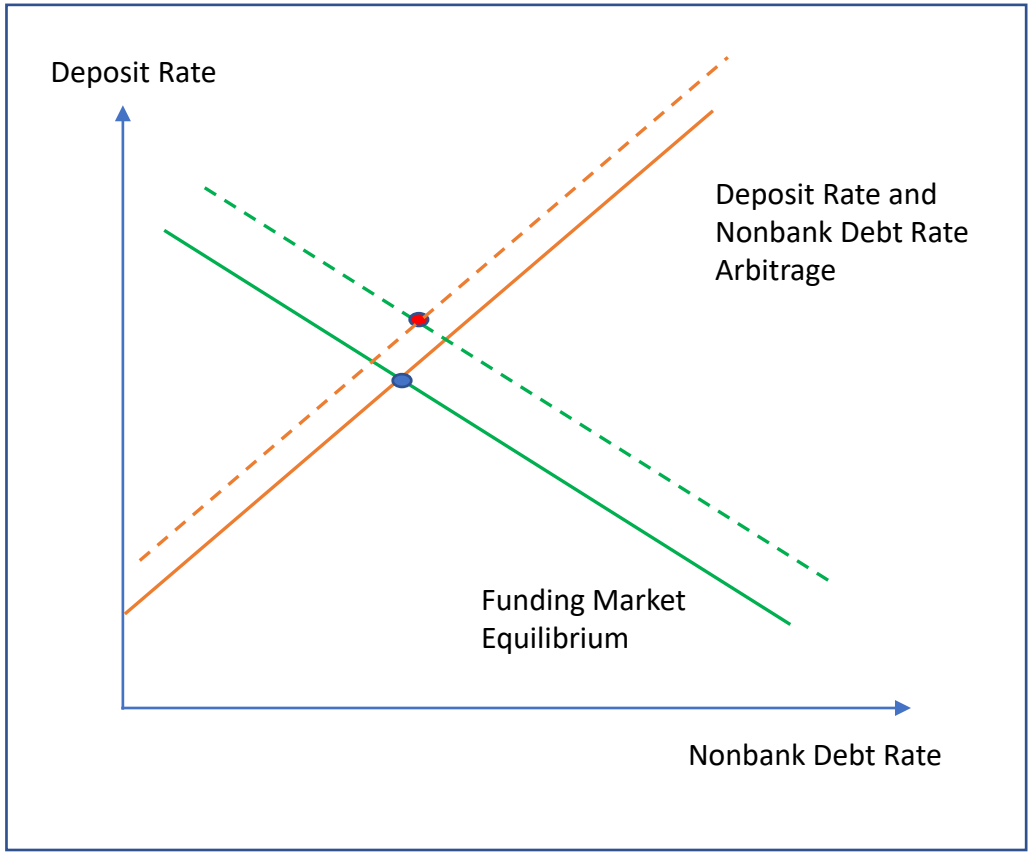
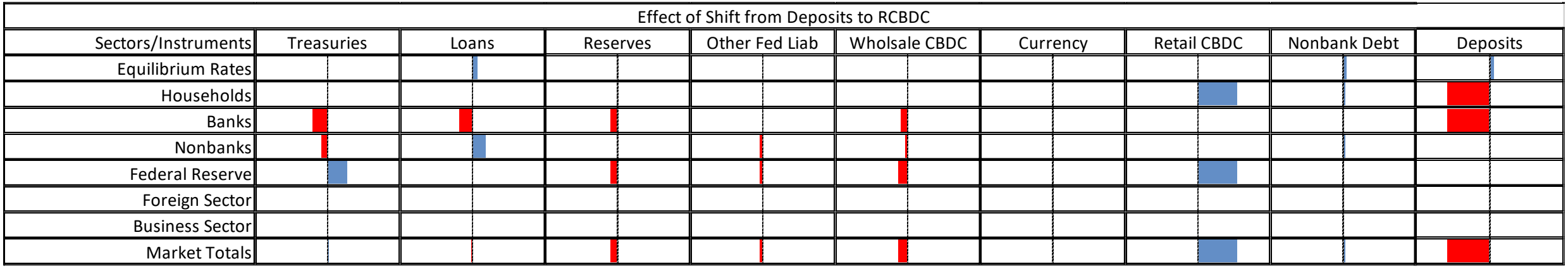


Figure 34: Response to Shift in Household Habits Away from Deposits Toward R_CBDC

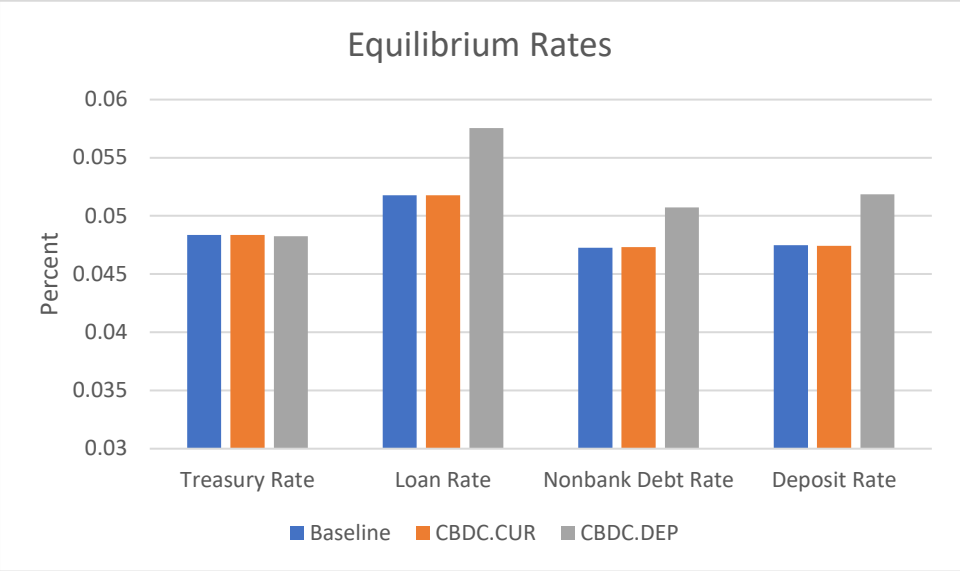


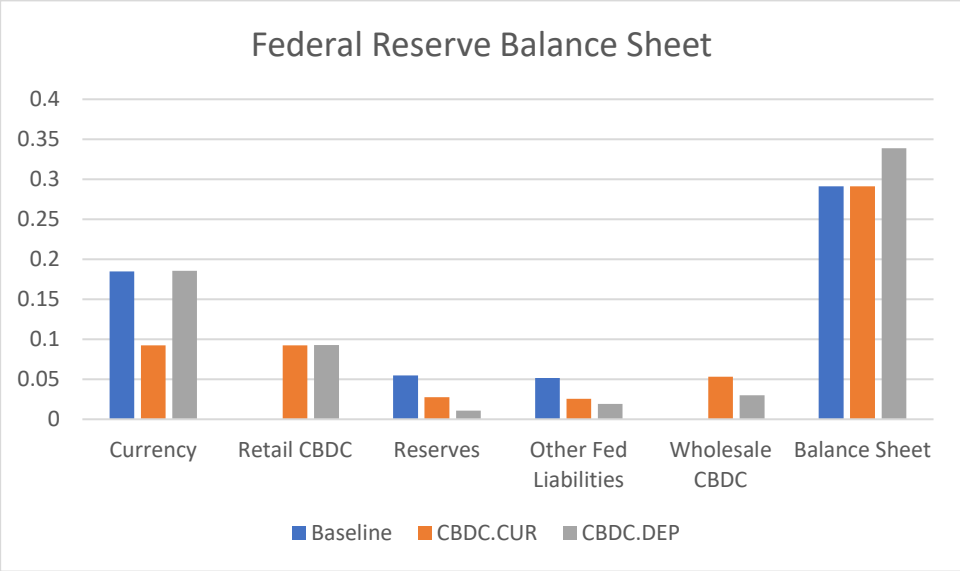



# Figure 35: Effect of Shift from Deposits to Retail CBDC

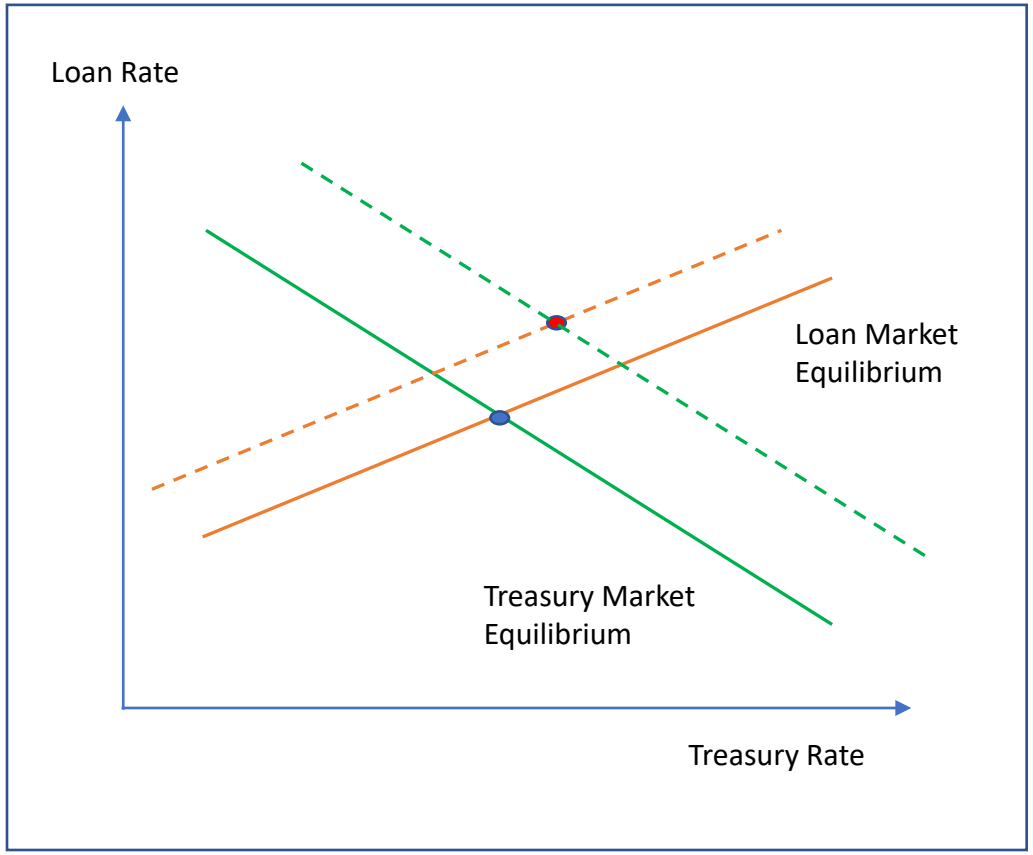


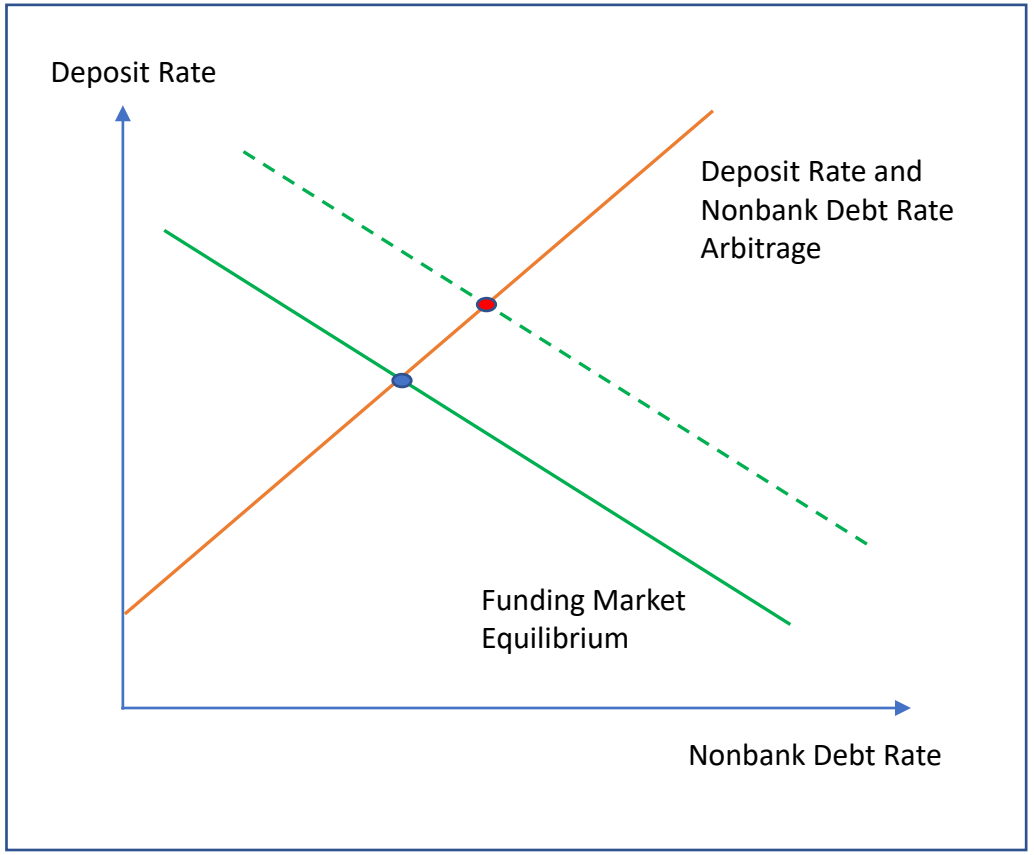
# Figure 36: Effects of Alternative Assumptions about Shifts in Habits



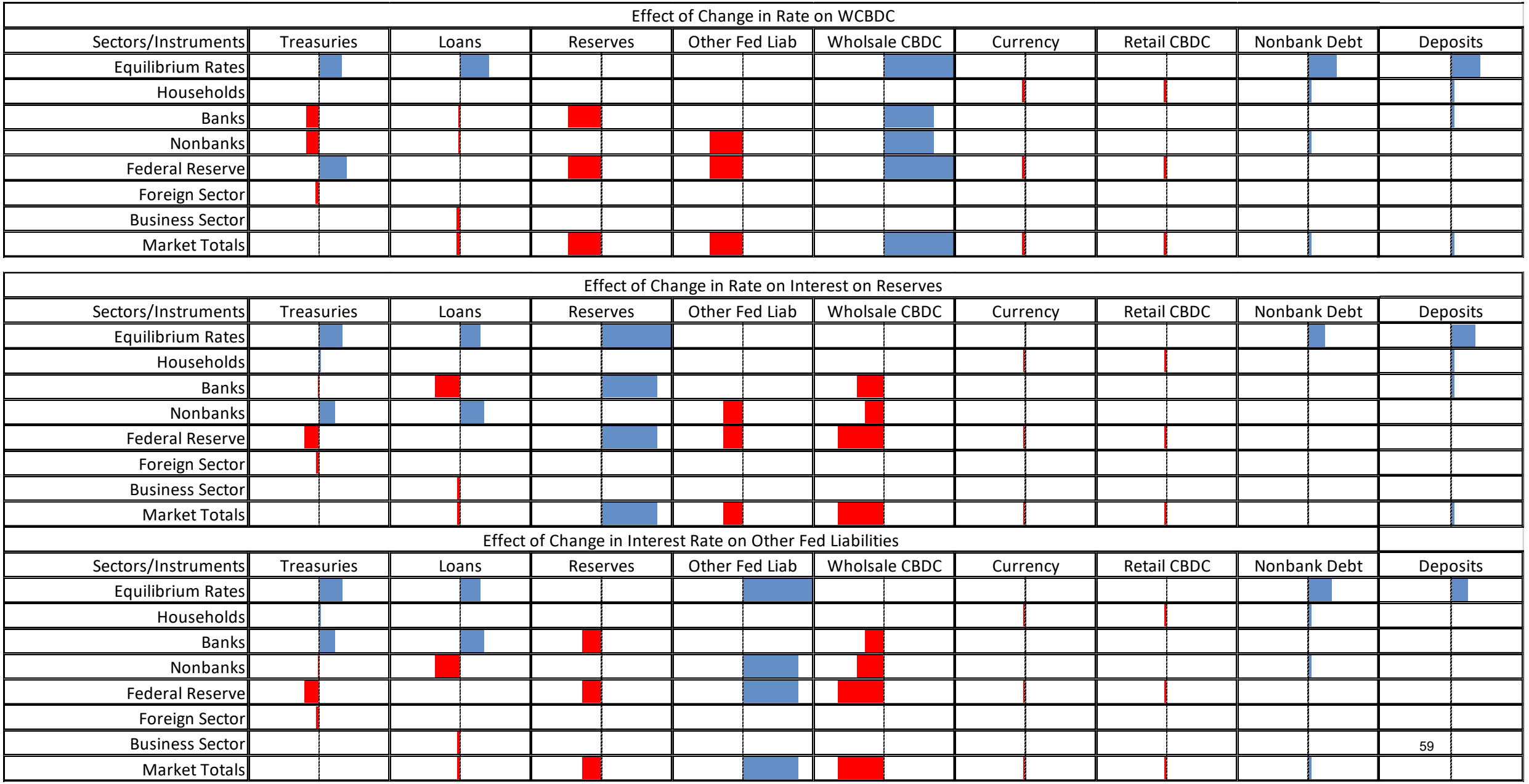



# Figure 37: Response to Increase in W_CBDC Rate

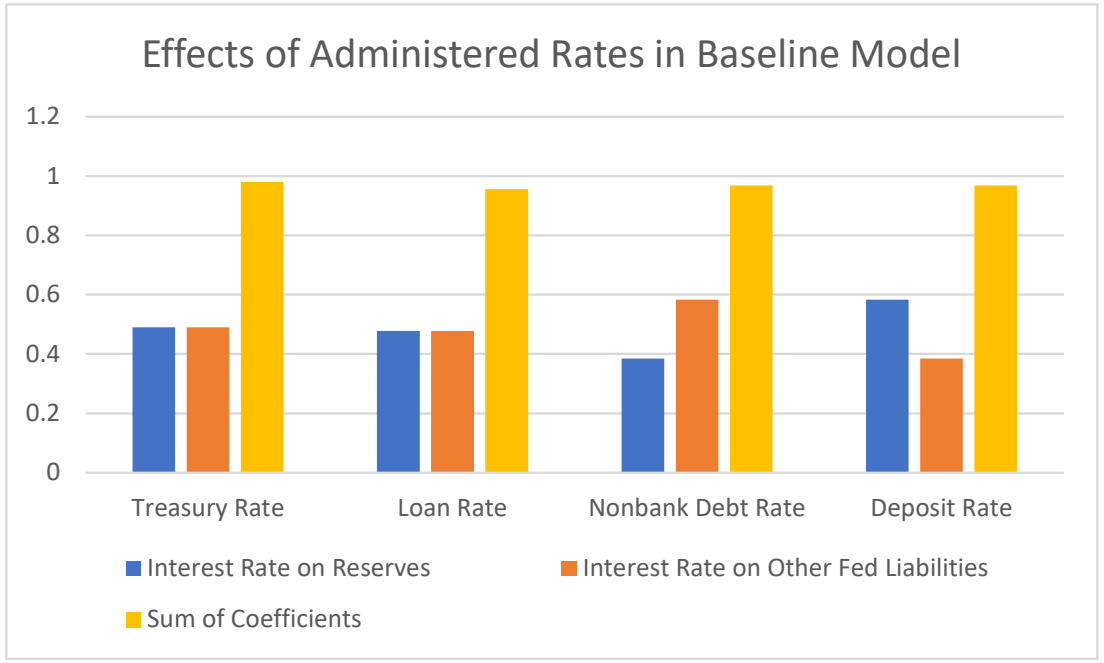


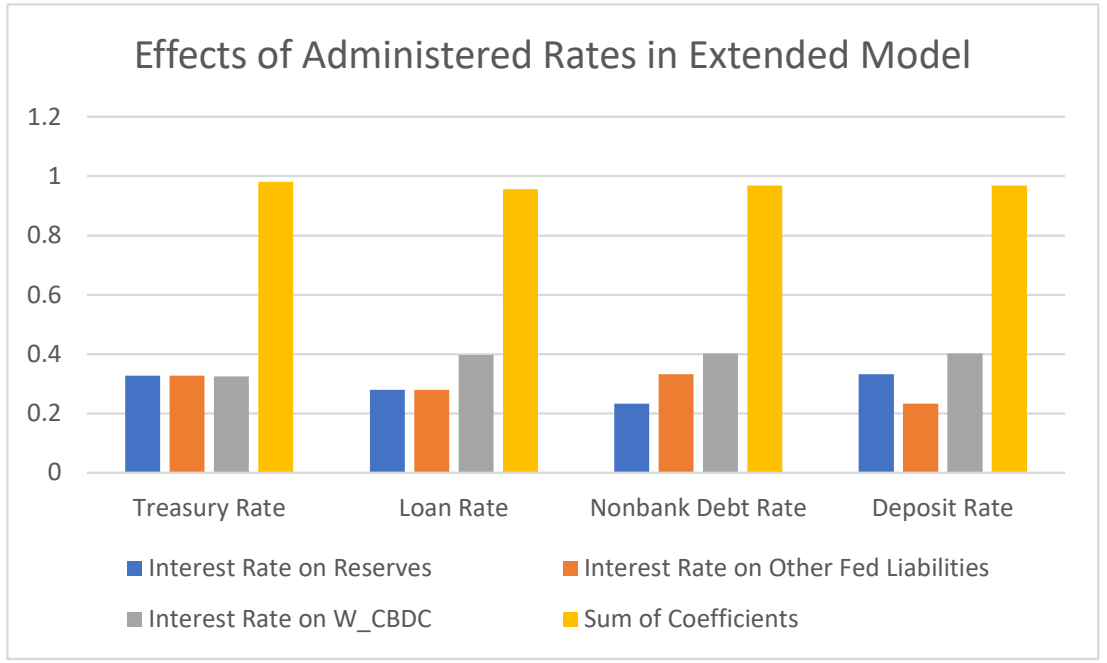



# Figure 38: Effect of Increase in Wholesale CBDC Rate



# Figure 39: Comparison of Effects of Administered Rates



assets that do not comprise a large portion of their portfolio. The more interest-rate sensitive households are to relative interest rates the larger the potential market effects of pushing the retail CBDC rate into negative territory.

## The Case with Narrow Nonbanks Issuing Stable Coins

The advent of "narrow" nonbanks focused on offering one specific type of liability or service has garnered significant attention of late. Much of this attention has centered on the development of so-called "stablecoins" that may be used to execute payments over internet-based block-chains and distributed ledgers.

As discussed in Baughman et. al. (2022), to date, much of the payment activity in stablecoin has been as a settlement media in connection with the trading of other "crypto" assets. However, private stable coins could develop in ways that would facilitate payments across a wide range of transactions. For our purposes, we examine a narrow nonbank that offers a stablecoin at a fixed rate, $r_{SC}$ (which could be zero), and we assume the narrow nonbank satisfies all demand for stablecoin at that fixed rate. The financial structure underlying this version of the model is shown in figure 40. Narrow nonbanks, shown in the lower right panel, issue stablecoins. For the purpose of this paper, we assume stablecoin issuers hold reserves as the sole asset backing these liabilities.[12]

The effects of introducing stablecoin in this way are exactly analogous to the introduction of retail CBDC discussed above. As shown in figure 41, in the case when the habit for stablecoin comes at the expense of physical currency (orange bars), equilibrium rates (and quantities) are unchanged relative to the baseline version of the model (blue bars). The composition of the Federal Reserve's liabilities (shown in the bottom panel) shifts away from currency toward reserves with the latter reflecting the increase in reserve demand coming from stable coin issuers.

The situation is much different when the habit for stablecoin comes at the expense of deposits. As shown in the top panels of figure 42, in this case, the loan market equilibrium curve shifts up, resulting in higher loan rates and slightly lower Treasury rates. Returning to figure 41, as shown by the gray bars, in the calibrated model, the magnitude of the effect on the loan rate is sizable. The equilibrium loan rate increases by about 70 basis points. The changes in the loan rate and Treasury rate result in an outward shift in the funding market equilibrium line, pushing both the deposit rate and nonbank debt rates up significantly by 45 basis points and 35 basis points, respectively.

The bottom panel of figure 42 illustrates the effect of the marginal shift in household habits from deposits to stablecoin across the balance sheets of all sectors. As noted above, that shift drives increases in the loan rate, bank deposit rates, and nonbank debt rates. The shift out of deposits leads banks to scale back their holdings of reserves, but that change is more than offset by the increases in reserves maintained by stablecoin issuers. Bank loans fall reflecting the loss in deposit funding, but a substantial portion of this

[12] This assumption is for simplicity in presentation. The Federal Reserve does not have the statutory authority to open accounts for private entities such as nonbank stablecoin issuers. However, at least one stablecoin issuer has explored the possibility of maintaining its reserve assets in the form of overnight reverse repurchase agreements with the Federal Reserve by establishing a money market mutual fund that would become a counterparty in open market operations and in which the stablecoin issuer would be the sole investor.

# Figure 40: Financial Market Structure in Model with Narrow Nonbanks

**Households**

| Assets | Liabilities |
|---|---|
| Currency | |
| Treasury Securities | |
| Nonbank Debt | |
| Deposits | |
| Stablecoin | Net Worth |

**Banks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Deposits |
| Loans | |
| Reserves | |
| | |
| | |

**Nonbanks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Nonbank Debt |
| Loans | |
| Other Fed Liabilities | |
| | |
| | |

**Business**

| Assets | Liabilities |
|---|---|
| Real Assets | Loans |
| | |
| | |
| | |
| | |

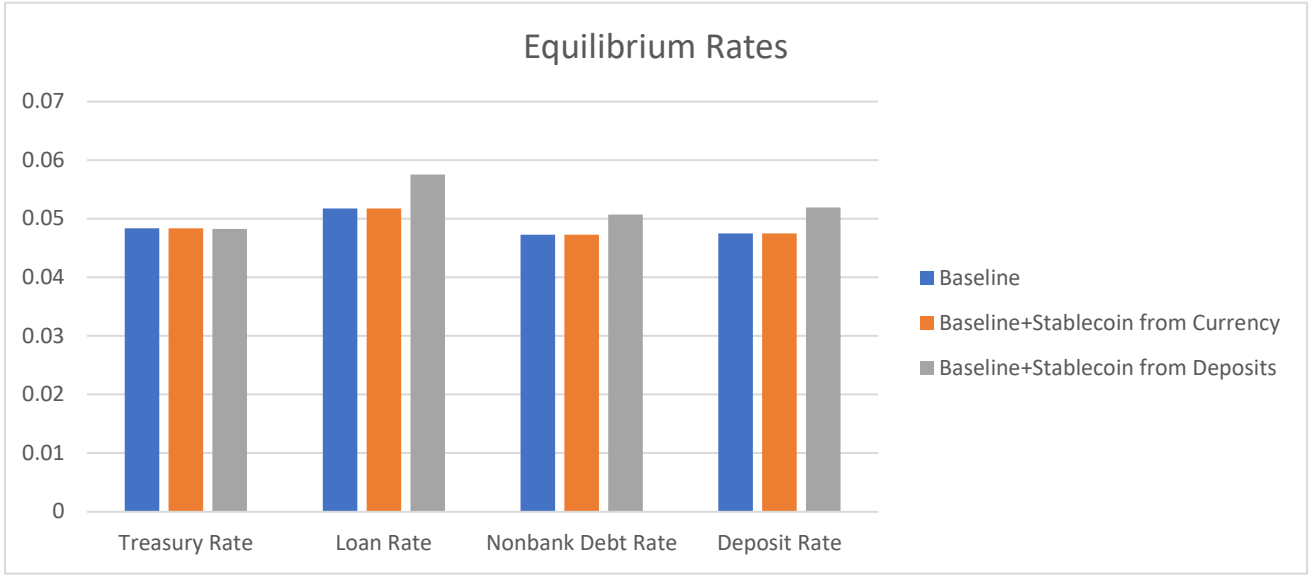
**Federal Reserve**

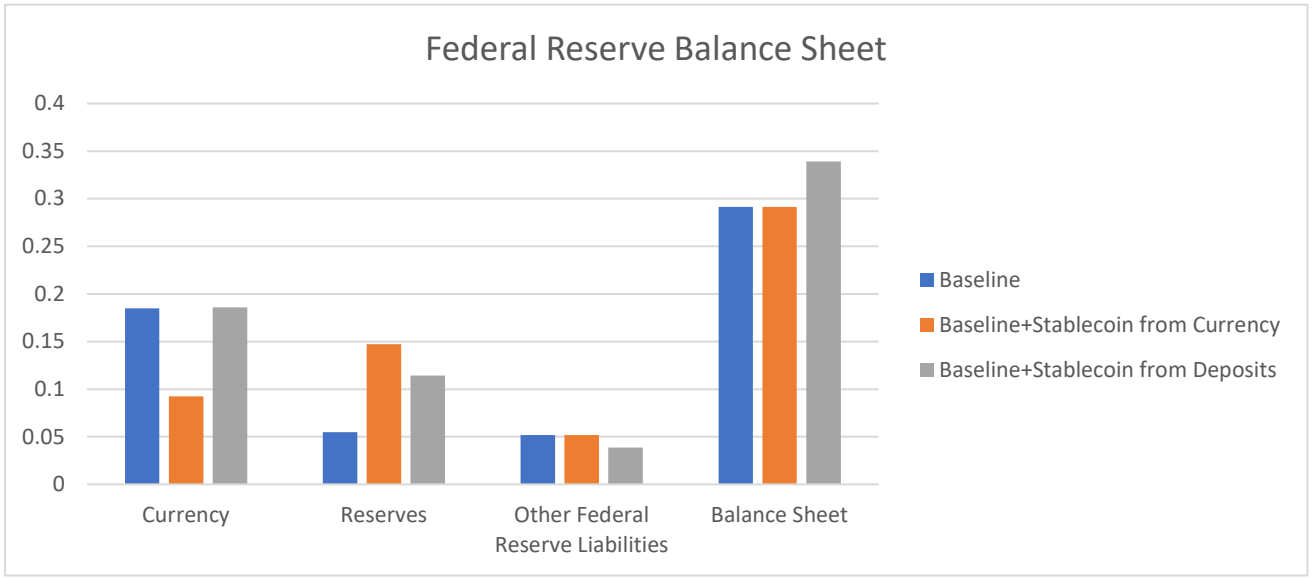
| Assets | Liabilities |
|---|---|
| Treasury Securities | Currency |
| | Reserves |
| | Other Liabilities |
| | Retail CBDC |
| | Wholesale CBDC |

**Narrow Nonbanks**

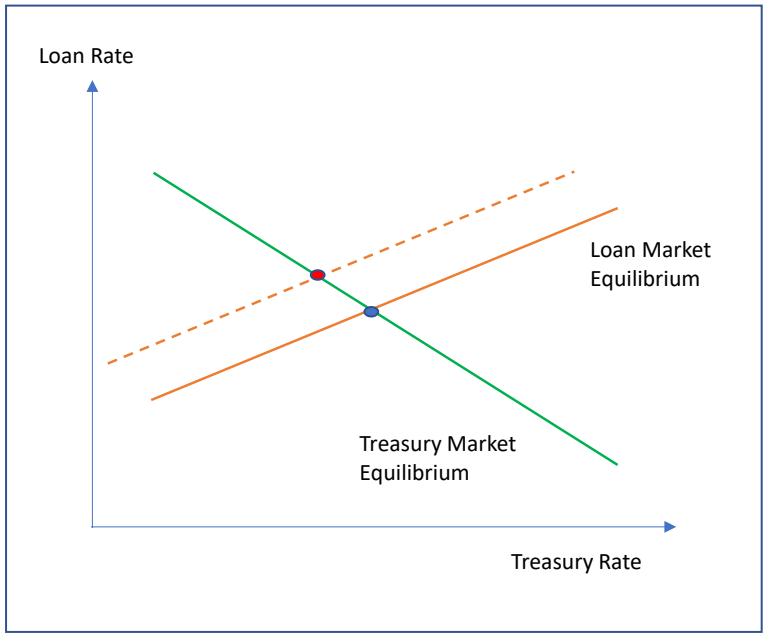
| Assets | Liabilities |
|---|---|
| Reserves | Stablecoin |
| | |
| | |
| | |
| | |

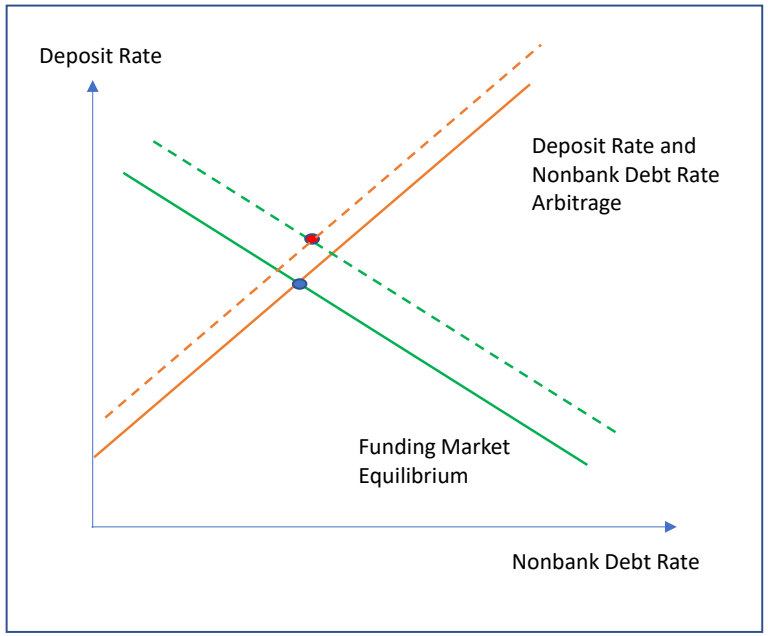
# Figure 41: Nonbank Stablecoin Issuers



# Figure 42: Effects of Shift from Deposits to Stablecoin




| Effect of Shift from Deposits to Stablecoin | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sectors/Instruments | Treasuries | Loans | Reserves | Other Fed Liab | Currency | Nonbank Debt | Deposits | Stablecoin |
| Equilibrium Rates | | | | | | | | |
| Households | | | | | | | | |
| Banks | | | | | | | | |
| Nonbanks | | | | | | | | |
| Narrow Banks | | | | | | | | |
| Federal Reserve | | | | | | | | |
| Foreign Sector | | | | | | | | |
| Business Sector | | | | | | | | |
| Market Totals | | | | | | | | |

drop is offset by a rise in lending in the nonbank sector. The size of the Federal Reserve's balance sheet increases notably reflecting the net increase in reserve demand coming from stablecoin issuers.

### Discussion: Potential Issues for Monetary Policy Implementation

A proliferation of narrow nonbank issuers of stablecoin raises a number of interesting issues for monetary policy implementation. In some cases, the expansion of stablecoin in household portfolios could be relatively benign; for example, when the habit for stablecoin comes at the expense of currency or Treasury securities, equilibrium rates and private sector portfolios are essentially unchanged. In the case in which the household habit comes at the expense of deposits (or other liabilities of financial intermediaries), the expansion of stablecoins can put material upward pressure on funding rates for financial intermediaries and increase the cost of credit to businesses on loans extended by traditional intermediaries. Policymakers could offset some of these effects through appropriate adjustments in the policy rate (and corresponding adjustments in administered rates). However, analogous to the discussion above with the introduction of retail CBDC, this adjustment would imply some reduction in the equilibrium level of the policy rate and a decline in the scope for policy actions to address future adverse shocks without being constrained by the zero lower bound.

The examples above focus on a structure in which stablecoin issuers pay essentially no interest on their stablecoin liabilities.[13] Over time, one might expect competition among stablecoin issuers to lead to increases in the rates offered on stable coins. In this case, higher stablecoin rates would tend to draw household investments away from other financial instruments and put upward pressure on market interest rates. To offset these effects, the Federal Reserve might need to implement marginal adjustments in its administered rates.

## The Case with Narrow Banks Issuing Deposits

Another type of structural innovation involves the possibility of so-called "narrow banks" that offer deposits and hold only Treasury securities or Federal Reserve liabilities as assets. There is a long and fascinating history of narrow bank proposals with much of the focus on whether such institutions could promote financial and monetary stability, (see Pennacchi (2012)).[14] For our purposes, we will regard a narrow bank as a simple profit maximizing bank holding a single asset in the form of reserves and offering deposits. As in the variation with narrow nonbanks issuing stablecoin, we assume narrow banks hold only reserves as the sole asset backing their deposits. Importantly, households regard deposits issued by banks and narrow banks to be perfect substitutes. The financial market structure underlying this version of the model is shown in figure 43. As shown in the bottom right panel, narrow banks hold only reserves as an asset and issue only deposits as a liability.

Narrow banks may have some balance sheet costs, but we assume they are small and linear. Under these assumptions, optimizing behavior by narrow banks should result in near complete interest rate arbitrage so that $r_{NBRS} = r_{DP} + c$ where $r_{NBRS}$ is the interest rate on reserves held by the narrow bank, $r_{DP}$ is the

[13] Implicitly, the associated rents are recycled to households in the form of lump sum payments.

[14] Various authors have noted that narrow banks offering demand deposits backed entirely by reserves at the central bank could enhance financial stability. Such banks would presumably not be subject to runs and, even if they were, the costs of a run on such banks would be minimal with depositors fully protected. Some counterarguments have suggested that a mandated requirement that would segment demand deposits into narrow banks could have adverse consequences for liquidity creation by traditional banks or liquidity elsewhere in the financial system, Dybvig (1993), Wallace (1996).

market rate on deposits, and $c$ is a per-unit cost representing non-interest operating expenses or "balance sheet costs." In the discussion below, we assume that reserves held by narrow banks are remunerated at the same rate as reserves maintained by traditional banks so that $r_{NBRS} = r_{RS}$.

The case of a deposit-issuing narrow bank is more complicated than the stablecoin-issuing narrow nonbank because narrow banks directly compete with banks in the deposit market. When narrow banks hold Federal Reserve liabilities as their sole asset, the deposit rate offered by narrow banks is pegged to the rate on Federal Reserve liabilities. If this rate is higher than would result in the absence of narrow banks, a portion of aggregate deposits migrates away from traditional banks to narrow banks. As shown in figure 44, this situation corresponds to the traditional supply and demand analysis of a price floor. Traditional banks take in deposits up to the point at which the marginal value of additional deposit funding falls below the fixed rate offered by narrow banks. Thereafter, narrow banks take in any additional deposit supply from households. The aggregate quantity of deposits increases from the blue dot to the red dot. As shown in figure 45, factors that shift traditional bank demand for deposit funding are reflected in an increase in deposits issued by traditional banks. However, the deposit rate is not affected, and the aggregate quantity of deposits is unaffected. The increase in deposits at traditional banks is offset by a corresponding reduction in deposits issued by narrow banks. Figures 44 and 45 help to illustrate the connection between the increase in interest in narrow banking models, the availability of fixed-rate assets such as reserves, and bank regulation that may increase balance sheet costs. As noted above, an increase in bank balance sheet costs in particular puts significant downward pressure on deposit rates relative to the interest rate on reserves. That gap is what can create space for narrow banks with different cost structures than traditional banks to operate profitably while offering higher deposit rates than would otherwise be offered by traditional banks.

As shown in figure 46, the structural changes in the deposit market have implications for the equilibrium rates in other markets. Perhaps most notably, the line representing equilibrium points in the loan market becomes considerably flatter (and the slope can even turn negative). This reflects the fact that changes in the Treasury rate have a more muted impact on the funding costs of traditional banks and nonbanks. In the baseline model, all else equal, an increase in the Treasury rate pulls funding away from the loan market through several different channels. An increase in the Treasury rate leads banks and nonbanks to substitute away from loans and toward Treasury securities on the asset side of the balance sheet. In addition, an increase in the Treasury rate induces households to shift away from investments in deposits and nonbank debt while at the same time encouraging banks and nonbanks to expand their balance sheets. As noted above, these changes result in higher funding costs for banks and nonbanks that tend to restrain the desired increase in balance sheets. However, in the model with a rate floor in the deposit market established by narrow banks, an initial increase in Treasury rates does not pull as much funding away from the loan market. With the deposit rate fixed, households have less incentive to shift their investments away from deposits. And banks do not have the same restraint on their incentives to expand the size of their balance sheet stemming from a higher deposit rate. And conversely, an increase in the loan rate tends to lead banks to want to expand loans by more than in the baseline model because the effect of an increase in the loan rate in pulling up funding rates is considerably reduced.

As shown in figure 47, the behavior of equilibrium rates and quantities in the financial system also is significantly affected. As illustrated in the bottom right panel, the advent of narrow banks offering a deposit rate above the pre-existing deposit rate offered by traditional banks results in a lower quantity of

deposits offered by traditional banks (orange bars) and a sizable quantity of deposits offered by narrow banks (green portion of the bars). The total quantity of Treasury securities, loans, and reserves held by the traditional banking system moves lower. Traditional nonbanks (top right panel) also experience a modest increase in funding costs as households substitute toward higher yielding deposits. However, total household demand for nonbank debt changes relatively little and the aggregate size of nonbank balance sheets is little changed. On the asset side of the nonbank balance sheets, the upward movement in the equilibrium loan rate is associated with a shift toward loans and away from holdings of Treasury securities and Federal Reserve liabilities. The increase in loans at nonbanks offsets a portion of the decline in loans extended by traditional banks. The Federal Reserve's balance sheet increases, on net, with the rise in reserves held by narrow banks exceeding the runoff of reserves and other Federal Reserve liabilities held by traditional banks and nonbanks.

The introduction of narrow banks also has important implications for the "pass through" of the Federal Reserve's administered rates to other market interest rates. As shown in the top left panel of figure 48, when reserves maintained by narrow banks are remunerated at the interest on reserves rate, the marginal effect of a change in the interest on reserves rate on equilibrium rates is higher than in the baseline model. That stems from the fact that narrow banks effectively provide access to the interest on reserves rate to households through the deposit market. The converse is true for the marginal effect of a change in the rate on other Federal Reserve liabilities. As shown in the top right panel, the marginal effect of this rate on funding markets and the loan market is much reduced relative to the baseline. The bottom panel shows the total effect of the pass through of the Federal Reserve's administered rates when the interest on reserves rate and interest rate on other Federal Reserve liabilities are increased in parallel. On net, the introduction of narrow banks tends to increase the total effect of changes in the Federal Reserve's administered rates, again because narrow banks effectively provide indirect access to the interest on reserves rate to households. One caveat in this, however, is that this result stems from assumptions about the cost structure and pricing power of narrow banks. Borrowing from the insights in Andolfatto (2022), if narrow banks had a degree of market power that allowed some flexibility in the pricing of deposits, then some of the increased effects of the Federal Reserve's administered rates shown in the bottom panel of figure 48 could be offset by narrow bank pricing behavior. For example, in the baseline model, an increase in the Federal Reserve's administered rates results in a modest widening of the spread between administered rates and the equilibrium deposit rate. This widening could, in principle, provide greater scope for narrow banks to increase the implicit fee charged in passing the interest on reserves rate on to depositors.

The presence of narrow banks offering deposits also has important implications for the effects of marginal changes in bank regulations. As an example, figure 49 displays the effect of a marginal change in the bank leverage ratio in the baseline model and in the model with narrow banks. As shown in the bottom panel, the most notable effect of an increase in the bank leverage ratio requirement in the baseline model is significant downward pressure on the equilibrium deposit rate. This decline in the deposit rate results in some modest changes in financial quantities as discussed above in connection with figure 27. In contrast, the price and quantity effects of a marginal change in bank leverage ratio requirements are much more pronounced in the presence of narrow banks. An increase in the leverage ratio in this case has no effect on the equilibrium deposit rate because narrow banks are not affected by the leverage ratio requirement. Deposits migrate away from traditional banks and in favor of deposits issued by narrow banks. The decline in deposit funding for traditional banks is associated with a pullback in lending by

# Figure 43: Financial Market Structure in Model with Narrow Banks

**Households**

| Assets | Liabilities |
|---|---|
| Currency | |
| Treasury Securities | |
| Nonbank Debt | |
| Deposits | |
| | Net Worth |

**Banks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Deposits |
| Loans | |
| Reserves | |
| | |
| | |

**Nonbanks**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Nonbank Debt |
| Loans | |
| Other Fed Liabilities | |
| | |
| | |

**Business**

| Assets | Liabilities |
|---|---|
| Real Assets | Loans |
| | |
| | |
| | |
| | |

**Federal Reserve**

| Assets | Liabilities |
|---|---|
| Treasury Securities | Currency |
| | Reserves |
| | Other Liabilities |
| | |
| | |

**Narrow Banks**

| Assets | Liabilities |
|---|---|
| Reserves | Deposits |
| | |
| | |
| | |
| | |

## Figure 44: Effect of Narrow Banks in the Deposit Market

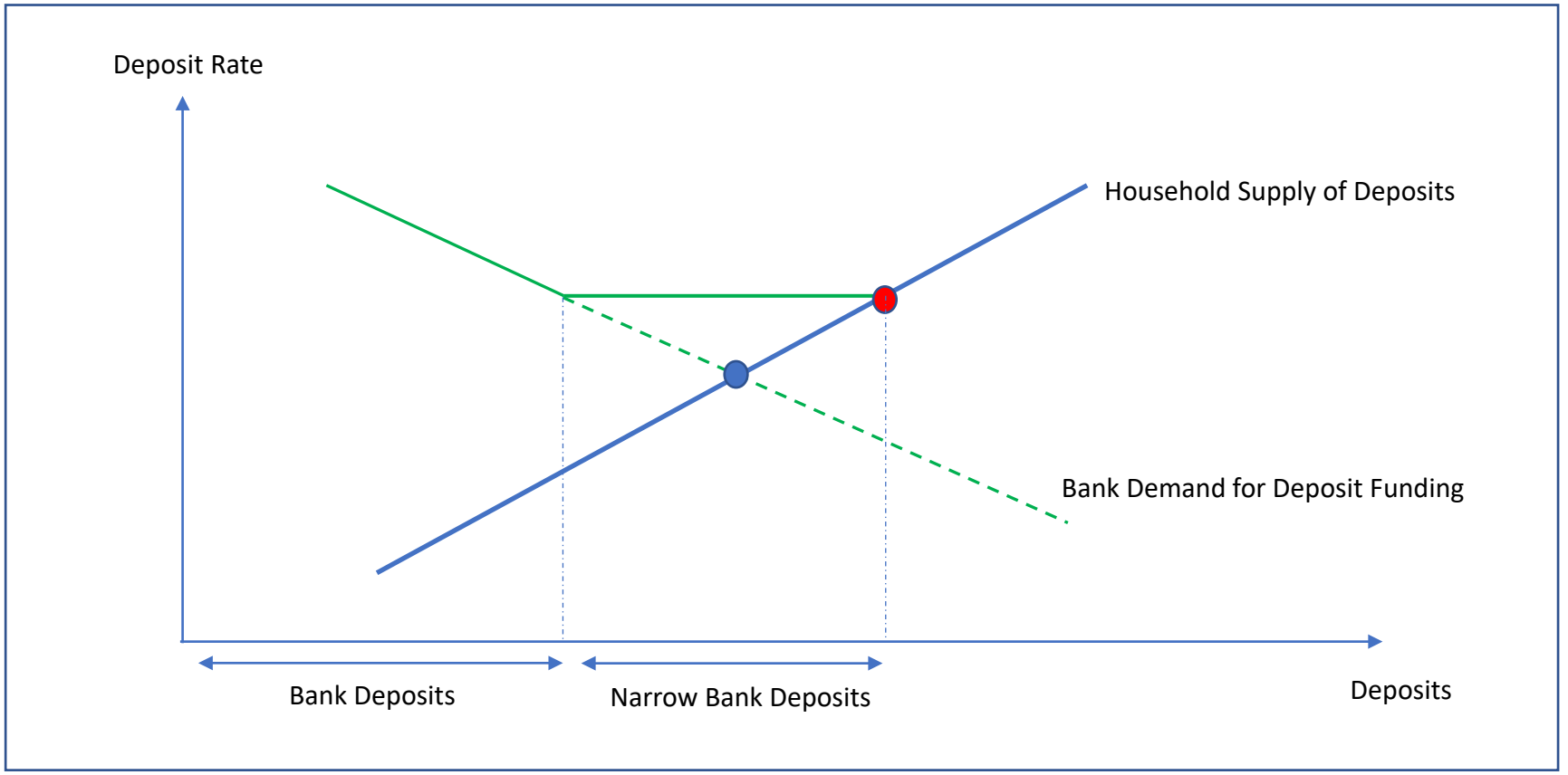
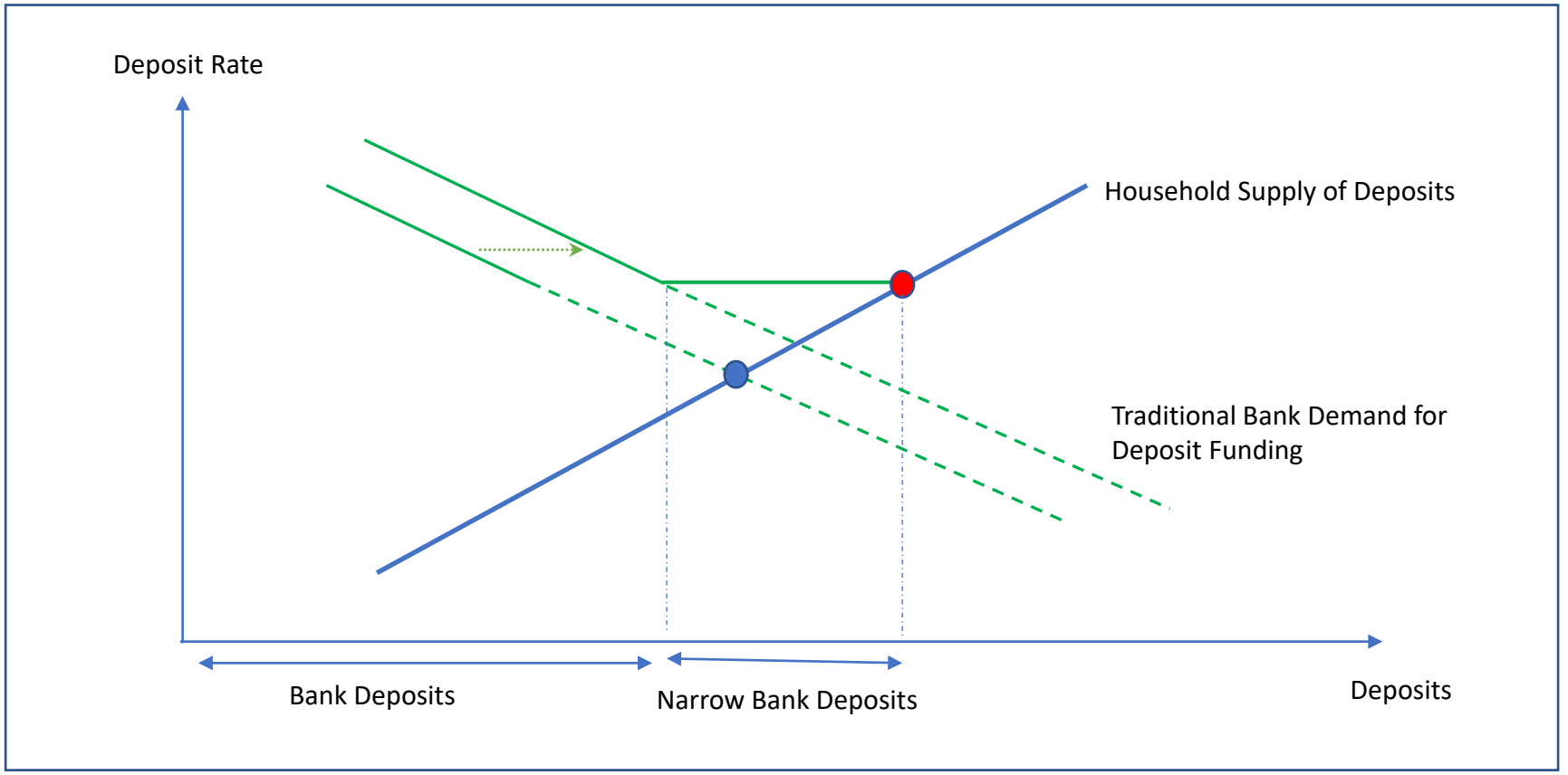
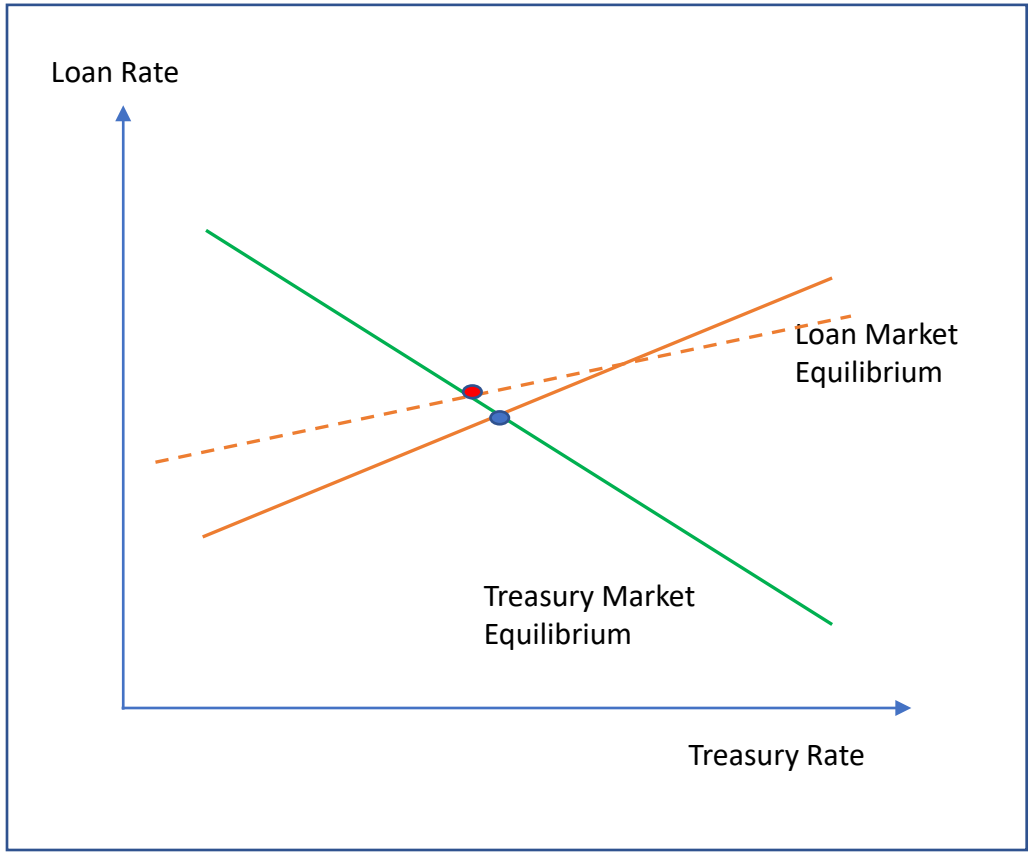
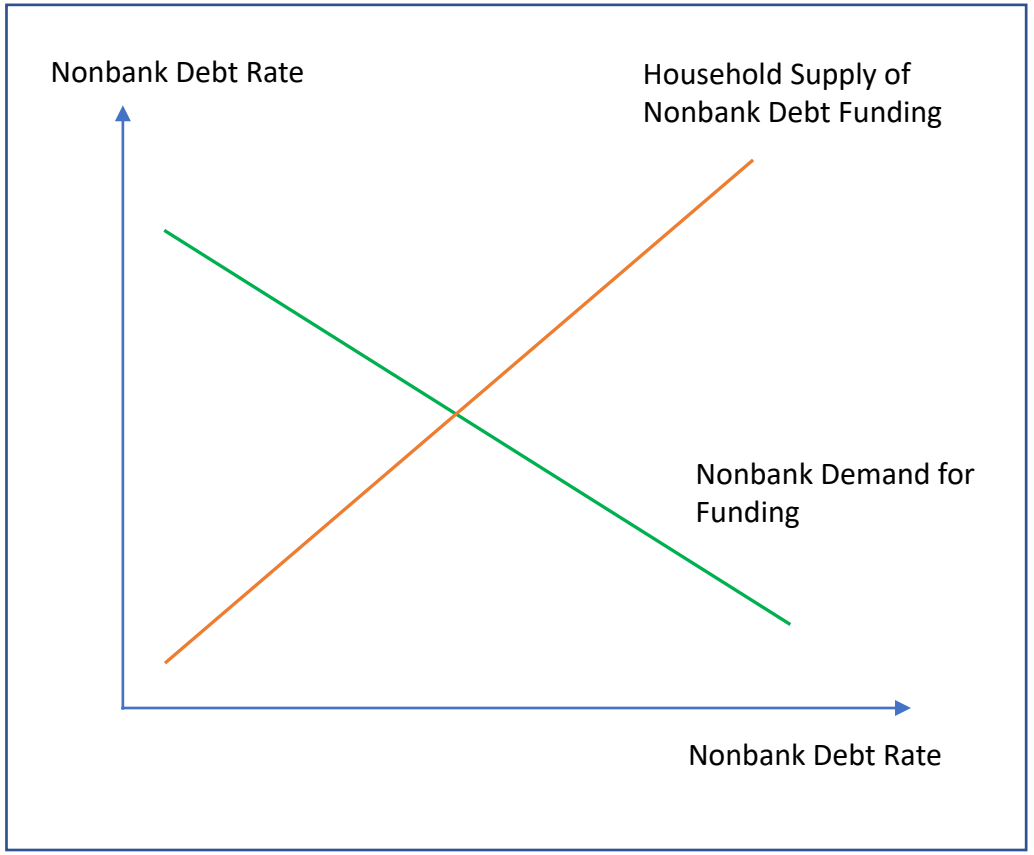


Figure 45: Effect of Shift in Traditional Bank Demand for Deposits with Narrow Banks

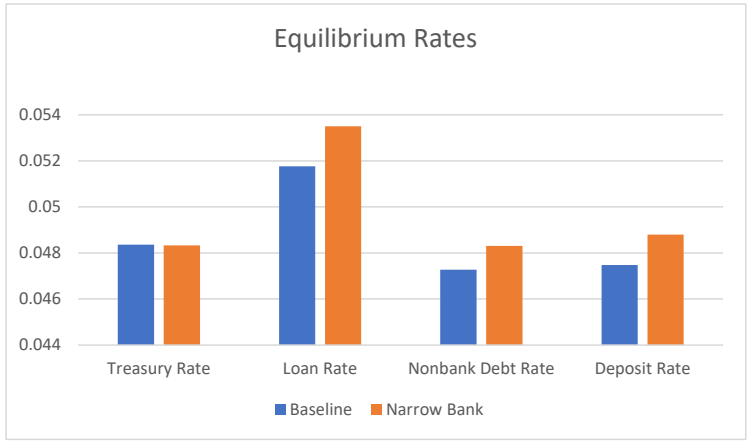


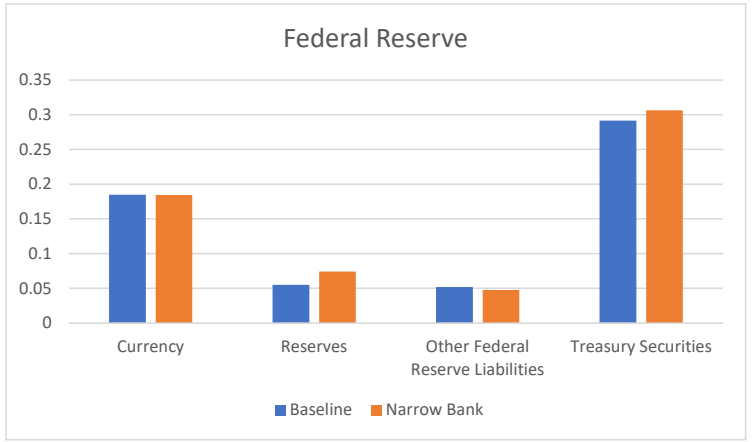
# Figure 46: Effect of Narrow Banks on Endogenous Rates

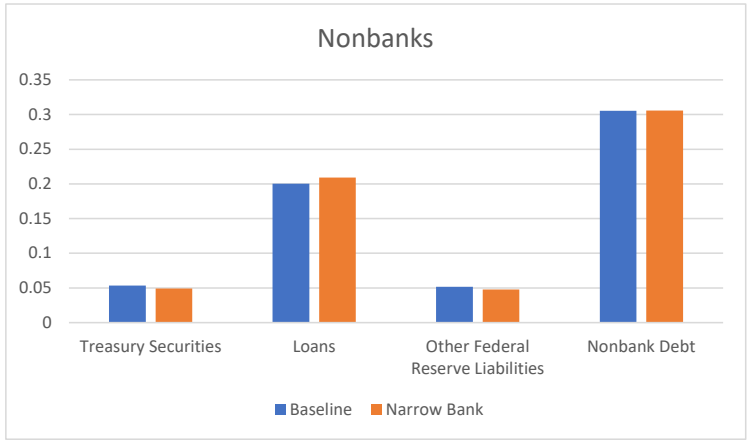


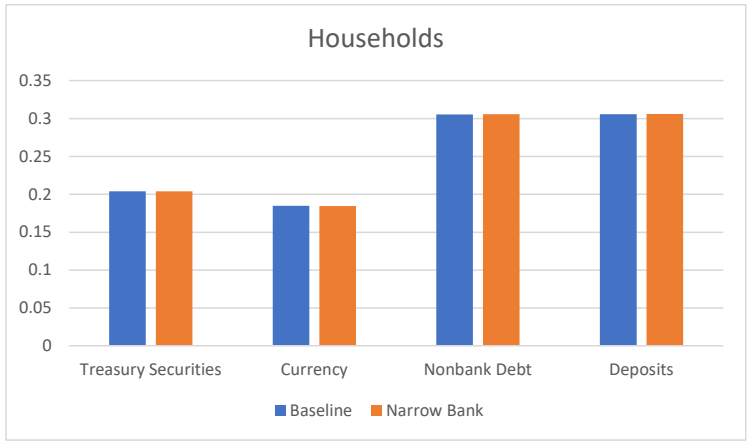



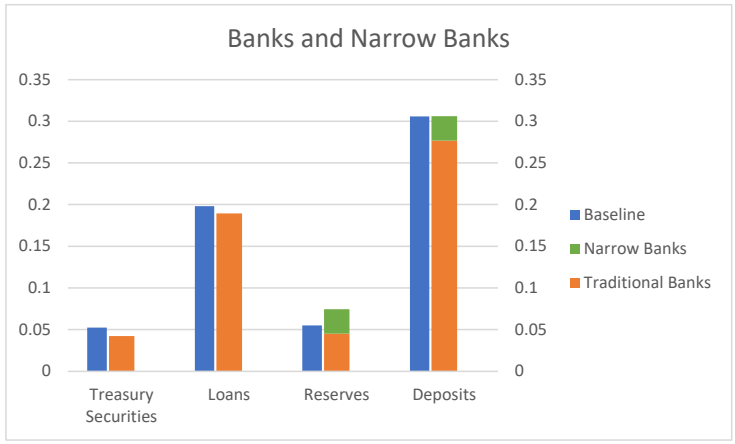
# Figure 47: Comparison of Baseline Model and Model with Narrow Banks



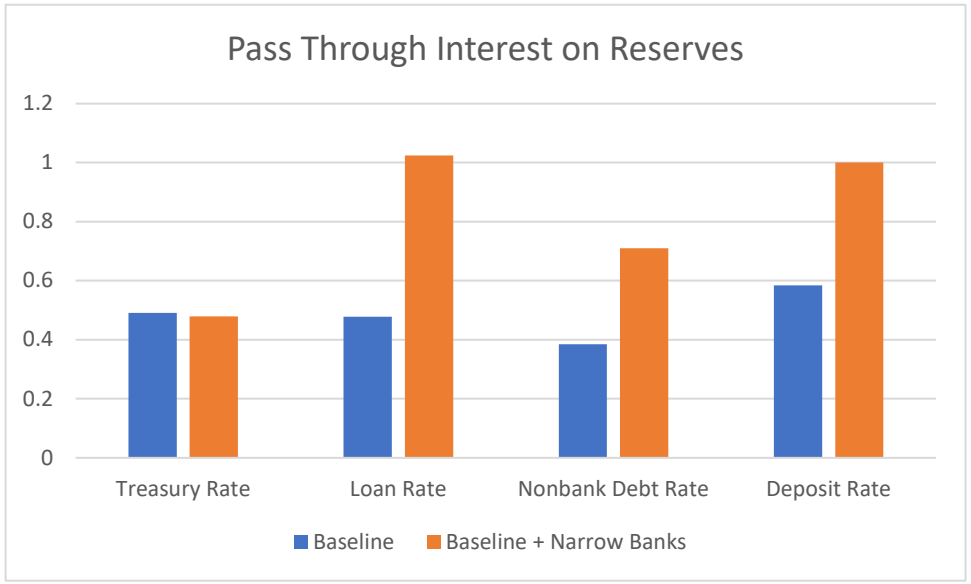



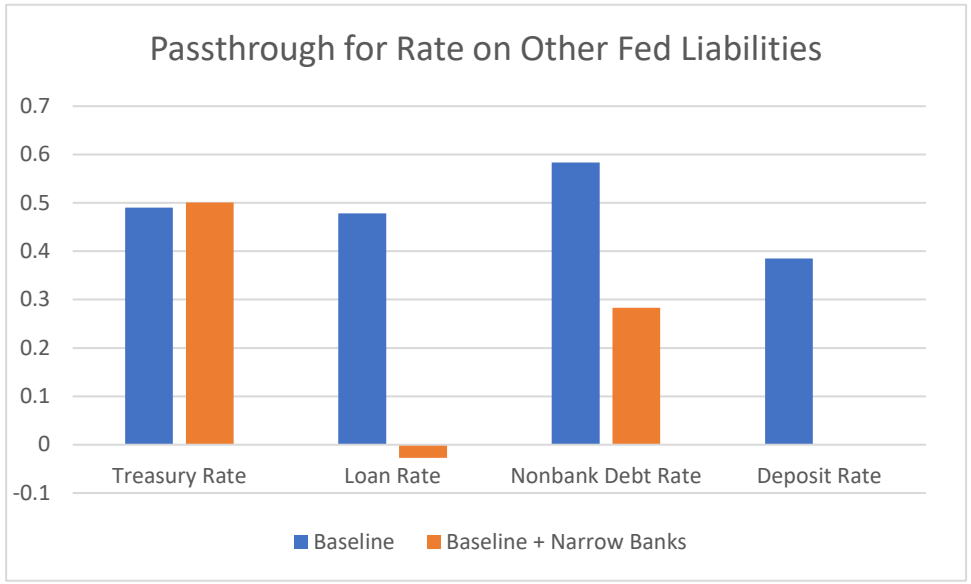



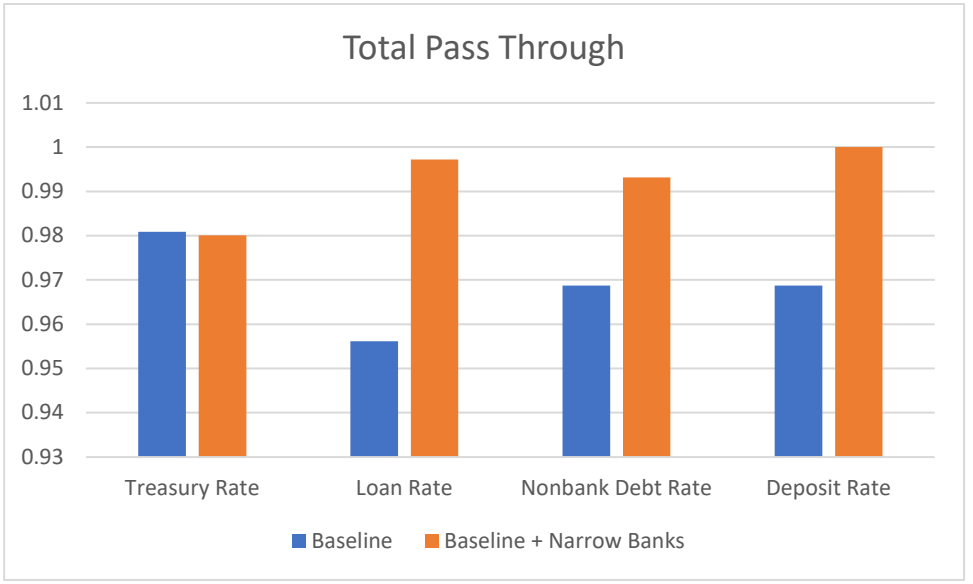



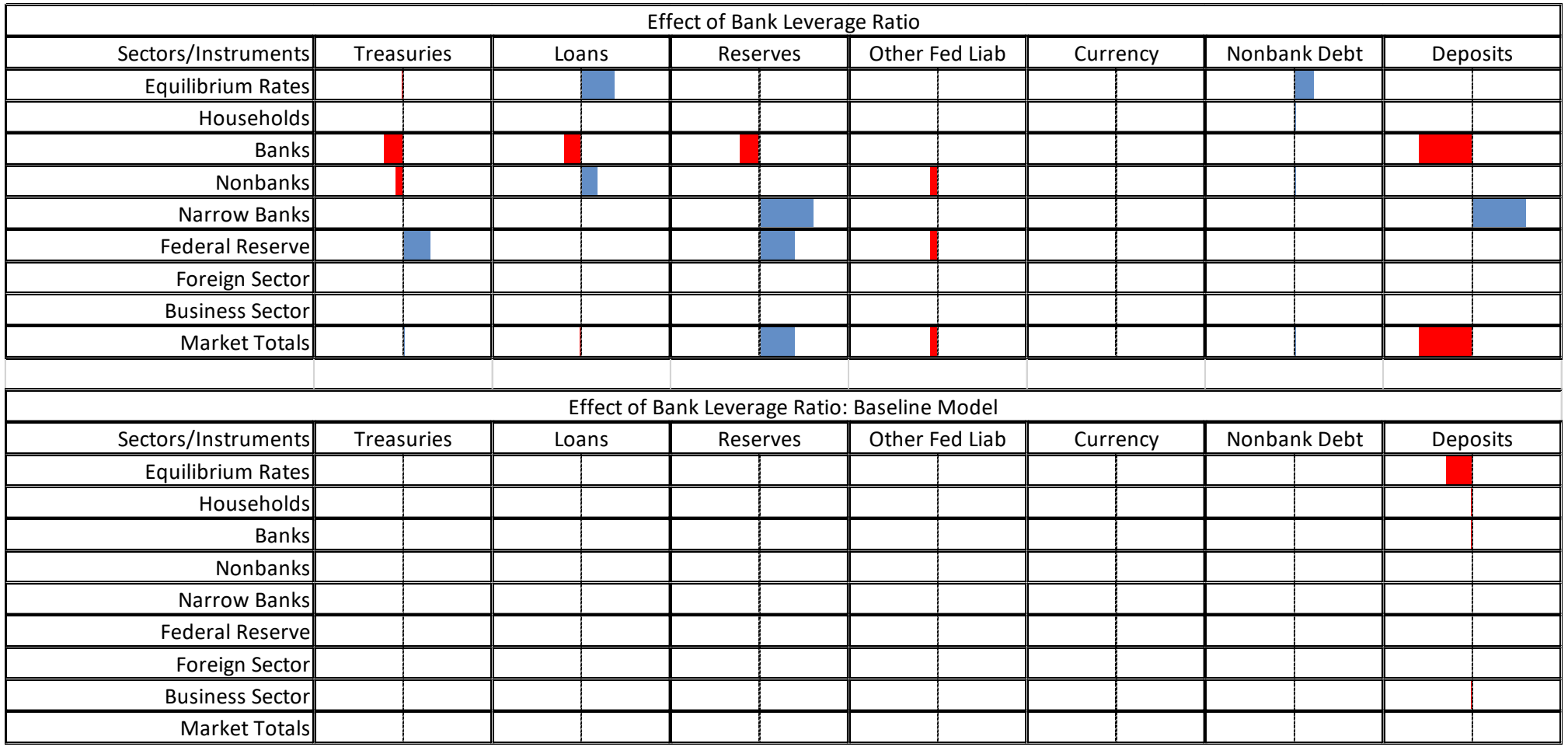
# Figure 48: Effect of Narrow Banks on Pass Through of Federal Reserve Administered Rates



# Figure 49: Effect of Narrow Banks on Pass Through of Federal Reserve Administered Rates



traditional banks and a sizable increase in loan rates. Nonbanks take advantage of the rise in loan rates by shifting out of Treasury securities and other Federal Reserve liabilities and into loans. These changes in quantities are much larger than in the baseline model. The net effect is a notable decline in total loans and a significant shift in lending from traditional banks to nonbanks. The liquidity of nonbank balance sheets declines significantly. The Federal Reserve's balance sheet expands with the increase in reserves held by narrow banks substantially exceeding the runoff in reserves by traditional banks and the decline in holdings of other Federal Reserve liabilities by nonbanks.

## Common Themes Across the Variations

Taken at face value, the analysis of variations in market structure discussed above suggest that the case of a stablecoin issuer holding reserves as an asset and the case of a narrow bank offering deposits and holding reserves as an asset are very different. In particular, in the model, the introduction of stablecoin has relatively muted effects on the broader financial system while the market effects of narrow banks offering deposits are much more pronounced. In large part, this difference reflects the underlying assumptions for these two cases. In the case of the narrow nonbank issuing stablecoin, there is a new asset being offered to households that is an imperfect substitute with existing financial assets. In contrast, the narrow bank is offering a deposit—an existing financial asset—that is a perfect substitute with deposits offered by traditional banks. In this setting, as long as narrow banks offer a deposit rate above the initial equilibrium deposit rate, deposits will flow from the traditional banking system to narrow banks. That process will continue up to a point at which the size of traditional bank balance sheets is aligned with that implied by the intermediation spread in the new equilibrium. In short, the difference in the cases studied above stem importantly from assumptions about the extent to which new assets substitute for existing assets. If one assumed that the deposits of narrow banks are fundamentally different than those of traditional banks, then the model would generate a structural demand for narrow bank deposits and the equilibrium rate for deposits offered by narrow banks could differ from the deposit rate for traditional banks. And if one assumed that stablecoins were a perfect substitute for deposits or any other existing financial asset, then the introduction of stablecoins would have broader implications than the case considered above.

Another point worth noting is that when the Federal Reserve passively adjusts its balance sheet to accommodate demand for its liabilities, there is no economic distinction between a narrow bank or nonbank issuing a new liability with reserves as an asset and the Federal Reserve itself issuing a new liability that mimics the features of those issued by narrow banks and nonbanks. Indeed, the solutions shown in Table A7 in the appendix for the case in which the Federal Reserve issues a retail CBDC are essentially identical to those for a stablecoin issuer holding reserves as an asset. The only difference is that the liability side of the Federal Reserve's balance sheet with a retail CBDC would reflect that new liability. With a stablecoin issuer holding reserves, the Federal Reserve's liabilities would include an equivalent amount of additional reserves reflecting the asset holdings of the stablecoin issuers. However, all equilibrium rates and quantities would be the same in these two cases.

The same type of connection would hold in a case in which the Federal Reserve issued a CBDC (or any other liability) that was a perfect substitute with deposits offered by traditional banks. If the rate offered by the Fed on that liability was higher than in the initial equilibrium, deposits would then flow out of the banking system and to the Federal Reserve with effects for equilibrium rates and quantities identical to those discussed above for the case of a narrow bank issuing deposits.

These observations shed some light on the potential for peaceful coexistence of Federal Reserve retail CBDC, stablecoin issued by narrow nonbanks, and deposits offered by narrow banks. In the context of the model, if all of these assets are viewed as distinct by households, the coexistence question could be relatively straightforward. Each asset would have its own structural demand. There would be some level of substitution between the new assets based on relative rates, but households would be content to hold all of these types of assets. This benign situation would be similar to the peaceful coexistence of physical currency and retail CBDC or the peaceful coexistence of physical currency and stablecoin in the model variations discussed above.

The coexistence question would be more complicated in cases in which a Federal Reserve liability is a very close substitute for another financial asset. For example, if households viewed retail CBDC to be a perfect substitute for stablecoin, then coexistence would require the rates on stablecoin and retail CBDC to be equal. If the stablecoin rate were higher, households would shift all of their holdings of retail CBDC to stablecoin and vice versa.

Alternatively, if retail CBDC were viewed as a perfect substitute for narrow bank deposits, then coexistence would require the rate on retail CBDC, and the rate offered on narrow bank deposits to be equal. If the rate on retail CBDC were higher than the deposit rate offered by narrow banks, all narrow bank deposits would flow to Federal Reserve retail CBDC and vice versa.

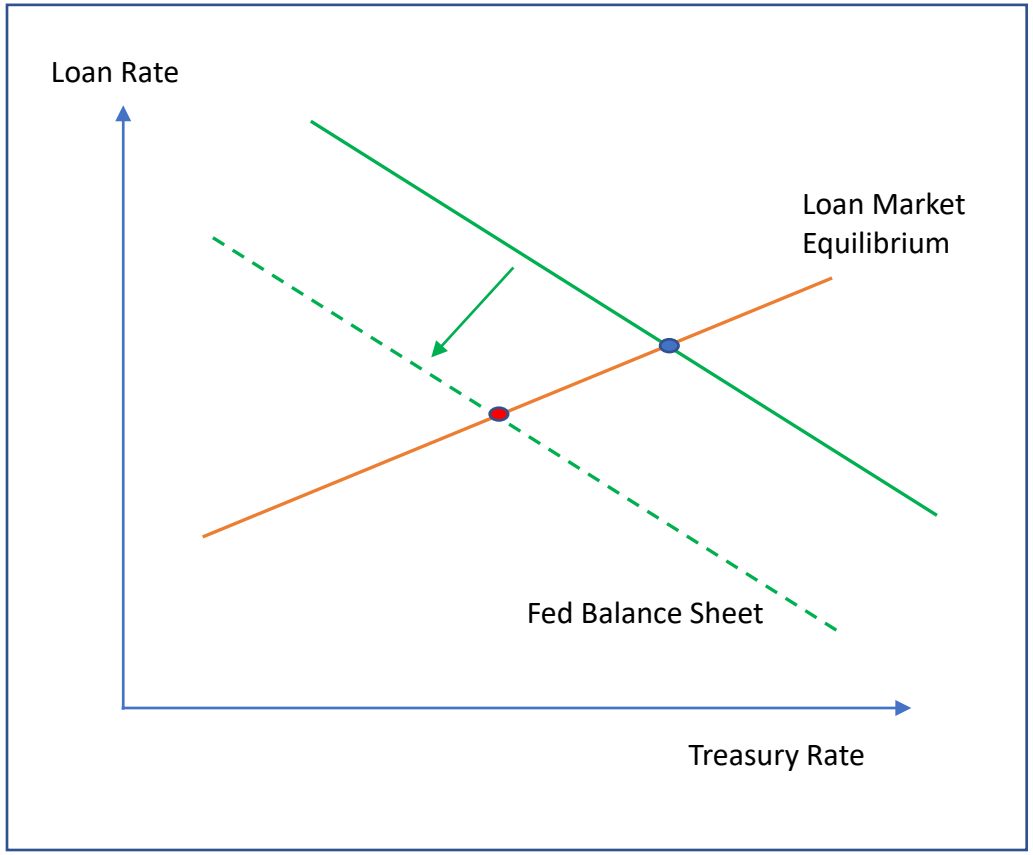
# 7. Active Balance Sheet Management in a Modified Baseline Model

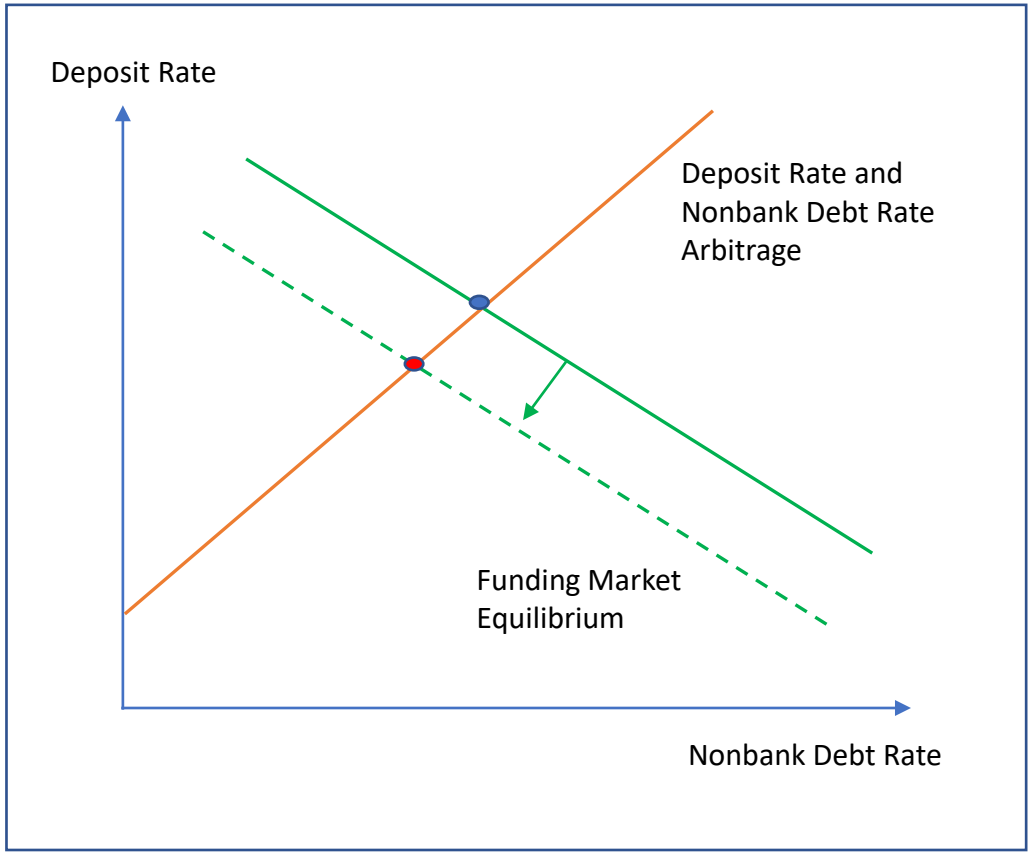
The baseline model and the variations discussed above all assumed that the Federal Reserve *passively* adjusts the size and composition of its balance sheet in response to the demand for its liabilities. In that setting, substitutions between different types of Federal Reserve liabilities or Treasury securities have little or no effect on equilibrium rates and quantities. Moreover, conspicuously absent in the baseline version of the model is the analysis of exogenous changes in the size of the Federal Reserve's balance sheet of the type that might be associated with large scale asset purchases.

In this section, we consider a modification of the baseline model that drops the passive balance sheet adjustment assumption and assumes instead that the Federal Reserve actively manages the size of its balance sheet, keeping the size of the balance sheet fixed in the short run. With this assumption, the Federal Reserve's balance sheet constraint effectively becomes a new market clearing condition (hereafter, this version of the model is referred to as the "modified baseline"). In order to keep demand and supply in balance across all markets (and the Treasury market in particular), another variable must adjust to effectively "pick up the slack" relative to the baseline model. To that end, in the modified version of the model, the foreign sector is assumed to stand ready to purchase any amount of Treasury securities at the prevailing market price. One could think of this as the foreign sector submitting noncompetitive bids at Treasury auctions that are filled after domestic entities have determined their optimal Treasury holdings.

The key results from the modified model are similar to those for the baseline model. As in the baseline model, an increase in all of the Federal Reserve's administered rates along with the equilibrium loan rate again passes through one for one to all endogenous rates. As shown in figure 50, the graphical description of equilibrium in the modified baseline model is similar to that for the baseline model except that the Treasury market equilibrium line is replaced with the Federal Reserve's balance sheet constraint.

## Figure 50: Response to Increase in Federal Reserve Balance Sheet



Increases in the size of the Federal Reserve's balance sheet shift this line inward, putting downward pressure on the Treasury rate and loan rate. As in the baseline model, those changes in loan and Treasury rates move the funding market equilibrium line inward in the diagram in the right panel, resulting in corresponding declines in the deposit rate and nonbank debt rate.

## Implications of Alternative Financial Structures in the Modified Baseline Model

One strong result from the baseline model and the variations considered above is that structural changes resulting in a larger "habit" for a new Federal Reserve liability (such as the introduction of central bank digital currency) and a corresponding decline in the habit of either another Federal Reserve liability or Treasury securities have little or no effect on equilibrium interest rates and the equilibrium quantities of various financial assets. The assumed passive adjustment of the Federal Reserve's balance sheet in the baseline model implies that any shift in demand away from a Federal Reserve liability or from Treasury securities in favor of a new Federal Reserve liability is fully accommodated by the Federal Reserve.

That logic partially holds up in the case when the Federal Reserve actively manages the size of its balance sheet in the short run as in the modified baseline model. When a shift in habit toward a new Federal Reserve liability comes at the expense of another Federal Reserve liability, equilibrium rates and quantities are again essentially unchanged relative to the baseline model. The same is not true though if the shift in habit toward a new Federal Reserve liability comes at the expense of Treasury securities. In that case, in the modified baseline model, the Federal Reserve's balance sheet is fixed, and market rates must adjust so that other Federal Reserve liabilities "make room" for the demand for the new Federal Reserve liability.

The modified version of the model extended to incorporate central bank digital currency provides an illustration of this effect. As shown in figure 51, when the demand for retail and wholesale CBDC in the extended modified model comes at the expense of other Federal Reserve liabilities (orange bars), the effect on equilibrium rates is small relative to the modified baseline model (blue bars). However, if household demand for CBDC is assumed instead to come at the expense of holdings of Treasury securities (gray bars), there is significant upward pressure on interest rates with the Treasury rate and loan rate increasing by about 240 and 110 basis points respectively. Funding rates for financial intermediaries also rise significantly. These increases in market interest rates, in turn, induce shifts away from currency, reserves, and other Federal Reserve liabilities so as to keep the size of the Federal Reserve's balance sheet unchanged.

These rate effects could be largely offset if the Federal Reserve increased the size of its balance sheet. In the modified model, the size of the Federal Reserve's balance sheet would need to increase by about 30 percent (essentially moving the size of the balance sheet to the level associated with the baseline version of the model under passive balance sheet management). Alternatively, if the Federal Reserve wished to minimize changes in the size of its balance sheet, it could adjust administered rates on reserves, other liabilities, and wholesale CBDC. For example, reducing these rates by about 100 basis points would largely eliminate the increase in the loan rate; however, the Treasury rate would remain more than 100 basis points higher than in the modified baseline model. And as noted above, a reduction in administered rates to offset effects of structural changes on the level of interest rates would imply less scope to adjust short-term interest rates in response to future adverse macroeconomic shocks.

## Asset Purchases in the Modified Model

The modified version of the model also provides a lens to examine the effects of structural changes on the effects of Federal Reserve asset purchases. As noted above, in the modified model, an increase in the size of the Federal Reserve's balance sheet puts downward pressure on interest rates. For the most part, as shown in figure 52, the marginal effects of the Federal Reserve's asset purchases are not greatly influenced by the introduction of stablecoin issuers or retail and wholesale CBDC. However, the same conclusion does not hold for the case of narrow banks issuing deposits. In that case, as shown by the yellow bars, the effects of asset purchases on the deposit rate fall to zero. And the effects on all other rates, and particularly loan rates, also are much attenuated relative to the modified baseline model. Once again, this effect stems from the fact that narrow banks effectively provide households with a way to avoid some of the downward pressure on other rates by shifting into fixed-rate deposits at narrow banks.

The response of equilibrium quantities in the system with narrow banks issuing deposits is also quite different relative to the modified baseline version of the model. As shown in the top panel of figure 53, in the modified baseline version of the model, the expansion of the Federal Reserve's balance sheet induces a decline in equilibrium rates and a corresponding slight expansion of financial intermediary balance sheets. The changes in the asset side of intermediary balance sheets include a marked reduction in holdings of Treasury securities and sizable increases in reserves and other Federal Reserve liabilities. Loans for both banks and nonbanks increase slightly. In the modified model with narrow banks (shown in the bottom panel), equilibrium interest rates drop by much less and the deposit rate is unchanged. With deposit rates fixed and a decline in Treasury rates, banks shrink the size of their balance sheets with corresponding significant declines across all asset categories. Nonbanks shift out of Treasury securities and into loans, largely offsetting the decline in loans at banks. Household holdings of deposits are essentially unchanged but there is a large migration from bank deposits to narrow bank deposits. Nearly all of the increase in Federal Reserve assets in this case is associated with a corresponding increase in reserves held by narrow banks.

As noted above, this analysis of "narrow banks" applies more generally to any new instrument with a fixed rate that is a close substitute with deposits or nonbank debt. If households viewed stablecoins as a close substitute for deposits, then any fixed rate offered on stablecoins would tend to attenuate the effect of Federal Reserve asset purchases. And the same conclusion would hold for retail CBDC offered by the Federal Reserve. Any new instrument with a fixed rate will tend to provide a way for households to escape some of the downward pressure on other rates stemming from the portfolio balance effects of the Federal Reserve's asset purchases.

## Narrow Nonbank Assets and Access to the Federal Reserve's Balance Sheet

The discussion above assumes that nonbank stablecoin issuers maintain reserve assets in the form of reserves at the central bank. An interesting policy issue in this context is whether allowing stablecoin issuers access to the central bank's balance sheet in this way is desirable. In the case of the Federal Reserve, the current provisions of the Federal Reserve Act allow depository institutions and a select group of other institutions to maintain balances directly in an account at the Federal Reserve.[15] Other types of

[15] Generally, Federal Reserve accounts are limited by statute to depository institutions, designated financial market utilities, the U.S. government and U.S. agencies, and foreign official institutions.

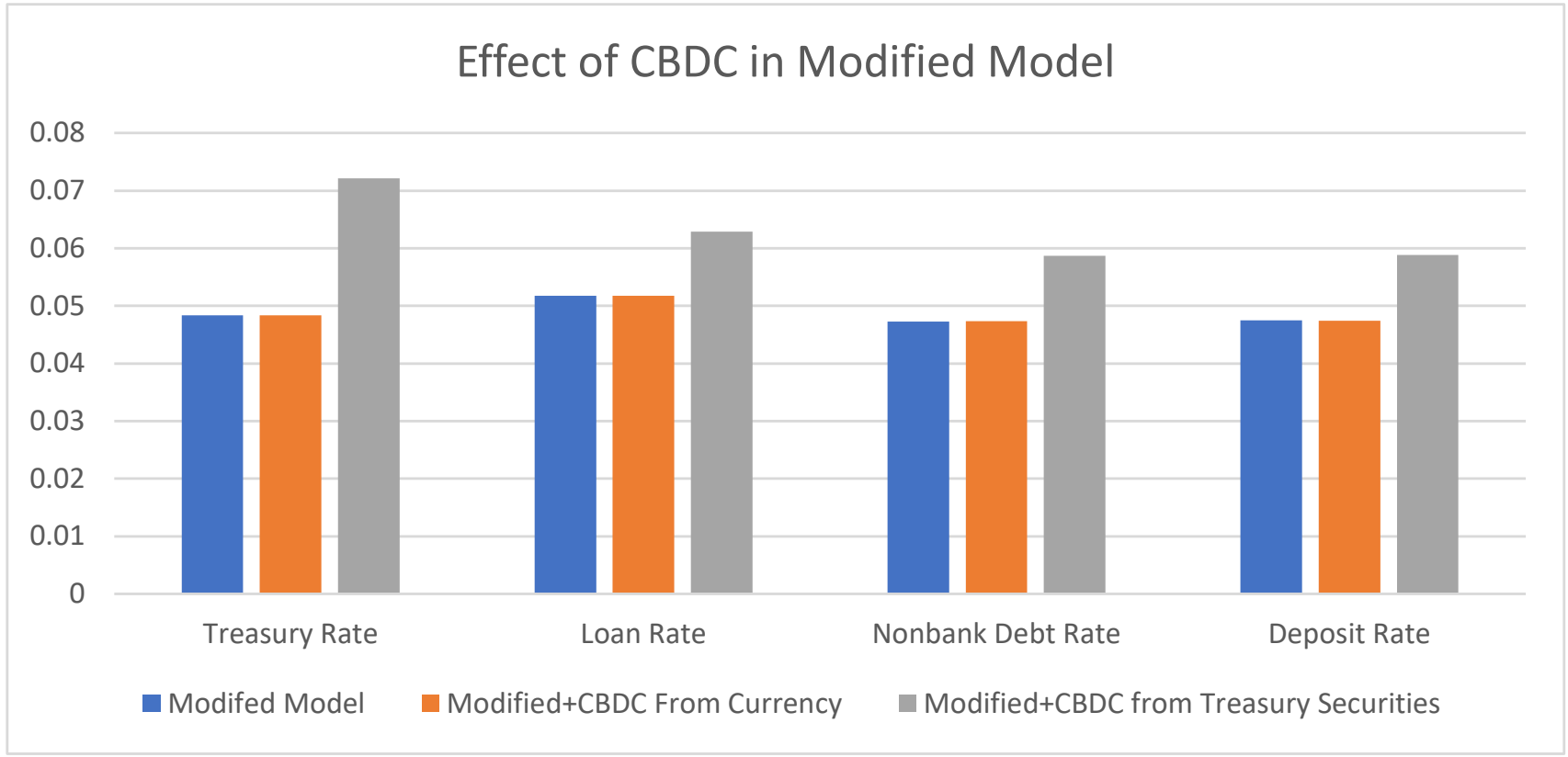
eligible financial institutions that have been designated as counterparties in open market operations may place balances in the overnight reverse repurchase agreement facility.

A basic question then is whether there is any real difference from a monetary policy perspective between scenarios in which stablecoin issuers maintain reserve assets in the form of claims on the Federal Reserve—reserves or other Federal Reserve liabilities—versus other safe assets such as Treasury securities. In the version of the model with passive balance sheet adjustment on the part of the Federal Reserve, equilibrium interest rates are essentially unchanged in these two scenarios as are private sector portfolios. The size and composition of the Federal Reserve's balance sheet is affected. If stablecoin issuers maintain all of their reserve assets in the form of reserves, the Federal Reserve accommodates this demand and acquires Treasury securities as assets. If stablecoin issuers hold reserve assets in the form of Treasury securities, the Federal Reserve would runoff Treasury securities that would be acquired by stablecoin issuers.

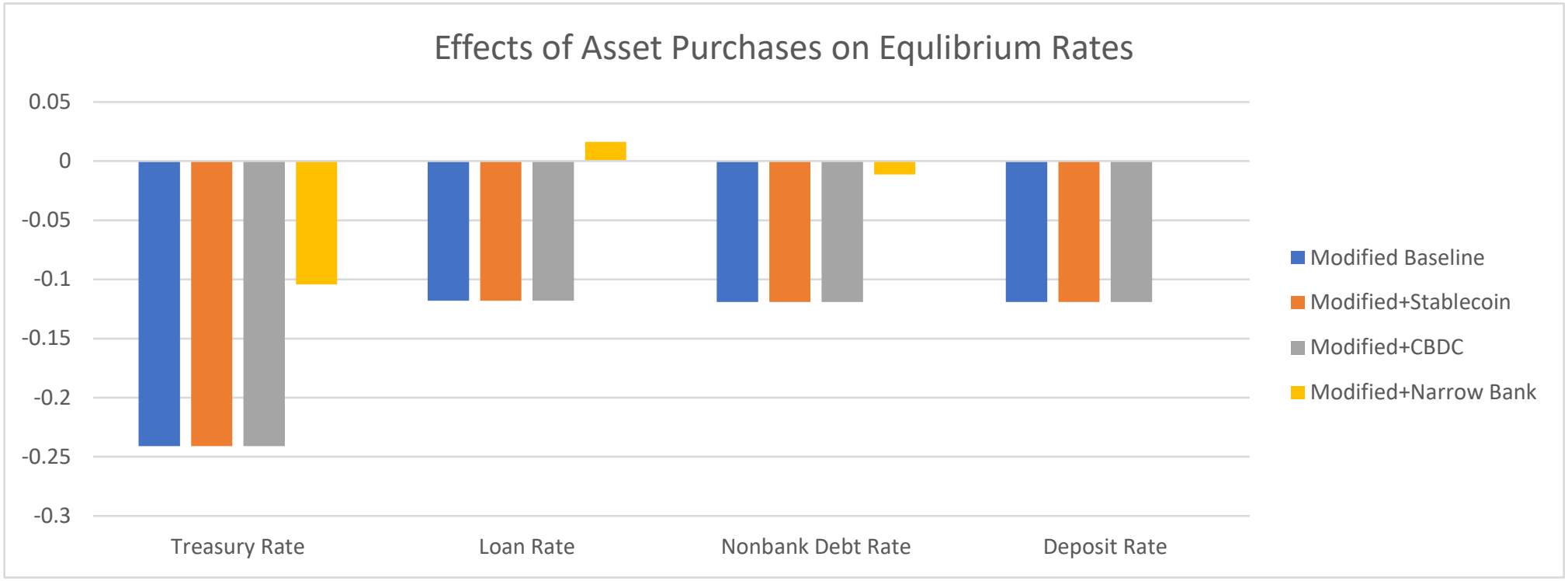
The situation is much different in the modified model in which the Federal Reserve fixes the size of its balance sheet in the short run. In the modified model, the net demand for Federal Reserve liabilities is a key factor influencing equilibrium outcomes. Figure 54 illustrates this feature of the model by displaying the equilibrium rates across two cases—one case (shown by the solid bars) in which stablecoin issuers maintain reserve assets in the form of reserves and another case (shown by the patterned bars) in which stablecoin issuers maintain reserve assets in the form of Treasury securities. For these two cases, the blue, orange and green bars show the results when the household habit for stablecoin comes at the expense of currency, deposits, and Treasury securities, respectively.

Focusing first on the solid bars, as discussed above, when the habit for stablecoin comes at the expense of deposits or Treasury securities (orange and green bars), the net demand for Federal Reserve liabilities increases. With the size of the Federal Reserve's balance sheet fixed, interest rates then move up to damp the demand for Federal Reserve liabilities. Conversely, as shown by the patterned bars, a significant amount of downward pressure on interest rates can arise in the case when stablecoin issuers maintain reserve assets in the form of Treasury securities. For example, if the habit for stablecoin comes at the expense of currency and stablecoin issuers maintain reserve assets in the form of Treasury securities (blue patterned bars), the net demand for Federal Reserve liabilities declines substantially. With a fixed Federal Reserve balance sheet, the net effect is downward pressure on market rates sufficient to induce banks and nonbanks to shift their portfolios away from Treasury securities and toward reserves and other Federal Reserve liabilities. The downward pressure on rates is less pronounced in the case when the habit for stablecoin comes at the expense of deposits. In this case, the demand for Federal Reserve liabilities declines reflecting a drop in bank's desired reserve holdings. Treasury rates fall again in a way that encourages portfolio shifts by financial intermediaries away from Treasury securities and toward reserves and other Federal Reserve liabilities. In the last case, shown by the green patterned bars, the equilibrium rates are almost identical to those in the case shown by the solid blue bars. In these two cases, the advent of stable coin involves no net change in the demand for Federal Reserve liabilities. In the case shown by the solid blue bars, the decline in demand for Federal Reserve liabilities stemming from the shift in household habits away from currency is offset by the increase in the demand for reserves by stablecoin issuers. And in the case shown by the patterned green bars, the shift in household habits away from Treasury securities has no direct effect on the demand for Federal Reserve liabilities, and stablecoin issuers effectively end up acquiring the Treasury securities shed by households.

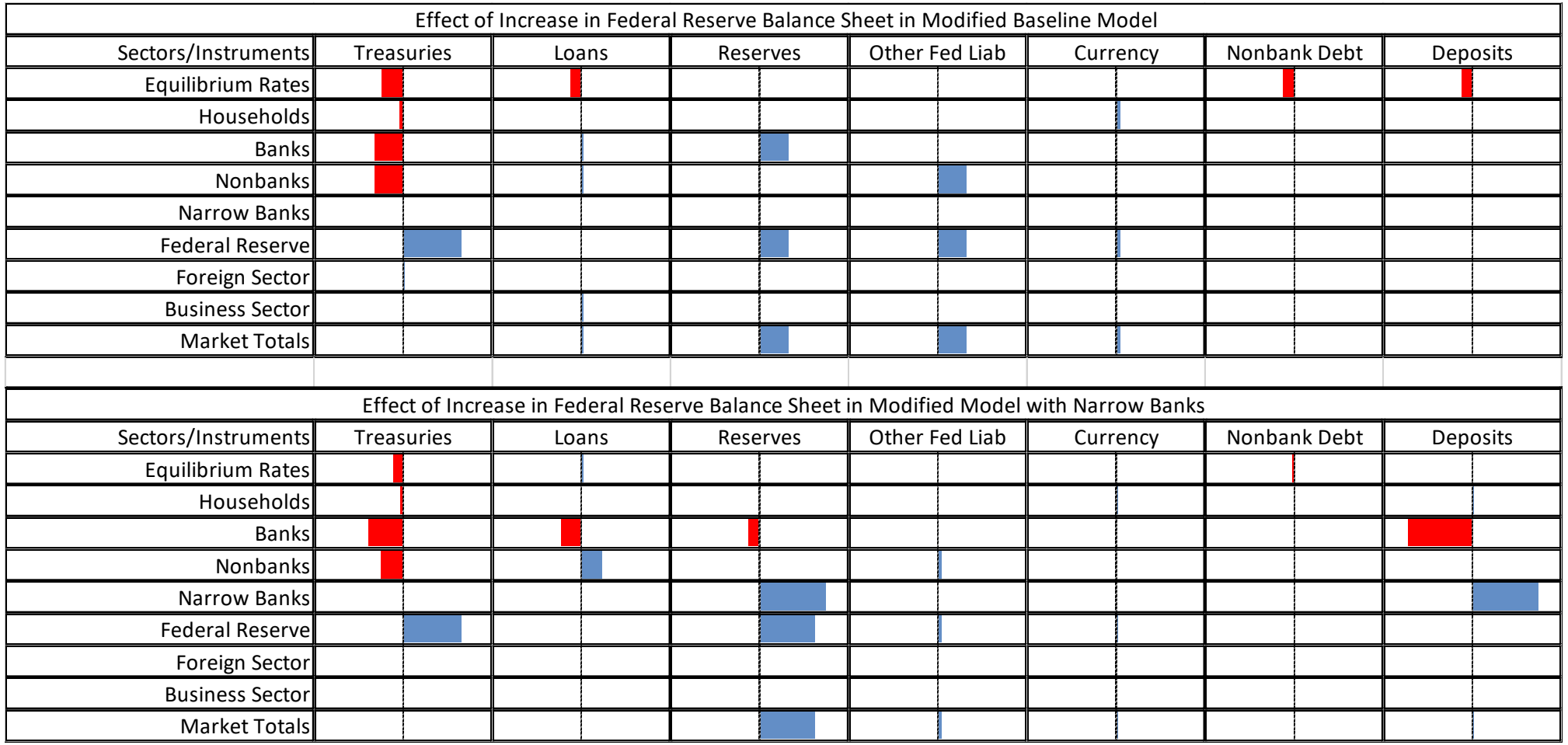
Figure 51: CBDC Demand and Reduced Treasury Demand



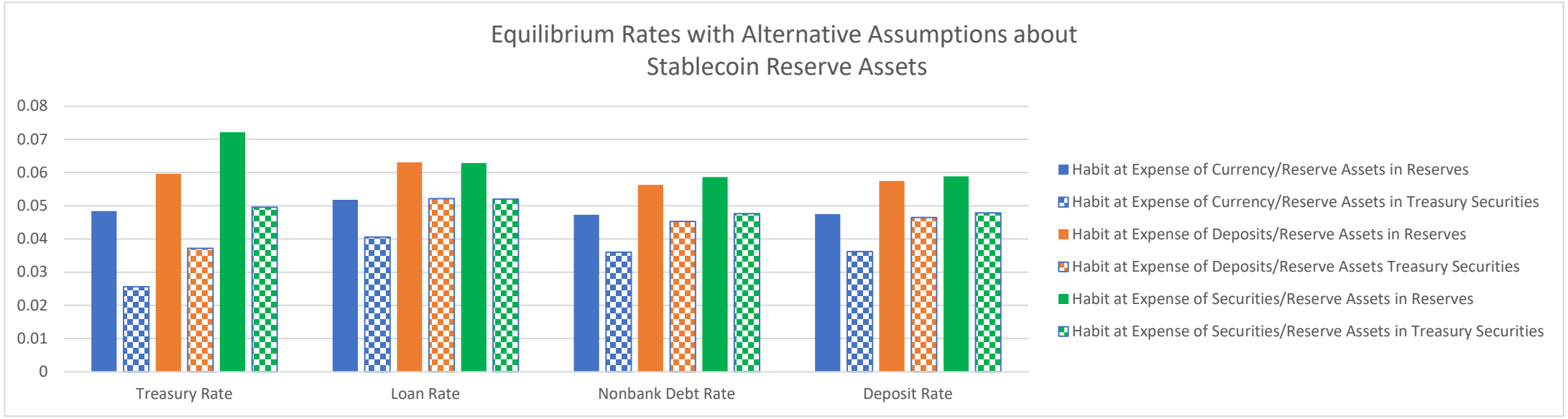
# Figure 52: Effects of Asset Purchases on Equilibrium Rates



# Figure 53: Effects of Asset Purchases on Rates and Sector Balance Sheets



# Figure 54: Effects of Alternative Assumptions about Reserve Assets for Stablecoin Issuers



The upshot of this analysis is that there are scenarios in which the advent of stablecoin issuers could present some challenging issues for central banks. If stablecoins became a significant portion of household portfolios with the shift at the expense of currency, then allowing stablecoin reserve assets to be maintained in the form of reserves or other Federal Reserve liabilities could relieve downward pressure on interest rates. Alternatively, the downward pressure on interest rates could be addressed by reducing the size of the balance sheet. If the habit for stablecoin came instead at the expense of Treasury securities, then allowing stablecoin issuers to maintain their reserve assets in the form of reserves or other Federal Reserve liabilities would put significant upward pressure on rates. That pressure could be addressed by either expanding the Federal Reserve's balance sheet or not allowing stablecoin issuers to maintain reserve assets in the form of claims on the Federal Reserve.

# 8. Conclusion

The analysis in this paper points to several avenues through which the evolution of technology, regulation, and financial structure may interact with monetary policy implementation and transmission. The introduction of fixed-rate assets by the Federal Reserve over recent years in the form of interest-bearing reserves and fixed-rate overnight reverse repurchase agreements has created powerful new tools for policy implementation—tools that are essential to maintain effective interest rate control in an environment with elevated reserve levels in an "ample" reserves regime. An implication of the analysis is that the introduction of additional fixed-rate financial assets by the Federal Reserve (in the form of retail and wholesale CBDC) or by specialized financial intermediaries (in the form of stablecoins or deposits offered by narrow banks) can interact with existing markets and institutions in ways that affect important aspects of policy implementation and transmission. These effects are most pronounced when new fixed-rate instruments are close substitutes for existing financial instruments. Anticipating how monetary policy implementation will develop in the future is challenging but, if the past is prologue, central banks will continue to find it necessary to adapt their policy tools and implementation frameworks to ongoing structural changes in the financial system. And that process, in turn, will likely have implications for the evolution of the financial system over time.

# Appendix: Mathematical Details

This appendix lays out some of the formal details underlying the baseline model including the optimization problems solved by households, intermediaries and businesses and the resulting market equilibrium.

## Financial Intermediaries

Financial intermediaries—banks and nonbanks—maximize profits given by an expression of the form shown below in equation (A1).

$$\sum_{i=1}^{n} r_i A_i - \sum_{j=1}^{k} r_j L_j - \frac{1}{2\phi} S^2 - \frac{1}{2} \tilde{A}' \Omega \tilde{A} - \frac{1}{2} \tilde{L}' Z \tilde{L} \qquad \text{(A1)}$$

Here

$$A_i = quantity\ of\ asset\ i$$
$$L_j = quantity\ of\ liability\ j$$
$$S = scale\ of\ balance\ sheet$$
$$\tilde{A}_i = habitat\ deviation\ for\ i^{th}\ asset = A_i - \alpha_i S$$
$$\tilde{L}_j = habitat\ deviation\ for\ j^{th}\ liability = L_j - \tau_j S$$

The parameters $\alpha_i$ and $\tau_j$ define the "preferred habit" shares of total assets and total liabilities for each individual asset and liability category. The "habit deviations" are then just the differences between the actual quantities for each individual asset and liability and the preferred habitat quantities. The individual habit deviations are written in matrix notation as:

$$\tilde{A}' = \left[ \tilde{A}_1, ..., \tilde{A}_I \right]$$
$$\tilde{L}' = \left[ \tilde{L}_1, ..., \tilde{L}_J \right]$$

The scale of the balance sheet is equal to the sum of individual asset holdings and individual liabilities.

$$S = \sum_{i=1}^{I} A_i = \sum_{j=1}^{J} L_j$$

The matrices $\Omega$ and $Z$ define the cost of departing from the preferred habitat for quantity of each variable.

With this structure, the optimal scale of the balance sheet is given by:

$$S = \phi(\alpha' r_A - \tau' r_L) \qquad \text{(A2)}$$

Here $\alpha$ and $\tau$ collect the individual preferred habitat share parameters into vectors. Equation (A2) says that the scale of the balance sheet is determined by the equilibrium spread between the weighted average return on assets and the weighted average cost of funds. The parameter $\phi$ represents the inverse of the

marginal cost of expanding the balance sheet. When this parameter is low, it could be interpreted as indicating that regulatory factors or other considerations make it quite costly to increase the scale of the balance sheet.

The solutions for the optimal habit deviations on the asset side of the balance sheet are given by:

$$\tilde{A} = \Omega^{-1}(r_A - \gamma_A u_A) \qquad \text{(A3)}$$

$$\gamma_A = (u_A' \Omega^{-1} r_A)/(u_A' \Omega^{-1} u_A)$$

$$A = \alpha S + \tilde{A} = \alpha S + \Omega^{-1}(r_A - \gamma_A u_A)$$

Note that the term $\gamma_A$ is a weighted average of all the rates in the vector $r_A$—the expression $u_A' \Omega^{-1}$ is a vector of the column sums of the matrix $\Omega^{-1}$ and the denominator $u_A' \Omega^{-1} u_A$ is the sum of those column sums. So the final expression for the optimal asset allocation in (A3) then is a function of the habit for each asset an optimal deviation and an optimal deviation from that habit level that depends on the extent to which the rate for the individual asset deviates from the weighted average rate of all assets in the portfolio.

The corresponding solutions for the optimal habit deviations on the liability side of the balance sheet are given by:

$$\tilde{L} = Z^{-1}(r_L - \gamma_L u_L) \qquad \text{(A4)}$$

$$\gamma_L = (u_L' Z^{-1} r)/(u_L' Z^{-1} u_L)$$

$$L = \tau S + \tilde{L} = \alpha S + Z^{-1}(r_L - \gamma_L u_L)$$

Here $u_A$ and $u_L$ are vectors of 1s with the same dimension as the vector of rates, $r_A$ or $r_L$. The values $\gamma_A$ and $\gamma_L$ are just scalars that correspond to the Lagrange multipliers for the constraints on assets and liabilities. In the solutions, these are equal to a cost-weighted average of rates on assets and liabilities. The expressions above indicate that the preferred habitat deviations are based on deviations of rates in individual markets from the cost-weighted average rate.

The optimal levels of the assets and liabilities are then given by:

$$A = \alpha S + \Omega^{-1}(r_A - \gamma_A u_A)$$

$$L = \tau S + Z^{-1}(r_L - \gamma_L u_L)$$

## Households

The problem for households is similar to that for intermediaries except that we assume households only make decisions about how to allocate their wealth. The scale of their balance sheet is fixed and equal to W.

Formally, the household solves:

$\sum_{i=1}^{n} r_i A_i - \frac{1}{2}\tilde{A}'\Omega_{HH}\tilde{A}$

Subject to

$u'A = W$

The optimal solution for this problem is identical to equation (4) with the scale variable replaced by net worth W.

$$A = \alpha W + \tilde{A} = \alpha W + {\Omega_{HH}}^{-1}(r_A - \gamma_A u_A) \quad \text{(A5)}$$

$\gamma_A = (u_A'{\Omega_{HH}}^{-1} r_A)/(u_A'{\Omega_{HH}}^{-1} u_A)$

### Businesses

Businesses borrow from banks to finance investment spending. We assume that investment spending is related to the level of output which, in turn, is a function of potential output and the spread between the loan rate and the equilibrium real rate. Under these assumptions, business demand for loans is given by the expression:

$$l = \mu - a(r_l - r_l^*) \quad \text{(A6)}$$

### Foreign Sector

The foreign sector in the model is effectively a source of residual demand for Treasury securities. The long-run demand for Treasuries in the foreign sector is given by:

$$For = FOR^* + f(r_T - x) \quad \text{(A7)}$$

Here, $x$, represents the rate of return on alternative assets available to foreign investors which we proxy by the average of the Federal Reserve's administer rates, $x = (r_{RS} + r_{OL})/2$.

### Government Sector

The government sector is assumed to supply an exogenous level of debt, $\bar{T}$.

## Equilibrium Conditions

### Demand and Supply Across Markets

Given these demand and supply curves, the market equilibrium can be described by setting demand equal to supply in each market. In the deposit market, we have the demand for deposits as an asset by the household sector equal to the desired quantity of deposit liabilities for banks.

$D_{HH}^A = D_{BK}^L$

In the nonbank debt market, the demand for nonbank debt investments by households is equal to the quantity of borrowing by in nonbank debt by nonbanks.

$P_{HH}^A = P_{DL}^L$

In the loan market, business demand for loans is equal to the supply of business loans from banks.

$$BL^A_{BK} + BL^A_{NB} = BL^L_{BS}$$

Equilibrium in the Treasury market is given by:

$$SEC^A_{FED} + SEC^A_{BK} + SEC^A_{NB} + SEC^A_{HH} + S^A_{FOR} = SEC^L_{GOV}$$

When each of the equilibrium conditions above is satisfied and the Federal Reserve adjusts its balance sheet passively to accommodate the demand for its liabilities, the holdings of government securities and bank loans across the system will equal household net worth plus foreign sector holdings of Treasury securities. That is,

$$S^A_{BK} + S^A_{NB} + S^A_{HH} + S^A_{FOR} + S^A_{FED} = S^L_{GOV} \quad \text{(A8)}$$

In the baseline version of the model in which the Federal Reserve passively adjusts the size of this balance sheet to accommodate demand for its liabilities, equation (A8) reduces to:

$$S^A_{FOR} + W = S^L_{GOV} + BL^L_{Business}$$

Equation (A8) illustrates the underlying structure of the model—the household sector and the foreign sector are the source of all net lending and the government sector, and the business sector are the source of all net borrowing. A portion of household lending is direct in the form of holdings of government securities. The remaining portion of household lending is intermediated through the financial sector and the Federal Reserve.

In the longer-run, the Federal Reserve is assumed to passively adjust the size of its balance sheet to satisfy demand for its liabilities at the market-determined rates. And we assume the foreign sector in the longer-run moves to a desired level of holdings of Treasury securities given by equation (A7). The long-run equilibrium is determined by the equilibrium condition in each market given by equations (A3) -(A5). The Federal Reserve passively adjusts its balance sheet to accommodate the public's demand for Federal Reserve liabilities. As a result, equation (A8) holds by assumption for any long-run equilibrium set of rates.

As noted above, in the short run, we assume the Federal Reserve fixes the size of its balance. The short-run market equilibrium is determined by the Federal Reserve's balance sheet constraint along with the market equilibrium conditions. Equilibrium in the Treasury market (equation A8) is assured by the assumption that the foreign sector in the short-run effectively acts as the "slack variable" variable equating demand and supply in the Treasury market.

## Equilibrium Rates and Quantities

Using the solutions for the optimal asset and liability quantities noted in equations (A3) to (A5) above and the equilibrium conditions in each market, the solution for the equilibrium rates can be expressed in matrix form as:

$$Ar = Be \quad \text{(A9)}$$

Where A is matrix collecting all the coefficients on the endogenous interest rates, r, in the four equilibrium equations and B is a matrix collecting all the coefficients on the exogenous rates and other factors. The equilibrium rates are then given by:

$$r = A^{-1}Be = Qe$$

With the solutions for the endogenous rates in hand from equation (A9), the corresponding equilibrium quantities for all financial instruments and all sectors can be computed from the demand and supply curves shown in equations A3 to A7.

As noted above, the solutions for the optimal habit deviations for each sector are a function of interest rate spreads. Similarly, the solutions for the optimal scale of financial intermediaries in (A2) are also functions of the spread between relevant interest rates. As a result, starting from a position in which the financial system is in equilibrium, if all interest rates (both endogenous and exogenous) increase by the same increment, the optimal asset and liability choices of households and financial intermediaries will be unchanged. Moreover, given the assumed form of the business demand for loans and foreign demand for Treasury securities, an equal increase in all interest rates would leave those demands as unchanged as well. This implies that the system after the assumed equal change in all interest rates will remain in equilibrium—that is the assumed new equilibrium endogenous rates and exogenous rates will be consistent with zero excess demand in all markets. It follows that an equal sized increase in all of the exogenous rates in the model—the Federal Reserve's administered rates and the long-run equilibrium loan rate—will pass through to an equivalent increase in all of the endogenous rates in the model.

## Baseline Model Specification

The version of the model discussed above is simplified by assuming that banks and nonbanks issue only deposits and nonbank debt, respectively. As a result, the habit deviations on the liability side of the balance sheet of financial intermediaries are not relevant. Moreover, we assume that the habits for banks and nonbanks are identical for securities, loans, and Federal Reserve liabilities. Moreover, we assume the balance sheet costs and asset deviation costs are also the same for both banks and nonbanks. On the asset side of the balance sheet, the only distinction then between banks and nonbanks in this simplified model is that banks earn more on their claims on the Federal Reserve (in the form of reserves) than nonbanks do on their claims on the Federal Reserve (in the form of other Federal Reserve liabilities). The distinction on the liability side of the balance sheet is only in the form of the liability issued—banks issue deposits while nonbanks issue nonbank debt. There is a difference between these types of obligations because households have preferences over the fraction of their wealth to invest in deposits versus nonbank debt. The matrices $\Omega$ and $Z$ that define the cost of deviating from the habit levels for households and financial intermediaries are assumed to be diagonal. Elements along the diagonal for each matrix are a scalar reflecting the baseline marginal cost of deviating from the habit divided by the habit share. This structure implies that the cost of deviating by a given dollar amount goes up when the habit for a particular asset is smaller (and vice versa). Many other assumptions are possible of course. This particular assumption seems plausible in that it seems unlikely that a household or financial intermediary would be comfortable with large nominal habit deviations for an asset class with only a small habit share.

Under these assumptions, the reduced form solution of the model is shown in Table A6. The first column of the table shows the coefficient on the exogenous variable listed in the left most column. The notation $r'_{LN}$, $r'_{TR}$, and $r'_{ND}$ in each row of the table refer to the derivatives of the loan rate, Treasury rate, and nonbank debt rate with respect to the *exogenous variable for each row*.

The key terms determining the response of the loan rate to various factors are of the form $\delta\alpha_{LN}\alpha_x - (\emptyset\alpha_{LN}\alpha_x)(1-\tau)$. This term captures the relative importance of the asset substitution effect for financial intermediaries, $\delta$, and the net scale effect a change in factor "x" on the quantity of loans. The model is parameterized so that terms of this form are positive; that is, the substitution effect outweighs the scale effect. For example, the assumption ensures that an increase in the interest rate on reserve balances results in a net decline in loans as banks substitute for reserves even though the higher rate on reserves increases banks intermediation spread and leads to a larger optimal scale of the bank.

The remaining tables show comparable model solutions for the versions incorporating CBDC, narrow nonbanks issuing stablecoin, and narrow banks issuing deposits. To keep the expressions relatively compact, the parameters "hhxx" refer to the household habit asset shares for the financial asset indicated by "xx." For example, *hhcu* refers to the household habit share for physical currency, *hhtr* is the household habit share for Treasury securities and so on. The solutions presented in the tables are for the special case when the habit shares for banks and nonbanks are equal. As a result, the habit shares for loans and Treasury securities, $\alpha_{LN}$ and $\alpha_{TR}$, are identical for banks and nonbanks and the superscript denoting bank or nonbank is dropped. Similarly, the habit shares for reserves and other Federal Reserve liabilities, $\alpha_{RS}$ and $\alpha_{OL}$, are equal and the superscript is dropped for these parameters as well.

## Baseline Model Calibration

The calibration of the baseline model involves setting plausible values for all of the key parameters. The values selected for the baseline model are listed below. A key feature of this calibration is that financial intermediaries are much more willing to substitute across asset and liabilities that households. That preference is reflected in a setting for the household asset substitution parameter $\delta_{HHA}$ that is much larger than the corresponding substitution parameter for banks and nonbanks. That assumption implies that quantity effects on financial intermediary balance sheets are generally larger in magnitude than those for households. Another important feature of the calibration is the setting of $\delta_{HHA}$ relative to the parameter governing balance sheet costs of financial intermediaries. We assume the financial intermediary balance sheet costs are relatively small. That assumption implies that the size of financial intermediaries in equilibrium is largely determined by the preferred size of household holdings of the liabilities of financial intermediaries—deposits and nonbank debt. Another important element of the calibration involves the relative settings of the substitution parameter for financial intermediaries and the balance sheet cost parameter. We choose parameter settings so that, in general, "substitution effects" of changes in relative rates tend to dominate the scale effects in on financial intermediary balance sheets. Tables A1 through A4 show the settings for all of the parameters in each variation of the baseline model. Table A5 shows the settings for parameters in the modified baseline model in which the Federal Reserve fixes the size of its balance sheet in the short run.

**Table A1: Baseline Model Calibration**

| Households | | |
|---|---|---|
| $\alpha_{CU}^{HH}$ | Currency | 0.2 |
| $\alpha_{TR}^{HH}$ | Treasury Securities | 0.2 |
| $\alpha_{ND}^{HH}$ | Nonbank Debt | 0.3 |
| $\alpha_{DP}^{HH}$ | Deposits | 0.3 |
| $\gamma_{HHA}$ | Asset Deviation Cost | 0.5 |

| Bank Assets | | |
|---|---|---|
| $\alpha_{TR}^{BK}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{BK}$ | Loans | 0.6 |
| $\alpha_{RS}^{BK}$ | Reserves | 0.2 |
| **Other** | | |
| $\gamma_{BKA}$ | Bank Asset Deviation Cost | 0.05 |
| $\varphi_{BK}$ | Bank Balance Sheet Cost | 0.01 |

| Nonbank Assets | | |
|---|---|---|
| $\alpha_{TR}^{NB}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{NB}$ | Loans | 0.6 |
| $\alpha_{OL}^{NB}$ | Other Fed Liabilities | 0.2 |
| **Other** | | |
| $\gamma_{NBA}$ | Nonbank Asset Deviation Cost | 0.05 |
| $\varphi_{NB}$ | Nonbank Balance Sheet Cost | 0.01 |

| Businesses | | |
|---|---|---|
| $\mu$ | Structural Loan Demand | 0.45 |
| a | Interest Responsiveness | 0.20 |

| Government Sector | | |
|---|---|---|
| $\bar{T}$ | Exogenous Treasury Supply | 1.5 |

| Foreign Sector | | |
|---|---|---|
| $\bar{F}$ | Structural Foreign Demand for Treasury Securities | 0.9 |
| $f$ | Interest Rate Responsiveness | 10 |

| Administered Rates | | |
|---|---|---|
| $r_{CU}$ | Rate on physical currency | 0.00 |
| $r_{RS}$ | Rate on reserves | 4.90 |
| $r_{OL}$ | Rate on other Fed liabilities | 4.80 |
| $r^*$ | Equilibrium Loan Rate | 4.50 |

## Table A2: Baseline Model With Narrow Banks Calibration

| Households | | |
|---|---|---|
| $\alpha_{CU}^{HH}$ | Currency | 0.2 |
| $\alpha_{TR}^{HH}$ | Treasury Securities | 0.2 |
| $\alpha_{ND}^{HH}$ | Nonbank Debt | 0.3 |
| $\alpha_{DP}^{HH}$ | Deposits | 0.3 |
| $\gamma_{HHA}$ | Asset Deviation Cost | 0.5 |

| Bank Assets | | |
|---|---|---|
| $\alpha_{TR}^{BK}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{BK}$ | Loans | 0.6 |
| $\alpha_{RS}^{BK}$ | Reserves | 0.2 |
| **Other** | | |
| $\gamma_{BKA}$ | Bank Asset Deviation Cost | 0.05 |
| $\varphi_{BK}$ | Bank Balance Sheet Cost | 0.01 |

| Nonbank Assets | | |
|---|---|---|
| $\alpha_{TR}^{NB}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{NB}$ | Loans | 0.6 |
| $\alpha_{OL}^{NB}$ | Other Fed Liabilities | 0.2 |
| **Other** | | |
| $\gamma_{NBA}$ | Nonbank Asset Deviation Cost | 0.05 |
| $\varphi_{NB}$ | Nonbank Balance Sheet Cost | 0.01 |

| Businesses | | |
|---|---|---|
| $\mu$ | Structural Loan Demand | 0.45 |
| a | Interest Responsiveness | 0.20 |

| Narrow Banks | | |
|---|---|---|
| $fee$ | Per-Unit Fee | 0.0002 |

| Government Sector | | |
|---|---|---|
| $\bar{T}$ | Exogenous Treasury Supply | 1.5 |

| Foreign Sector | | |
|---|---|---|
| $\bar{F}$ | Structural Foreign Demand for Treasury Securities | 0.9 |
| $f$ | Interest Rate Responsiveness | 10 |

| Administered Rates | | |
|---|---|---|
| $r_{CU}$ | Rate on physical currency | 0.00 |
| $r_{RS}$ | Rate on reserves | 4.90 |
| $r_{OL}$ | Rate on other Fed liabilities | 4.80 |
| $r^*$ | Equilibrium Loan Rate | 4.50 |

**Table A3: Calibration for Extended Model with CBDC**

| **Households** | | |
|---|---|---|
| $\alpha_{CU}^{HH}$ | Currency | 0.1 |
| $\alpha_{RCBDC}^{HH}$ | Retail CBDC | 0.1 |
| $\alpha_{TR}^{HH}$ | Treasury Securities | 0.2 |
| $\alpha_{ND}^{HH}$ | Nonbank Debt | 0.3 |
| $\alpha_{DP}^{HH}$ | Deposits | 0.3 |
| $\gamma_{HHA}$ | Asset Deviation Cost | 0.5 |
| **Bank Assets** | | |
| $\alpha_{TR}^{BK}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{BK}$ | Loans | 0.6 |
| $\alpha_{RS}^{BK}$ | Reserves | 0.1 |
| $\alpha_{WCBDC}^{BK}$ | Wholesale CBDC | 0.1 |
| **Other** | | |
| $\gamma_{BKA}$ | Bank Asset Deviation Cost | 0.05 |
| $\varphi_{BK}$ | Bank Balance Sheet Cost | 0.01 |
| **Nonbank Assets** | | |
| $\alpha_{TR}^{NB}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{NB}$ | Loans | 0.6 |
| $\alpha_{OL}^{NB}$ | Other Fed Liabilities | 0.1 |
| $\alpha_{WCBDC}^{NB}$ | Wholesale CBDC | 0.1 |
| **Other** | | |
| $\gamma_{NBA}$ | Nonbank Asset Deviation Cost | 0.05 |
| $\varphi_{NB}$ | Nonbank Balance Sheet Cost | 0.01 |

| **Businesses** | | |
|---|---|---|
| $\mu$ | Structural Loan Demand | 0.45 |
| a | Interest Responsiveness | 0.20 |
| **Government Sector** | | |
| $\bar{T}$ | Exogenous Treasury Supply | 1.5 |
| **Foreign Sector** | | |
| $\bar{F}$ | Structural Foreign Demand for Treasury Securities | 0.9 |
| $f$ | Interest Rate Responsiveness | 10 |
| **Administered Rates** | | |
| $r_{CU}$ | Rate on physical currency | 0.00 |
| $r_{RS}$ | Rate on reserves | 4.90 |
| $r_{OL}$ | Rate on other Fed liabilities | 4.80 |
| $r_{RCBDC}$ | Rate on Retail CBDC | 0.00 |
| $r_{WCBDC}$ | Rate on Wholesale CBDC | 4.85 |
| $r^*$ | Equilibrium Loan Rate | 4.50 |

**Table A4: Calibration for Baseline Model with Stable Coin Issuers**

| Households | | |
|---|---|---|
| $\alpha_{CU}^{HH}$ | Currency | 0.1[0.2] |
| $\alpha_{SC}^{HH}$ | Stablecoin | 0.1 |
| $\alpha_{TR}^{HH}$ | Treasury Securities | 0.2 |
| $\alpha_{ND}^{HH}$ | Nonbank Debt | 0.3 |
| $\alpha_{DP}^{HH}$ | Deposits | 0.3[0.2] |
| $\gamma_{HHA}$ | Asset Deviation Cost | 0.5 |
| **Bank Assets** | | |
| $\alpha_{TR}^{BK}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{BK}$ | Loans | 0.6 |
| $\alpha_{RS}^{BK}$ | Reserves | 0.2 |
| **Other** | | |
| $\gamma_{BKA}$ | Bank Asset Deviation Cost | 0.05 |
| $\varphi_{BK}$ | Bank Balance Sheet Cost | 0.01 |

| Nonbank Assets | | |
|---|---|---|
| $\alpha_{TR}^{NB}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{NB}$ | Loans | 0.6 |
| $\alpha_{OL}^{NB}$ | Other Fed Liabilities | 0.2 |
| **Other** | | |
| $\gamma_{NBA}$ | Nonbank Asset Deviation Cost | 0.05 |
| $\varphi_{NB}$ | Nonbank Balance Sheet Cost | 0.01 |

| Businesses | | |
|---|---|---|
| $\mu$ | Structural Loan Demand | 0.45 |
| a | Interest Responsiveness | 0.20 |
| **Stablecoin Issuer** | | |
| $r_{SC}$ | Stablecoin Rate | 0.00 |
| **Government Sector** | | |
| $\bar{T}$ | Exogenous Treasury Supply | 1.5 |
| **Foreign Sector** | | |
| $\bar{F}$ | Structural Foreign Demand for Treasury Securities | 0.9 |
| $f$ | Interest Rate Responsiveness | 10 |
| **Administered Rates** | | |
| $r_{CU}$ | Rate on physical currency | 0.00 |
| $r_{RS}$ | Rate on reserves | 4.90 |
| $r_{OL}$ | Rate on other Fed liabilities | 4.80 |
| $r^*$ | Equilibrium Loan Rate | 4.50 |

**Table A5: Modified Baseline Model Calibration with Active Balance Sheet Management**

| **Households** | | |
|---|---|---|
| $\alpha_{CU}^{HH}$ | Currency | 0.2 |
| $\alpha_{TR}^{HH}$ | Treasury Securities | 0.2 |
| $\alpha_{ND}^{HH}$ | Nonbank Debt | 0.3 |
| $\alpha_{DP}^{HH}$ | Deposits | 0.3 |
| $\gamma_{HHA}$ | Asset Deviation Cost | 0.5 |

| **Bank Assets** | | |
|---|---|---|
| $\alpha_{TR}^{BK}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{BK}$ | Loans | 0.6 |
| $\alpha_{RS}^{BK}$ | Reserves | 0.2 |
| **Other** | | |
| $\gamma_{BKA}$ | Bank Asset Deviation Cost | 0.05 |
| $\varphi_{BK}$ | Bank Balance Sheet Cost | 0.01 |

| **Nonbank Assets** | | |
|---|---|---|
| $\alpha_{TR}^{NB}$ | Treasury Securities | 0.2 |
| $\alpha_{LN}^{NB}$ | Loans | 0.6 |
| $\alpha_{OL}^{NB}$ | Other Fed Liabilities | 0.2 |
| **Other** | | |
| $\gamma_{NBA}$ | Nonbank Asset Deviation Cost | 0.05 |
| $\varphi_{NB}$ | Nonbank Balance Sheet Cost | 0.01 |

| **Businesses** | | |
|---|---|---|
| $\mu$ | Structural Loan Demand | 0.45 |
| a | Interest Responsiveness | 0.20 |

| **Government Sector** | | |
|---|---|---|
| $\bar{T}$ | Exogenous Treasury Supply | 1.5 |

| **Federal Reserve** | | |
|---|---|---|
| $\overline{FD}$ | Size of Federal Reserve's Balance Sheet | 0.2915 |

| **Administered Rates** | | |
|---|---|---|
| $r_{CU}$ | Rate on physical currency | 0.00 |
| $r_{RS}$ | Rate on reserves | 4.90 |
| $r_{OL}$ | Rate on other Fed liabilities | 4.80 |
| $r^*$ | Equilibrium Loan Rate | 4.50 |

# Table A6: Reduced Form Solutions for Equilibrium Rates in the Baseline Model

| | $r_{LN}$ | $r_{TR}$ | $r_{ND}$ | $r_{DP}$ |
|---|---|---|---|---|
| $r_{CU}$ | $2\alpha_{LN}\cdot\tau\cdot hhcu\cdot hhdp\cdot\beta/D$ | $-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+\left(\frac{\beta}{\emptyset}\right)hhcu\cdot hhdp\cdot\tau$ | $r'_{ND}$ |
| $r_{CBDC}$ | 0 | 0 | 0 | 0 |
| $r_{RS}$ | $(-\emptyset\alpha_{LN}\alpha_{RS}+\emptyset\alpha_{LN}\alpha_{RS}\tau+\delta\alpha_{LN}\alpha_{RS}+\frac{q}{2})/D$ | $\frac{1}{2}-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau-v)(\frac{\alpha_{RS}}{2})$ | $r'_{ND}+\alpha_{RS}v$ |
| $r_{OL}$ | $(-\emptyset\alpha_{LN}\alpha_{OL}+\emptyset\alpha_{LN}\alpha_{OL}\tau+\delta\alpha_{LN}\alpha_{OL}+\frac{q}{2})/D$ | $\frac{1}{2}-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau+v)(\frac{\alpha_{OL}}{2})$ | $r'_{ND}-\alpha_{OL}v$ |
| $r_{WCBDC}$ | 0 | 0 | 0 | 0 |
| $\overline{T}$ | $q/(fD)$ | $1/f-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $\overline{F}$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhcu$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhcb$ | 0 | 0 | 0 | 0 |
| $hhnd$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau-v)(\frac{1}{2\emptyset})$ | $r'_{ND}+v/\emptyset$ |
| $hhdp$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau+v)(\frac{1}{2\emptyset})$ | $r'_{ND}-v/\emptyset$ |
| $hhtr$ | $-q/(fD)$ | $-(1/f+\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhsc$ | 0 | 0 | 0 | 0 |
| $\mu$ | $(1+q/f)/D$ | $\left(\frac{1}{f}\right)-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $r^{*}_{LN}$ | $a\cdot(1+q/f)/D$ | $\left(\frac{\alpha}{f}\right)-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |

$\tau=\emptyset/(\emptyset+hhdp\cdot(1-2\cdot hhdp)\cdot\beta))$ $\quad D=(a+2\delta\alpha_{LN}(1-\alpha_{LN})+2\alpha_{LN}\alpha_{LN}\emptyset(1-\tau)+\frac{qa}{f})$ $\quad q=(2\delta\alpha_{LN}\alpha_{TR}-2\alpha_{LN}\alpha_{TR}\emptyset(1-\tau)+2\alpha_{LN}\cdot\tau\cdot hhdp\cdot hhtr\cdot\beta)$

$v=\emptyset/(\emptyset+hhdp\cdot\beta\cdot(2hhnd+hhcu+hhtr))$

# Table A7: Reduced Form Solutions for Equilibrium Rates in the Extended Baseline Model with CBDC

| | $r_{LN}$ | $r_{TR}$ | $r_{ND}$ | $r_{DP}$ |
|---|---|---|---|---|
| $r_{CU}$ | $2\alpha_{LN}\cdot\tau\cdot hhcu\cdot hhdp\cdot\beta/D$ | $-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+\left(\frac{\beta}{\emptyset}\right)hhcu\cdot hhdp\cdot\tau$ | $r'_{ND}$ |
| $r_{CBDC}$ | $2\alpha_{LN}\cdot\tau\cdot hhcb\cdot hhdp\cdot\beta/D$ | $-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+\left(\frac{\beta}{\emptyset}\right)hhcb\cdot hhdp\cdot\tau$ | $r'_{ND}$ |
| $r_{RS}$ | $(-\emptyset\alpha_{LN}\alpha_{RS}+\emptyset\alpha_{LN}\alpha_{RS}\tau+\delta\alpha_{LN}\alpha_{RS}+\frac{q}{3})/D$ | $\frac{1}{3}-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau-v)(\frac{\alpha_{RS}}{2})$ | $r'_{ND}+\alpha_{RS}v$ |
| $r_{OL}$ | $(-\emptyset\alpha_{LN}\alpha_{OL}+\emptyset\alpha_{l}\alpha_{OL}\tau+\delta\alpha_{LN}\alpha_{OL}+\frac{q}{3})/D$ | $\frac{1}{3}-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau+v)(\frac{\alpha_{OL}}{2})$ | $r'_{ND}-\alpha_{OL}v$ |
| $r_{WCBDC}$ | $(-2\emptyset\alpha_{LN}\alpha_{WCB}+2\emptyset\alpha_{LN}\alpha_{WCB}\tau+2\delta\alpha_{LN}\alpha_{WCB}+\frac{q}{3})/D$ | $\frac{1}{3}-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+\alpha_{WCB}*\tau$ | $r'_{ND}$ |
| $\overline{T}$ | $q/(fD)$ | $1/f-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $\overline{F}$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhcu$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhcb$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhnd$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau-v)(\frac{1}{2\emptyset})$ | $r'_{ND}+v/\emptyset$ |
| $hhdp$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau+v)(\frac{1}{2\emptyset})$ | $r'_{ND}-v/\emptyset$ |
| $hhtr$ | $-q/(fD)$ | $-(1/f+\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhsc$ | 0 | 0 | 0 | 0 |
| $\mu$ | $(1+q/f)/D$ | $\left(\frac{1}{f}\right)-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $r^{*}_{LN}$ | $a\cdot(1+q/f)/D$ | $\left(\frac{a}{f}\right)-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |

$\tau=\emptyset/(\emptyset+hhdp\cdot(1-2\cdot hhdp)\cdot\beta))$ $D=(a+2\delta\alpha_{LN}(1-\alpha_{LN})+2\alpha_{LN}\alpha_{LN}\emptyset(1-\tau)+\frac{qa}{f})$ $q=(2\delta\alpha_{LN}\alpha_{TR}-2\alpha_{LN}\alpha_{TR}\emptyset(1-\tau)+2\alpha_{LN}\tau\cdot hhdp\cdot hhtr\cdot\beta)$

$v=\emptyset/(\emptyset+hhdp\cdot\beta\cdot(2hhnd+hhcu+hhtr+hhcb))$

# Table A8: Reduced Form Solutions for Equilibrium Rates in the Extended Baseline Model with Stablecoin

| | $r_{LN}$ | $r_{TR}$ | $r_{ND}$ | $r_{DP}$ |
|---|---|---|---|---|
| $r_{CU}$ | $2\alpha_{LN}\cdot\tau\cdot hhcu\cdot hhdp\cdot\beta/D$ | $-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_l\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+\left(\frac{\beta}{\emptyset}\right)hhcu\cdot hhdp\cdot\tau$ | $r'_{ND}$ |
| $r_{CBDC}$ | 0 | 0 | 0 | 0 |
| $r_{SC}$ | $2\alpha_{LN}\cdot\tau\cdot hhsc\cdot hhdp\cdot\beta/D$ | $-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_l\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+\left(\frac{\beta}{\emptyset}\right)hhsc\cdot hhdp\cdot\tau$ | $r'_{ND}$ |
| $r_{RS}$ | $(-\emptyset\alpha_{LN}\alpha_{RS}+\emptyset\alpha_{LN}\alpha_{RS}\tau+\delta\alpha_{LN}\alpha_{RS}+\frac{q}{2})/D$ | $\frac{1}{2}-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_l\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau-v)(\frac{\alpha_{RS}}{2})$ | $r'_{ND}+\alpha_{RS}v$ |
| $r_{OL}$ | $(-\emptyset\alpha_{LN}\alpha_{OL}+\emptyset\alpha_{LN}\alpha_{OL}\tau+\delta\alpha_{LN}\alpha_{OL}+\frac{q}{2})/D$ | $\frac{1}{2}-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_l\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau+v)(\frac{\alpha_{OL}}{2})$ | $r'_{ND}-\alpha_{OL}v$ |
| $r_{WCBDC}$ | 0 | 0 | 0 | 0 |
| $\overline{T}$ | $q/(fD)$ | $1/f-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $\overline{F}$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhcu$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhcb$ | 0 | 0 | 0 | 0 |
| $hhnd$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau-v)(\frac{1}{2\emptyset})$ | $r'_{ND}+v/\emptyset$ |
| $hhdp$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{\alpha}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}+(\tau+v)(\frac{1}{2\emptyset})$ | $r'_{ND}-v/\emptyset$ |
| $hhtr$ | $-q/(fD)$ | $-(1/f+\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $hhsc$ | 0 | 0 | 0 | 0 |
| $\mu$ | $(1+q/f)/D$ | $\left(\frac{1}{f}\right)-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |
| $r^*_{LN}$ | $a\cdot(1+q/f)/D$ | $\left(\frac{\alpha}{f}\right)-\left(\frac{\alpha}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)hhtr\cdot hhdp\cdot\tau\right)\cdot r'_{TR}$ | $r'_{ND}$ |

$\tau=\emptyset/(\emptyset+hhdp\cdot(1-2\cdot hhdp)\cdot\beta))$ $D=(a+2\delta\alpha_{LN}(1-\alpha_{LN})+2\alpha_{LN}\alpha_{LN}\emptyset(1-\tau)+\frac{q\alpha}{f})$ $q=(2\delta\alpha_{LN}\alpha_{TR}-2\alpha_{LN}\alpha_{TR}\emptyset(1-\tau)+2\alpha_{LN}\tau\cdot hhdp\cdot hhtr\cdot\beta)$

$v=\emptyset/(\emptyset+hhdp\cdot\beta\cdot(2hhnd+hhcu+hhtr+hhsc))$

# Table A9: Reduced Form Solutions for Equilibrium Rates in the Extended Baseline Model With Narrow Banks

| | $r_{LN}$ | $r_{TR}$ | $r_{ND}$ | $r_{DP}$ |
|---|---|---|---|---|
| $r_{CU}$ | $\alpha_{LN}\cdot\tau\cdot hhcu\cdot hhdp\cdot\beta/D$ | $-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhcu\cdot hhdp$ | 0 |
| $r_{CBDC}$ | 0 | 0 | 0 | 0 |
| $r_{RS}$ | $(-\emptyset\alpha_{LN}\alpha_{RS}+\emptyset\alpha_{LN}\alpha_{RS}\tau+\delta\alpha_{LN}\alpha_{RS}+\_q/2)/D$ | $\frac{1}{2}-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}+\left(\frac{\tau}{2}\right)\alpha_{RS}-(\frac{v}{2})\alpha_{RS}$ | 1 |
| $r_{OL}$ | $(-\emptyset\alpha_{LN}\alpha_{OL}+\emptyset\alpha_{LN}\alpha_{OL}\tau+\delta\alpha_{LN}\alpha_{OL}+q/2)/D$ | $\frac{1}{2}-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}+\left(\frac{\tau}{2}\right)\alpha_{OL}+(\frac{v}{2})\alpha_{OL}$ | 0 |
| $r_{WCBDC}$ | 0 | 0 | 0 | 0 |
| $\overline{T}$ | $q/(fD)$ | $1/f-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}$ | 0 |
| $\overline{F}$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}$ | 0 |
| $fee$ | $-(\emptyset\alpha_{LN}+\alpha_{LN}\tau\beta\cdot\ hhnd\cdot hhdp)/D$ | $-\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}-\tau\cdot\beta\cdot hhnd\cdot hhdp/\emptyset$ | -1 |
| $hhcu$ | $-q/(fD)$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}$ | 0 |
| $hhcb$ | 0 | 0 | 0 | 0 |
| $hhnd$ | $-(\alpha_{LN}\tau+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}-(\tau/\emptyset)-v/(2\emptyset)$ | 0 |
| $hhdp$ | -$q/(fD)$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot rr'_{TR}-(\tau/\emptyset)+v/(2\emptyset)$ | 0 |
| $hhtr$ | $-q/(fD)$ | $-(1/f+\left(\frac{a}{f}\right)r'_{LN}$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}$ | 0 |
| $hhsc$ | 0 | 0 | 0 | 0 |
| $\mu$ | $(1+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}$ | 0 |
| $r^{*}_{LN}$ | a$\cdot(1+q/f)/D$ | $-(\frac{1}{f}+\left(\frac{a}{f}\right)r'_{LN})$ | $\alpha_{LN}\cdot\tau\cdot r'_{LN}+\left(\alpha_{TR}\cdot\tau+\left(\frac{\beta}{\emptyset}\right)\tau\cdot hhtr\cdot hhdp\right)\cdot r'_{TR}$ | 0 |

$\tau=\emptyset/(\emptyset+hhnd\cdot(1-hhnd)\cdot\beta))$ $\quad D=(a+2\delta\alpha_{LN}(1-\alpha_{LN})+2\alpha_{LN}\alpha_{LN}\emptyset-\tau\alpha_{LN}\alpha_{LN}\emptyset+\frac{qa}{f})$ $\quad q=(2\delta\alpha_{LN}\alpha_{TR}-2\alpha_{LN}\alpha_{TR}\emptyset+\tau\alpha_{LN}\alpha_{TR}\emptyset+\alpha_{LN}\tau\cdot hhdp\cdot hhtr\cdot\beta)$

$v=\emptyset/(\emptyset+hhdp\cdot\beta\cdot(2hhnd+hhcu+hhtr))$

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