Precautionary Savings and Financial Frictions *

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Abstract

Financial frictions not only impair lending, but also the expansion of the funding side of banks' balance sheets. They restrict the supply of bank-issued demand deposits, which are the dominant liquid asset in households' portfolios. Tight financial conditions, thus, render economies less resilient to shocks that lead households to demand more liquid savings. I first show empirically that one such shock, a shock to household income uncertainty, leads to a deeper recession and a muted creation of liquid deposits when financial conditions are tight. Next, I rationalize this in a two-asset New Keynesian model with heterogeneous households and a leverage constraint in the banking system that constrains liquidity transformation. A binding leverage constraint impairs the intermediation of precautionary savings, dampens the rise of both bank credit and liquid deposits, and leaves the increased demand for liquidity unsatisfied. This, finally, leads to a marked fall in household consumption.

Keywords: liquidity transformation, precautionary savings, financial frictions, incomplete markets, nominal rigidities

JEL codes: E32, E21, E44

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1 Introduction

A long tradition in monetary macroeconomics, going back at least to Tobin (1969), views the liquidity characteristics of assets and portfolio choices of agents as central to business cycle fluctuations.[1] In this view, the state of the banking system not only matters because the banking system provides *credit* to *firms*, but also because it issues *demand deposits* and engages in liquidity transformation. Doing this, the banking system provides a liquid store of value to *households*. The current paper seeks to probe into the importance of banking frictions in this household-centric view of intermediation, both empirically and in a model environment that explicitly accounts for households' needs of a liquid store of value.

First, I empirically assess the transmission of a shock that induces households to rebalance their portfolios towards more liquid assets: a shock to households' uncertainty about their own labor income.[2] I find that the resilience of an economy to swings in the desired composition of household portfolios crucially depends on the state of the banking sector. A rise in labor-income uncertainty is substantially more recessionary if financial conditions are tight. In addition, only when financial conditions are loose, banks respond to higher income uncertainty by issuing more demand deposits.

This suggests a more general mechanism: suppose that households seek to rebalance their portfolios toward demand deposits and away from outright capital investment. Unconstrained banks can meet this demand, and in the process, provide funding to investment projects that now lack the funding from households. Constrained banks, instead, cannot increase deposit supply. Thus, households' demand for deposits itself has to fall back to a lower level. Excess demand for deposits is mirrored by a lack of demand for goods. If the aggregate supply of goods is demand-determined, output and household incomes fall, reducing the demand for liquid savings until the market for deposits clears.

I study this channel, second, in a formal business-cycle model (a "HANK" model, Kaplan et al. 2018). In its core, the model follows Bayer et al. (2019): households face idiosyncratic income risk; they can invest into illiquid capital, and they can purchase a liquid store of value. Into this setting, I introduce banks. The modeling follows Gertler and Karadi (2011), but with an emphasis on banks' ability to provide a liquid store of value: They issue demand deposits. Restrictions on bank leverage can limit the ability of banks to increase the supply of liquid assets. This gives rise to the paper's novel mechanism. Calibrating the environment to the US, I first document that the model replicates the gist of the empirical findings. Through a policy experiment, I show that liquidity provision (the household view) is essential for this: the muted creation of liquid deposits accounts for half of the deeper recession when financial conditions are tight.

[1] Further classic references are Brunner and Meltzer (1972, 1976) and Friedman (1978).

[2] Wide swings in household uncertainty have been documented in Storesletten et al. (2004) and Bayer et al. (2019). What makes a shock to household income risk particularly useful for the question at hand is that it is measurable in a model-independent way and affects the household level first and foremost.

More in detail, the empirical evidence arises as follows. I rely on a series of shocks to household income risk that Bayer et al. (2019) identify from the U.S. Survey on Income and Program Participation data, following the methodology of Storesletten et al. (2004). The series is designed such that the shocks measure an exogenous impulse that, for a while, raises the spread of shocks to the persistent part of household income going forward, for all households in the economy. I then study the response of GDP aggregates, bank credit, and deposits to these shocks by means of local projections (Jordà, 2005). The projections are state-dependent in that I estimate separate responses for times when financial conditions are tight and when they are loose. Following Adrian et al. (2019), I rely on the National Financial Conditions Index constructed by the Federal Reserve Bank of Chicago to determine the state of the financial sector.[3] I first document that, empirically, in response to an increase in household income uncertainty, deposits markedly rise in loose financial conditions. Instead, when financial conditions are tight, deposits do not rise. If anything, they fall. What is more, the effect of the shock on aggregate activity is benign when financial conditions are loose. Instead, when they are tight, a recession ensues: aggregate consumption persistently falls. Output drops more, too, since investment contracts sharply along with bank credit. The empirical results, thus, are suggestive of the state of the banking system being fundamental in shaping how shocks to household risk (and the ensuing shift in the desired portfolio composition) transmit to economic activity.[4]

Next, in order to understand the drivers of these empirical findings, I build a quantitative New Keynesian model with heterogeneous households, a portfolio choice between liquid and illiquid assets (Kaplan et al., 2018, Bayer et al., 2019), and banks (Gertler and Karadi, 2011). Households can save in high-return illiquid claims on capital or low-return liquid bank deposits. The illiquidity of capital stems from the assumption that these assets can only be traded with a certain probability each period. Therefore, liquid bank deposits are better suited to smooth consumption. Only banks can issue such deposits to households. Banks themselves are subject to a leverage constraint. When this binds, net worth of banks restricts lending to firms. At the same time, and this is the focus of the current paper, it also restricts the funding side of banks, namely, the creation of liquid deposits. Thus, the aggregate amount of liquid household savings in the economy, bank deposits, is endogenous to banking frictions. This is a distinctive feature of the current paper. I calibrate this model to the U.S. economy. Households face the same income risk process that underpinned the estimated shocks that I used in the empirical study.

I then look at the transmission of a shock to household income uncertainty. Upon the shock, households reduce their demand for consumption goods and increase their demand for savings. What is more, they seek to rebalance their portfolios from illiquid

[3] An advantage of the National Financial Conditions Index over other measures is that it offers a wide coverage of the financial sector. It includes commercial banks, the main suppliers of households' deposits.

[4] The reader may raise questions of the endogeneity of financial conditions themselves. I show that my results are robust to, among others, controlling for the state of the business cycle.

claims on capital to liquid bank deposits. I look at two scenarios: one in which the leverage constraint never binds, the other when banks' leverage constraint always binds. When the banks are unconstrained, if income risk rises the model sees an expansion in deposit creation. Indeed, the economy as a whole is able to provide the desired increase in household savings: investment rises since banks extend the funding to firms that households no longer seek to provide. As a result, while consumption falls, the effect of the income-uncertainty shock on output is mild. In stark contrast, when the leverage constraint binds, the shock leads to a sharp contraction in output. Constrained banks cannot meet households' increased demand for liquid savings, and deposits only rise somewhat. With sticky prices, the real interest rate does not fall fast enough to clear the deposit market. Thus, the excess demand for deposits comes with a lower demand for consumption goods. As the supply of goods is demand-determined, household income falls, leading to an even larger contraction in consumption. Next to this, since banks cannot provide further loans to firms, not only does consumption contract, but aggregate investment and asset prices fall sharply as well. Falling household income and falling asset prices weaken households' demand for liquid savings, restoring the equilibrium. Both lower consumption and lower investment amplify the recession.

The current paper assigns a dual role for banks: they intermediate funds between households and firms, and they supply a liquid store of value to households. I analyze the different roles of the bank through two counterfactuals. First, I exogenously fix the supply of deposits and compare this to the response of the economy with a binding leverage constraint. Fixing the supply of deposits, on impact, consumption and output fall by 40 percent more. What is more, the larger contraction of consumption is not explained by a deeper fall in investment: it falls just as much in both cases. This suggests that the limited supply of deposits is central for the larger contraction in consumption.

A second counterfactual quantifies the role of liquidity provision through looking at unconventional monetary policy. In the scenario of a binding leverage constraint, the monetary authority purchases assets from banks. In doing so, it relaxes their leverage constraint. This stimulates bank lending and investment. The effect on the supply of deposits depends on how the policy is financed, however. I consider two financing schemes. In a first one, the central bank purchases banks' assets in exchange for reserves. This is just a swap of assets, from one asset counting towards the leverage constraint against another not counting. Hence, new lending is financed by issuing deposits. This raises the supply of liquid assets. In the second financing scheme, central bank asset purchases are financed through lump-sum taxes on banks' shareholders. In this case, banks finance new loans with the funds obtained from selling assets to the central bank. Now, the monetary intervention has no direct effect on the supply of liquid assets. A reserves-financed policy stimulates lending, raises the supply of liquid assets, and entirely eliminates the amplification arising from a binding leverage constraint. A tax-financed policy stimulates investment, too. However, it barely expands the supply of deposits. Without liquidity provision, the effectiveness of the policy is cut in half for output and consumption. Therefore, a muted creation of liquid assets can explain half of the amplification when the leverage constraint binds. This shows that banking frictions not only matter because they constrain lending, but also because they restrict the supply of liquid assets to households.

The model also has implications for inequality. I document that, in the model, the distributional consequences of a shift in the desired liquidity of household portfolios are shaped by the state of the financial system, too. Upon a rise in household income risk, wealth inequality rises in tight financial conditions, whereas it falls when conditions are loose. This is surprising since the desired shift in the portfolio allocation sharply reduces the price of capital in tight financial conditions. This tends to hurt wealth-rich households more, who – as in the data – have more illiquid portfolios. At the same time, the sharp fall in incomes means that it is the wealth-poor who – in spite of the increase in risk – reduce their savings and end up holding fewer deposits and less wealth. In contrast, when banks are unconstrained, meaning that the recession is mild, the wealth-poor exhibit the strongest build-up of precautionary savings, compressing the wealth distribution.

Related literature

In studying the role of banks' liquidity provision to the household sector I contribute to several strands of the literature. First, my work relates to a strand of literature that views portfolio choice, and supply and demand of assets with different liquidity characteristics as key to studying business cycle fluctuations. That a shift in the desired liquidity of household portfolios can be recessionary has been documented in Den Haan et al. (2017) and Bayer et al. (2019). My contribution is twofold. I provide empirical evidence that the state of the financial system affects the transmission of such shocks. And I explicitly model the supply of liquid assets to the household sector as being provided by banks. This gives a novel perspective on the importance of the funding of banks.[5]

Second, my paper relates to the literature that studies the macroeconomic consequences of financial frictions. I share with Bernanke et al. (1999), Kiyotaki and Moore (1997), and, in particular, Gertler and Karadi (2011) the central idea that financial frictions can amplify aggregate shocks. My modeling builds on this literature. What I add is a shift of emphasis: from the asset side of banks (loans to firms) to the role of the funding side (creating liquid assets for households). The focus on liquidity transformation relates my paper to Brunnermeier and Sannikov (2016). Where I focus on households and labor-income uncertainty, they model idiosyncratic investment risk. The focus on liquidity provision and financial frictions relates my work to Kiyotaki and Moore (2019) and Del Negro et al. (2017). Liquid savings in my model are endogenously created, and affected by banking frictions. Finally, I share with Diamond and Dybvig (1983) the view

[5] Other papers investigating the propagation of idiosyncratic income risk directly abstract from aggregate savings, e.g. Ravn and Sterk (2017), Challe (2020). Or, like Gornemann et al. (2021), they model aggregate savings in a one-asset model where all capital is liquid.

that banks perform liquidity transformation. I abstract from bank runs. I focus, instead, on the aggregate equilibrium consequences of limited liquidity provision to households.

Third, my paper relates to a literature that looks at uncertainty as a driver of the business cycle. For the firm sector, the literature has discussed real options channels (Bloom, 2009) and financial frictions (Gilchrist and Zakrajšek, 2012, Gilchrist et al., 2014). Basu and Bundick (2017) also show that rigid prices can amplify shocks to aggregate risk even in complete-market settings. In my paper, aggregate uncertainty remains constant. The recession arises from an exogenous shift in idiosyncratic risk. I see this shift as a primitive, different from other work in the HANK literature, for example, Challe (2020), Den Haan et al. (2017), Gornemann et al. (2021), McKay and Reis (2021), and Ravn and Sterk (2017). That is, I abstract from uncertainty feedback loops. This is in line with evidence presented by Bayer et al. (2020) that the uncertainty of persistent income changes appears to be an exogenous driver of portfolio choices and the business cycle.

Several other exciting papers have recently incorporated financial frictions into models with heterogeneous households. In all of these, to my knowledge, the focus differs from my work. Fernández-Villaverde et al. (2019), using a global solution method, study the non-linear interaction between the wealth distribution and leverage over the business cycle in a one-asset model with heterogeneous agents. They show that this gives rise to aggregate risk. Lee et al. (2020) build a one-asset New Keynesian model with heterogeneous agents and financial intermediaries. They focus on the consequences of a countercyclical spread on consumer loans. Instead, I emphasize the role of the supply of a liquid vehicle for household saving. Bigio and Sannikov (2021) build a heterogeneous agents economy with financial frictions in the interbank market. I explore the link between deposit creation for households and shocks to idiosyncratic risk on the household side. Closely related, too, is Lee (2021) who studies the distributional effect of quantitative easing in a two-asset HANK model with banks and equilibrium unemployment. What I add to this work, is a focus on banks as the main providers of liquidity to households, presenting empirical evidence that appears to support the importance of the channel that I study.

Finally, this paper also contributes to an active empirical literature that explores the state-dependent effects of aggregate shocks and policies. The literature has investigated the state-dependent effects of fiscal policy (e.g. Ramey and Zubairy 2018, Auerbach and Gorodnichenko 2012) and monetary policy (Tenreyro and Thwaites, 2016), for example. To the best of my knowledge, my paper is the first to document how changes in household income uncertainty depend on financial conditions.

The remainder of the paper is organized as follows. Section 2 provides the empirical evidence. Section 3 lays out the model environment. Section 4 discusses the numerical implementation and calibration. Section 5 provides the model-based results. It discusses the transmission of a shock to income risk and the role of liquidity creation, policy counterfactuals, and inequality consequences. A final section concludes. The appendix provides additional results and robustness checks.

2 Empirical Evidence

The banking sector, through deposits, is the main provider of liquid assets to households. The current paper emphasizes that banking frictions not only hamper credit supply to firms but also impair liquidity provision to households. In order to see the empirical relevance of this mechanism most clearly, this section documents the transmission of a shock that affects households' demand for liquid assets. Namely, I document how an increase in idiosyncratic labor income risk affects banks' deposit creation and aggregate activity, and how that effect in turn depends on the state of the financial sector. I first describe the data, then the baseline empirical specification, and finally, the main empirical results.

2.1 Data

Times of increased idiosyncratic income risk should be times of high demand for liquid assets. Labor income being the main source of income for working-age households, I focus on labor income risk.

I rely on the measure of household income risk shocks identified in Bayer et al. (2019); and available from 1983 until 2013. These authors extend the procedure of Storesletten et al. (2004) to estimate a time series of shocks to the variance of the persistent component of after-tax household labor income. In particular, they first specify an income process consisting of a transitory component, a household-fixed, a deterministic and a persistent component with time-varying variance. Then, they estimate this income process using panel data from the U.S. Survey of Income and Program Participation (SIPP). Changes in the dispersion of residual income across cohorts over time allow them to estimate a time series for the variance of the persistent component of income (income risk) and a time series of the shocks to this variance (income risk shocks). Figure A.1 in appendix A.1 displays the estimated time series of household income uncertainty and the shocks to household income uncertainty.

Therefore, my measure of shocks to household income risk consists of the innovations to the variance of the persistent component of household income. Thus, I focus on swings in uncertainty about long-term household income, rather than on uncertainty about short-term household income fluctuations. This means that these shocks are less likely to be contaminated by aggregate fluctuations that only induce changes in household income at business cycle frequency. This point receives further empirical support by the results of Bayer et al. (2020). These authors, extending the procedure of Bayer et al. (2019), allow idiosyncratic household income uncertainty to respond endogenously to fluctuations in aggregate output in an estimated quantitative heterogeneous agents model. They find the estimated feedback of aggregate activity to idiosyncratic household income risk to be negligible. Still, in the next subsection, I present further robustness checks addressing potential concerns regarding the exogeneity of shocks.

Following Adrian et al. (2019), I use the National Financial Conditions Index (NFCI) constructed by the Federal Reserve Bank of Chicago to measure the state of the financial system.[6] The NFCI provides a weekly estimate of financial conditions of the U.S. in money markets, debt and equity markets, and the traditional and shadow banking systems. The index is a weighted average of several measures of financial activity, grouped into a leverage subindex, a risk subindex, and a credit subindex. Although the NFCI starts in 1971, I only use the sample period between 1983 and 2013, the period for which the household income risk shocks are available. I aggregate these weekly estimates to quarterly frequency by averaging over the quarter. I define financial conditions to be tight when the NFCI takes value above its average over the sample period and to be loose otherwise. Figure A.2 in appendix A.1 provides the resulting time series for the quarterly NFCI.

The rest of the aggregate data used in the analysis consist of quarterly U.S. time series from 1983 to 2016, retrieved from FRED, Federal Reserve Bank of St. Louis. In particular, my measure of households' liquid savings consists of total currency and deposits held by the household sector.[7] As of credit, I employ total bank credit from all commercial banks.[8] I use the log of real aggregate output, consumption, investment, and the unemployment rate to assess the effects of income risk on aggregate activity. Finally, I employ the 3-Month Treasury Bill as a measure of the nominal interest rate. See appendix A.1 for further details.

2.2 Empirical Response to Household Income Risk Shocks

I compute the responses of macroeconomic aggregates to household income risk shocks by means of state-dependent local projections (Jordà, 2005). Local projections provide a flexible alternative to structural vector autoregressions, allowing for a direct estimation of impulse response functions without imposing dynamic restrictions. Furthermore, local projections can be easily extended to study state-dependent responses, rendering them well-suited for my analysis. More precisely, I distinguish between two states, tight financial conditions ("FT") and loose financial conditions ("FNT"). I entertain the following state-dependent specification,

[6] An advantage of the NFCI over other measures is that it offers a wide coverage of the financial sector, including commercial banks that are the main suppliers of households' deposits.

[7] The original source of this data series is the Flow of Funds (FoF). Therefore, the household sector, which is computed as a residual in the FoF, includes nonprofit organizations serving households as well.

[8] In the model presented later, credit will be only provided to firms. In the US, small firms are the most reliant on bank credit, that may finance themselves through the personal collateral of the firm-owner (e.g., Abdulsaleh and Worthington 2013, Petersen and Rajan 1994). This makes it difficult to distinguish in the data between a loan to a firm and a loan to a household that is used for firm investment.

$$
\begin{aligned}
y_{t+l} = & \mathbb{I}_{t-1}^{FT}\left[\alpha_{FT,l} + \phi_{FT,l}(L)\mathbf{x}_t + \beta_{FT,l}\frac{\varepsilon_t^s}{\sigma_s}\right] \\
& + (1-\mathbb{I}_{t-1}^{FT})\left[\alpha_{FNT,l} + \phi_{FNT,l}(L)\mathbf{x}_t + \beta_{FNT,l}\frac{\varepsilon_t^s}{\sigma_s}\right] + \gamma_l \text{trend}_t + \nu_{t+l}\ ,\ l \geq 0,
\end{aligned} \tag{1}
$$

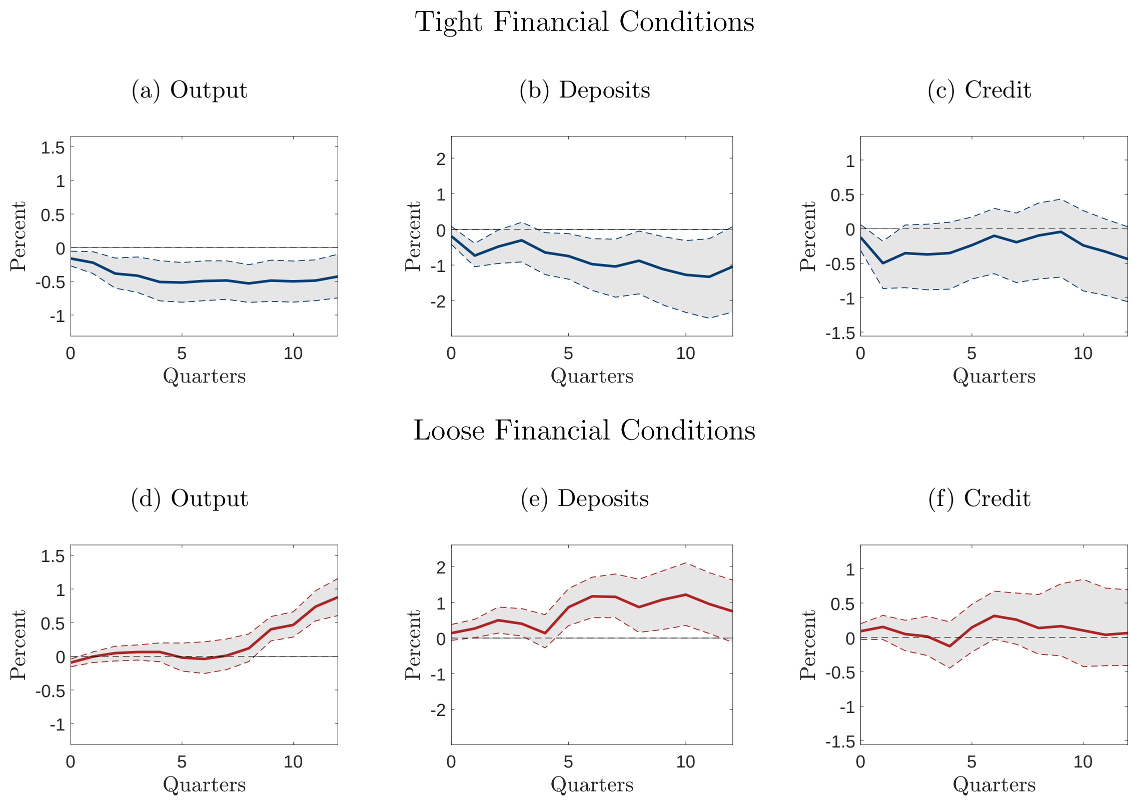
where y_{t+l} is the variable of interest, $\mathbf{x}_t$ is a set of controls, $\phi_{FT,l}(L)$ and $\phi_{FNT,l}(L)$ are lag operators and ε_t^s is the household income-risk shock normalized by its standard deviation σ_s. $trend_t$ is a linear trend and $\alpha_{FT,l}$ and $\alpha_{FNT,l}$ are constant terms. The variable $\mathbb{I}_{t-1}^{FT}$ is an indicator variable that takes value one if financial conditions are tight at $t-1$, as measured by the NFCI, before the shock hits. The coefficient $\beta_{FT,l}$ gives the response of the variable of interest y_{t+l}, at horizon l, to the household income-risk shock that occurs at time t when the state of the economy is characterized by tight financial conditions. Similarly, $\beta_{FNT,l}$ provides the response of y_{t+l} at horizon l when financial conditions are loose. The controls include one lag of household income uncertainty, the 3-Month Treasury Bill, the unemployment rate, the log of real output, and the lagged value of the variable of interest y.

Figure 1 shows the empirical response of output, deposits, and credit to a one standard-deviation shock to household income risk. The top panel shows the response of these variables when financial conditions are tight. The bottom panel shows the response during periods of loose financial conditions. Block bootstrapped 66% confidence bounds are shown in gray areas delimited by dashed lines. Appendix A.2 reports the response of further variables (consumption, investment, and unemployment) in Figure A.3 and the difference in the response between times of tight and loose financial conditions in Figure A.4.

Theory suggests that a shock to households' income risk induces them to reduce demand for goods as to build a buffer of precautionary savings. In particular, households may seek to accumulate more liquid savings as to self-insure against heightened income risk. Figure 1 shows that the effects on aggregate activity of such shock markedly depend on the state of the financial system, however. During times of tight financial conditions, the shock leads to a recession. Output persistently falls by around 0.5% (panel a). In contrast, the contractionary effects of the shock are muted if financial conditions are tight. In this case, output barely falls and tends to increase after two years (panel d). Figure A.3 in the appendix further shows that aggregate consumption and investment display a similar state-dependent response. They fall notably if financial conditions are tight, while the response is muted during periods of benign financial conditions.

What is more, the aggregate response of liquid deposits to an increase in income uncertainty is notably shaped by the health of the financial sector, too. Loose financial conditions come with an ample expansion of liquid savings. In response to an income risk

Figure 1: Empirical Response to an Increase in Income Risk



Notes: Estimated responses to one standard-deviation shock to household income risk, as identified in Bayer et al. (2019). The top panel shows the empirical responses when financial conditions are tight as measured by the National Financial Condition Index (NFCI). The bottom panel shows the responses when financial conditions are loose. Block bootstrapped 66% confidence bounds are shown in gray areas delimited by dashed lines. Appendix A.2 reports the response of further variables in Figure A.3 and the difference in the response between times of tight and loose financial conditions in Figure A.4.

shock, liquid deposits persistently increase to around 1% (panel e). In marked contrast, and despite the increase in income risk, this expansion of liquid savings is absent during periods of tight financial conditions. Instead, deposits tend to fall (panel b). On the asset side of the financial system, credit falls during periods of tight financial conditions (panel c), while the response is muted if financial conditions are benign (panel f).

In sum, Figure 1 shows that the effects of a shock that induces households to increase their demand for liquid savings, an increase in income risk, crucially depend on the state of the financial sector. During periods of benign financial conditions, the creation of liquid savings by the financial system, in form of deposits, is ample, and the consequences on aggregate activity mild. On the contrary, the shock triggers a pronounced recession if financial conditions are tight, and the creation of liquid deposits is markedly muted. These empirical results, thus, are suggestive of the state of the banking system being fundamental in shaping how shocks to household income risk transmit to economic activity.

Appendix A.3 provides a series of robustness checks. As can be observed in the time series for the NFCI in Figure A.2, times of tight financial conditions sometimes coincide with economic slumps, the last financial crisis being a salient example of this. This may raise the concern that the state-dependent responses shown in Figure 1 are due to differences between expansions and recessions, and not to financial conditions. To address this issue, in appendix A.3.1, I extend my baseline specification (1) to control for the state of the business cycle, using the unemployment rate to determine expansions and recessions. Figure A.5 shows that results remain largely unchanged.

Second, the National Financial Conditions Index contains financial indicators for risk, credit, and leverage. However, in my model, financial conditions will be tightly linked to leverage in the financial sector. In appendix A.3.2 I use the leverage subindex of the NFCI as an indicator variable for financial conditions instead. I obtain similar results under this alternative specification, as shown in Figure A.7.

An important assumption in the baseline regression (1) is that the estimated shocks to household income risk identified in Bayer et al. (2019) are purely exogenous and orthogonal to other structural shocks ν_{t+l} in the economy. My baseline specification (1) can be understood as ordering income risk first in a Cholesky identified SVAR. As a robustness check, in appendix A.3.3 I take the opposite assumption and entertain a specification where only uncertainty itself responds contemporaneously to the income risk shock. Figure A.10 in the appendix shows that results remain robust.

3 Model

The empirical evidence presented in the previous section suggests that the state of the financial system is central for the aggregate consequences of a shock that shifts households' demand for liquid assets: a household income risk shock. I seek to explore next the channels behind these findings. Towards this end, I build a two-asset New Keynesian model with heterogeneous households (Kaplan et al., 2018, Bayer et al., 2019) and financial intermediaries that engage in liquidity transformation, subject to a potentially binding leverage constraint (Gertler and Karadi, 2011). While the literature typically focuses on the banks' role in financing firms, this paper focuses on their role in creating liquid savings for households.

More precisely, the model economy is composed of a household sector, a production sector, financial intermediaries, and a government. The production sector is comprised of a final good producer, capital goods producers, resellers that set prices subject to adjustment costs à la Rotemberg (1982), and intermediate good producers that use labor and capital as production inputs. Financial intermediaries use deposits issued to households and their own net worth to purchase financial claims on physical capital subject to a leverage constraint. Households consume, supply labor, and face time-varying idiosyncratic income risk, described in detail below. In order to self-insure, households can save in two assets: liquid bank deposits and financial claims on physical capital, that can only be traded infrequently.

Financial claims on physical capital are modeled following Gertler and Karadi (2011). In particular, non-financial firms in this economy will use labor and capital as production inputs. I assume that the entirety of firms' capital has to be financed through loans. These loans take the form of state-contingent claims on the earnings generated by capital. Therefore, they can be thought of as equity of the non-financial firm. Financial claims (or equity) can be purchased by both the household sector and financial intermediaries.

3.1 Households

The household sector builds on Bayer et al. (2019). I use small case letters to denote individual variables and capital letters to denote aggregate variables. There is a unit mass of ex-ante identical infinitely-lived households indexed by $i \in [0, 1]$. A household can be a worker or an entrepreneur. Both types of households consume and participate in asset markets, but only workers supply labor. Entrepreneurs, instead, receive a non-tradable share of aggregate profits.[9] Households randomly transition between being one of the two types.

3.1.1 Idiosyncratic Productivity and Labor Supply

Workers face time-varying idiosyncratic labor productivity $h_{i,t}$. As in Bayer et al. (2019), labor productivity follows a $AR(1)$ process in logs with time-varying variance and a constant transition probability between the worker and the entrepreneur state:

$$\tilde{h}_{i,t} = \begin{cases} \exp\left(\rho_h \log \tilde{h}_{i,t-1} + \varepsilon^h_{i,t}\right), & \text{with probability } 1-\zeta \text{ if } h_{i,t-1} \neq 0, \\ 1, & \text{with probability } \iota \text{ if } h_{i,t-1} = 0, \\ 0, & \text{else,} \end{cases} \tag{2}$$

with individual productivity $h_{i,t} = \frac{\tilde{h}_{i,t}}{\int_0^1 \tilde{h}_{i,t} di}$, such that average worker productivity remains constant. The shocks $\varepsilon^h_{i,t}$ to labor productivity are normally distributed with time-varying variance given by

$$\sigma^2_{h,t} = \bar{\sigma}^2_h \exp(s_t), \quad \bar{\sigma}_h > 0, \tag{3}$$

$$s_{t+1} = \rho_s s_t + \varepsilon^s_t, \quad |\rho_s| < 1, \tag{4}$$

$$\varepsilon^s_t \sim \mathcal{N}(-\frac{\sigma^2_s}{2(1+\rho_s)}, \sigma^2_s), \quad \sigma_s > 0. \tag{5}$$

[9]The introduction of an entrepreneur state is useful for two reasons. First, it solves the problem of the allocation of profits without distorting factor returns and without the computational complexity of introducing a third tradable asset. Second, the entrepreneurial state, as a high-income state, is a useful modeling device to match the wealth distribution, following the idea of Castaneda et al. (1998).

In words, a household that is a worker, $h \neq 0$, remains a worker next period with probability $1-\zeta$. With complementary probability, ζ, the household becomes an entrepreneur next period and has zero labor productivity, $h = 0$, but is compensated with a share of aggregate profits. A household that is currently an entrepreneur with zero productivity in the labor market returns to the workforce next period with median productivity with probability ι.

Households maximize the discounted sum of utility over consumption and leisure. In particular, they have time-separable Greenwood–Hercowitz–Huffman (GHH) preferences over consumption $c_{i,t}$ and leisure with time-discount factor β,

$$\mathbb{E}_0 \max_{\{c_{i,t}, n_{i,t}\}} \sum_{t=0}^{\infty} \beta^t u(c_{i,t} - G(n_{i,t}; h_{i,t})), \tag{6}$$

where $n_{i,t}$ denotes hours worked.[10] The felicity function u is of the constant-relative-risk-aversion (CRRA) type with risk aversion parameter $\xi > 0$,

$$u(x_{i,t}) = \frac{1}{1-\xi} x_{i,t}^{1-\xi}, \tag{7}$$

where $x_{i,t} = c_{i,t} - G(n_{i,t}; h_{i,t})$ is a composite good of consumption and leisure, with $G(n_{i,t}; h_{i,t})$ measuring the disutility from working. In the following, I assume $G(n_{i,t}; h_{i,t}) = h_{i,t} n_{i,t}^{1+\gamma}/1+\gamma$, with $\gamma > 0$.

The labor income of a household $h_{i,t} n_{i,t} w_t$ is the product of the wage rate w_t, hours worked $n_{i,t}$, and idiosyncratic productivity $h_{i,t}$. Given a tax rate τ, the labor supply first order condition is,

$$h_{i,t} n_{i,t}^{\gamma} = (1-\tau) w_t h_{i,t}, \tag{8}$$

so that all households supply the same amount of hours, $n_{i,t} = N(w_t)$. Consequently, the total amount of effective hours worked $\int h_{i,t} n_{i,t} di$ is also equal to $N(w_t)$ since $\int h_{i,t} di = 1$.

3.1.2 Consumption and Saving Decisions

Financial markets are incomplete, and households can only use two assets to self-insure. They can hold liquid deposits, $d_{i,t}$, issued by financial intermediaries, with real gross return R_t. As described previously, households can also purchase financial claims on physical capital, $k_{i,t}^h$, at price q_t. The dividends generated by these claims will be, in equilibrium, equal to the net returns on physical capital, denoted by r_t^k. While households can access their savings in deposits every period, financial claims are illiquid. More specifically, following Luetticke (2021), I assume that in any given period only a random

[10]The assumption of GHH preferences together with the functional form assumed for $G(n_{i,t}; h_{i,t})$ simplifies the numerical analysis substantially, since it will imply that all households work the same number of hours.

fraction $\nu \in (0,1)$ of households is allowed to trade these assets. Households that are allowed to participate in the market for claims on capital face the following budget and non-borrowing constraints:

$$
\begin{aligned}
c_{i,t} + q_t k^h_{i,t+1} + d_{i,t+1} &= (q_t + r^k_t) k^h_{i,t} + R_t d_{i,t} + (1-\tau)(w_t n_{i,t} h_{i,t} + \mathbb{1}_{h_{i,t}=0} \Xi_t), \\
k^h_{i,t+1} \geq 0, &\quad d_{i,t+1} \geq 0,
\end{aligned} \tag{9}
$$

where $\mathbb{1}_{h_{i,t}=0}$ is an indicator function that takes value one if the household is an entrepreneur and Ξ_t marks aggregate profits. Further note that households are not allowed to hold negative amounts of any of the two assets.[11] The real interest rate paid on deposits in period t is linked to the nominal interest rate $1 + i_t$, set by the central bank in $t-1$, and inflation, $1 + \pi_t$, through the Fisher equation:

$$
R_t = \frac{1 + i_t}{1 + \pi_t}. \tag{10}
$$

The fraction $1 - \nu$ of households that cannot trade the illiquid asset at period t can access its liquid deposits and receive the dividends generated by their claims on physical capital. The budget constraint of these households simplifies to:

$$
\begin{aligned}
c_{i,t} + d_{i,t+1} &= r^k_t k^h_{i,t} + R_t d_{i,t} + (1-\tau)(w_t n_{i,t} h_{i,t} + \mathbb{1}_{h_{i,t}=0} \Xi_t), \\
d_{i,t+1} &\geq 0.
\end{aligned} \tag{11}
$$

The optimal consumption and saving choices of a household depend on its idiosyncratic states (d, k^h, h). As a consequence, aggregate prices will be a function of the joint distribution Θ_t over these idiosyncratic states at period t. This renders Θ_t a state variable of the household problem that will fluctuate in response to aggregate shocks. The programming problem of a household is characterized by the following two Bellman equations, for the case of households who cannot and can adjust their holdings of capital claims:

$$
\begin{aligned}
V^n_t(d, k^h, h) = \max_{d'_n} u \left[x \left(d, d'_n, k^h, k^h, h \right) \right] &+ \beta \mathbb{E}_t \left[\nu V^a_{t+1} \left(d'_n, k^h, h' \right) \right. \\
&\left. + (1-\nu) V^n_{t+1} \left(d'_n, k^h, h' \right) \right],
\end{aligned} \tag{12}
$$

$$
\begin{aligned}
V^a_t(d, k^h, h) = \max_{d'_a, k^{h'}} u \left[x \left(d, d'_a, k^h, k^{h'}, h \right) \right] &+ \beta \mathbb{E}_t \left[\nu V^a_{t+1} \left(d'_a, k^{h'}, h' \right) \right. \\
&\left. + (1-\nu) V^n_{t+1} \left(d'_a, k^{h'}, h' \right) \right],
\end{aligned} \tag{13}
$$

where time subscripts summarize the dependence on aggregate states, including the joint

[11] For a model that allows for consumer loans see Lee et al. (2020).

distribution Θ_t. I denote by $d^*_{a,t}$ and $d^*_{n,t}$ the optimal savings policy in liquid deposits for adjusters and non-adjusters, respectively. Accordingly, $k^{h*}_{a,t}$ denotes the optimal savings policy for claims on capital for adjusters, and $k^{h*}_{n,t} = k$ for non-adjusters. These policies depend on the current idiosyncratic and aggregate states of the economy – including the joint distribution $\Theta_t(d, k^h, h)$ – as well as on current and future prices, summarized through expected continuation values $\left\{V^n_{t+1}, V^a_{t+1}\right\}$. Therefore, the aggregate amount of capital claims purchased by the household sector, K^h_{t+1}, is given by:

$$K^h_{t+1} = \mathbb{E}_t \left[\nu k^{h*}_{a,t} + (1-\nu) k^{h*}_{n,t}\right] \tag{14}$$

3.2 Financial Intermediaries

Financial intermediaries are the main providers of liquid savings to households. Thus, banks play a central role in this economy: they perform liquidity transformation, supplying the liquid deposits that households demand to self-insure against swings in labor income uncertainty. Through the balance sheet of banks, the supply of these assets will depend on the lending capacity of the financial sector. The financial system is modeled following Gertler and Karadi (2011), but with an emphasis on banks' ability to provide a liquid store of value.

3.2.1 Bank Problem

There is a continuum of ex-ante identical financial intermediaries (or banks) of measure one. I use small-case letters to denote individual bank variables. Financial intermediaries use short-term deposits issued to households, d_t, and their own net worth, e_t, to finance their purchases of financial claims on capital, k^b_t. Due to financial market frictions described in detail below, banks may be constrained in the amount of assets that they can purchase.

The objective of the bank is to maximize the expected discounted profits from intermediating funds. At the beginning of the period a measure $(1-\sigma)/\sigma$ of banks enters the industry, where $\sigma \in (0, 1)$. All banks are then hit by an idiosyncratic random shock, indicating whether the bank should close down. With probability $1-\sigma$ the bank is forced to exit and pay back all its accumulated net worth, e_t, to its shareholders – the entrepreneurs – as dividends. With complementary probability the bank continues to operate. New entrants start with equity ω_t, that they receive from shareholders. By means of entry, the measure of operating banks always equals 1.[12]

Banks perform liquidity transformation. In particular, and contrary to households, financial intermediaries can trade financial claims on capital every period. I assume,

[12]This device is commonly used in the literature to ensure that banks do not accumulate enough net worth to render the leverage constraint described below irrelevant.

however, that they face a linear utility cost ς for each financial claim that they trade. [13] Therefore, the franchise value of a surviving bank V_t^b is given by:

$$V_t^b = \mathbb{E}_t \Lambda_{t,t+1} \left[(1-\sigma) e_{t+1} + \sigma V_{t+1}^b \right] - \varsigma q_t k_{t+1}^b, \tag{15}$$

where $\Lambda_{t,t+1}$ is the discount factor of a bank, and e_{t+1} is the net worth that an exiting bank pays as dividends. I assume that $\Lambda_{t,t+1} = 1/R_{t+1}$. [14] At each period t the bank faces the following balance sheet constraint:

$$q_t k_{t+1}^b = e_t + d_{t+1}. \tag{16}$$

The left-hand side of (16) gives the volume of loans that the bank provides to firms, k_{t+1}^b being the claims on physical capital purchased by the bank at time t. The right-hand side shows that loans have to be financed through net worth or by issuing deposits to the household sector. The net worth of a bank born in period t is simply given by its start-up transfer $e_t = \omega_t$. Due to frictions left unmodeled, banks cannot issue new outside equity. They accumulate net worth through retained earnings. Hence, the net worth of a surviving bank in period $t+1$ is given by the market value of the assets intermediated in the previous period, $q_{t+1} k_{t+1}^b$, plus the dividends they receive on them, $r_{t+1}^k k_{t+1}^b$, net of the funding costs from deposits, $R_{t+1} d_{t+1}$:

$$e_{t+1} = (q_{t+1} + r_{t+1}^k) k_{t+1}^b - R_{t+1} d_{t+1}. \tag{17}$$

Banks further face a leverage constraint that constrains its franchise value, V_t^b, to not be lower than a fraction θ of the market value of its holdings of capital claims, $q_t k_{t+1}^b$:

$$\theta q_t k_{t+1}^b \leq V_t^b. \tag{18}$$

The leverage constraint (18) sets an upper bound on the amount of credit that banks can offer. What is more, through its balance sheet (16), the leverage constraint also influences the amount of liquid deposits that the financial system can supply to households. Therefore, as explained in more detail below, financial frictions not only impair lending, but also limit the expansion of the funding side of banks' balance sheets.

The above constraint can be motivated by the following moral hazard problem. Suppose that each period a bank can decide to divert a fraction θ of its holdings of capital claims. If it decides to divert assets, depositors force the bank to declare bankruptcy, and hence the financial intermediary loses its franchise value V_t^b. Under this setup, house-

[13] This utility cost can be motivated as a monitoring or origination cost for each loan that the bank provides. In my baseline calibration, this cost will be set to zero. However, it will be useful to make sure that all the experiments that I consider share the same steady state.

[14] I have entertained different specifications for the discount factor $\Lambda_{t,t+1}$. Results remain robust.

holds will only be willing to lend to banks when these do not have incentives to declare bankruptcy, effectively implying that the franchise value of the bank cannot be lower than the amount of assets that can be diverted.

To derive a solution for the bank problem it useful to use equations (16) and (17) to derive the evolution of net worth of a continuing bank:

$$e_{t+1} = [(R^k_{t+1} - R_{t+1})\psi_t + R_{t+1}]e_t, \tag{19}$$
$$\psi_t = \frac{q_t k^b_{t+1}}{e_t},$$
$$R^k_{t+1} = \frac{q_{t+1} + r^k_{t+1}}{q_t},$$

where ψ_t denotes the leverage ratio and R^k_{t+1} the gross return on claims on capital holdings. Using (19) we can write the franchise value of the bank (15) as:

$$V^b_t = (\mu^b_t \psi_t + \eta^b_t)e_t, \tag{20}$$

where

$$\mu^b_t = \mathbb{E}_t[\Lambda^b_{t,t+1}(R^k_{t+1} - R_{t+1}) - \varsigma], \tag{21}$$
$$\eta^b_t = \mathbb{E}_t \Lambda^b_{t,t+1} R_{t+1}, \tag{22}$$
$$\Lambda^b_{t,t+1} = \Lambda_{t,t+1}(1 - \sigma + \sigma\varphi^b_{t+1}), \tag{23}$$
$$\varphi^b_t \equiv \frac{V^b_t}{e_t}. \tag{24}$$

The variable μ^b_t is the expected discounted excess return on banks' assets relative to deposits, net of intermediation utility costs ς, and η^b_t is the expected discounted cost of a unit of deposits. Intuitively, the marginal value of an extra unit of net worth to the bank, φ^b_t, will be higher when spreads or the return on deposits is high. In this situation, an additional unit of net worth would allow the bank to increase loans taking advantage of higher returns without relying on deposits.

Under the previous notation, the problem of a bank is to choose leverage, ψ_t, to solve:

$$\varphi^b_t = \max_{\psi_t}(\mu^b_t \psi_t + \eta^b_t), \tag{25}$$

subject to the leverage constraint

$$\theta\psi_t \leq \mu^b_t \psi_t + \eta^b_t. \tag{26}$$

Note that since the bank problem, (25) and (26), is linear in leverage, all banks, in equilibrium, will choose the same leverage ratio ψ_t. Consequently, financial intermediaries can be aggregated into a single representative bank. Summing across individual banks, we have that the aggregate value of capital claims held by the financial sector, $q_t K^b_{t+1}$, is related to aggregate net worth, E_t, according to,

$$q_t K^b_{t+1} = \psi_t E_t. \tag{27}$$

The evolution of aggregate net worth E_t is given by the sum of retaining earnings from surviving banks plus the start-up funds of new born banks, ω_t. I assume that start-up funds are given by a constant fraction of the current value of assets intermediated in the previous period $\omega_t = \frac{\bar{\omega}}{1-\sigma} q_t K^b_t$.[15] As a result, the evolution of aggregate net worth of banks is given by:

$$E_{t+1} = \sigma[(R^k_{t+1} - R_{t+1})\psi_t + R_{t+1}]E_t + \bar{\omega} q_{t+1} K^b_{t+1}. \tag{28}$$

3.2.2 Solution to the Bank Problem and Mechanisms

This paper focuses on how financial frictions on banks impair liquidity provision, and how this affects aggregate activity. This section provides intuition for why this is the case. Towards this end, I start by characterizing the solution to the bank problem. The solution to the bank problem, (25) and (26), is characterized by the following first-order condition and the complementary slackness condition:

$$\mathbb{E}_t \Lambda^b_{t,t+1}(R^k_{t+1} - R_{t+1}) = \varsigma + \lambda_t \theta, \tag{29}$$

$$\lambda_t(\theta\psi_t - \mu^b_t \psi_t - \eta^b_t) = 0, \tag{30}$$

where λ_t denotes the lagrange multiplier on the leverage constraint (26).

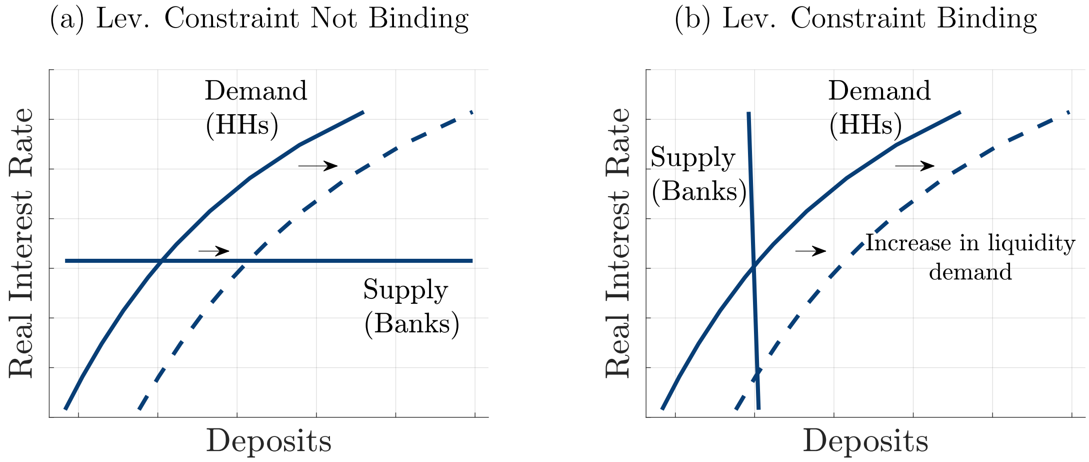
The economy can be in two different regimes. A first one, where the financial system is unconstrained, is characterized by a non-binding leverage constraint ($\lambda_t = 0$); and a second one, where the leverage constraint is binding ($\lambda_t > 0$) and the financial system is impaired. In the former case, banks are on their Euler equation (29), implying that the expected excess return on capital claims over deposits will be constant up to first order, leading to an elastic supply of liquid deposits from the financial sector.

A constrained financial system, $\lambda_t > 0$, makes the supply of bank deposits less elastic. More precisely, we can impose a binding leverage constraint (18), and combine it with the balance sheet of a bank (16) and equation (24), to obtain the supply of liquid deposits from the financial system:

$$d_{t+1} = \frac{\mathbb{E}_t \Lambda^b_{t,t+1} R^k_{t+1} - \theta - \varsigma}{\theta - \mathbb{E}_t[\Lambda^b_{t,t+1}(R^k_{t+1} - R_{t+1}) - \varsigma]} e_t. \tag{31}$$

[15]This formulation of the start-up transfer, ω_t, is common in the literature, see Gertler and Karadi (2011) or Bocola (2016).

Figure 2: Demand and Supply for Liquid Deposits



Notes: Equilibrium in the deposit market. Right panel: the downward-sloping curve represents the supply of liquid deposits from banks when the leverage constraint binds, equation (31), after aggregating across banks. Left panel: the horizontal line represents the supply of liquid deposits from banks when the leverage constraint does not bind, equation (29) with $\lambda_t = 0$. In both panels the upward-sloping solid curve represents households' demand for liquid deposits. The dashed upward-sloping curve in both panels represents an increase in households' demand for liquid deposits.

When the financial system is constrained, according to (31), an increase in the supply of liquid deposits must come with either a fall in the expected real interest rate, R_{t+1}, or an increase in the expected return on capital claims, R^k_{t+1}. A fall in the interest rate on deposits, or an increase in the return on capital, increases banks' margins. As a consequence, net worth and the franchise value of the bank increase. This relaxes the leverage constraint (26), allowing the bank to increase lending and, in the process, issue deposits to households, performing liquidity transformation.

The central observation of this paper is that financial frictions are crucial to determine equilibrium households' liquid savings. In order to show this more clearly, Figure 2 displays the equilibrium in the deposit market schematically. The left panel shows the case when the leverage constraint does not bind. The right panel the case when it binds. Each panel shows the demand and supply of deposits on the horizontal axis and the real interest rate on the vertical axis.

Focus first on the case in which the leverage constraint is not binding (panel a). In this situation, banks are only constrained by their balance sheet. Hence, they can freely issue more deposits to lever up and increase lending. This means that banks' supply of liquid assets is fairly elastic. Suppose that the demand for deposits rises, shifting the demand schedule to the right, see the dashed line in panel (a). Such an increase could, for example, be caused by an increase in idiosyncratic income risk. An unconstrained financial system is able to meet this increase in demand for deposits. Thus, there is an ample creation of liquid savings in equilibrium with small movements in the interest rate.

If the financial system is impaired (panel b), the supply of deposits is downward-sloping and inelastic: banks can only issue more deposits if the real interest rate falls sufficiently to reduce funding costs, increase net worth, and hence relax the leverage constraint (18). In this scenario, the financial system is not able to meet the increase in households' demand for liquid savings (dashed line, panel b). Instead, the interest rate on deposits falls markedly. A lower real interest rate reduces households' demand for liquid savings, restoring equilibrium. Therefore, the creation of liquid savings is muted with a constrained financial system: financial frictions impair the provision of liquid assets from the banking sector to households.

As we shall see in the quantitative results in section 5, the limited expansion in the supply of liquid deposits feeds back into aggregate activity. With sticky prices, the adjustment in the real interest rate observed in panel (b) will be sluggish. In such a situation, the excess demand of liquid savings will be mirrored by a lack of demand for consumption goods. With the aggregate supply of goods being demand-determined, aggregate activity and household income will fall, amplifying the contraction in consumption and output.

3.3 Final Good Producer

Final good producers are perfectly competitive and use differentiated goods as inputs. The final good can be used for both consumption and investment. The problem of the representative final good producer is:

$$\max_{Y_t, y_{j,t} \in [0,1]} P_t Y_t - \int_0^1 p_{j,t} y_{j,t} dj \tag{32}$$
$$\text{s.t.} \quad Y_t = \left(\int_0^1 y_{j,t}^{\frac{\eta-1}{\eta}} dj \right)^{\frac{\eta}{\eta-1}},$$

where $y_{j,t}$ is the quantity of the differentiated good j demanded. The first-order conditions of the final good producer deliver the following demand for differentiated goods:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\eta} Y_t. \tag{33}$$

The zero-profit condition implies that the price of the final good is given by $P_t = \left(\int_0^1 p_{j,t}^{1-\eta} dj \right)^{\frac{1}{1-\eta}}$.

3.4 Intermediate Goods Producers

Intermediate goods are produced with a constant returns to scale production function, using labor, hired in a competitive market, and capital as inputs:

$$Y_t = A_t N_t^{\alpha} K_t^{(1-\alpha)}, \tag{34}$$

where A_t is total factor productivity (TFP). It follows a first-order autoregressive process in logs:

$$logA_t = \rho_A logA_{t-1} + \varepsilon_t^A, \quad \varepsilon_t^A \sim \mathcal{N}(0, \sigma_A^2). \tag{35}$$

Let MC_t be the relative price at which the intermediate good is sold to resellers. The first-order condition with respect to labor implies,

$$w_t = \alpha A_t MC_t \left(\frac{K_t}{N_t}\right)^{1-\alpha}. \tag{36}$$

As noted previously, intermediate good producers have to finance the purchases of capital through state-contingent claims on the earnings generated by this asset. These can be thought of as equity of these firms. In particular, the firm issues claims on capital (equity) to households and banks at price q_t. Then, it uses these funds to buy capital from the capital good producer. Using (36), we can express the profit per unit of capital, r_t^k, as,

$$r_t^k = \frac{Y_t - w_t N_t - \delta}{K_t} = (1-\alpha) A_t MC_t \left(\frac{N_t}{K_t}\right)^{\alpha} - \delta, \tag{37}$$

where δ is the depreciation rate of capital. As it will be clear below, repairing depreciated capital stock is not subject to adjustment costs, and therefore its price is unity. Through perfect competition, the price of new capital goods will also be equal to q_t, and therefore the intermediate good producer makes zero profits state by state.

3.5 Resellers

Resellers differentiate intermediate goods and set prices, subject to quadratic adjustment costs à la Rotemberg (1982). Price setting is delegated to a measure zero of managers, that are compensated with a share of profits. As with financial intermediaries, I assume that the discount factor of managers, and therefore firms, is equal to the inverse of the real interest rate $\Lambda_{t,t+1} = 1/R_{t+1}$. [16] Managers set prices taking as given the demand for good j (33), i.e., they maximize,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \left(\frac{1}{R_{t+1}}\right)^t Y_t \left\{ \left(\frac{p_{j,t}}{P_t} - MC_t\right) \left(\frac{p_{j,t}}{P_t}\right)^{-\eta} - \frac{\eta}{2\kappa} \left(\log \frac{p_{j,t}}{p_{j,t-1}}\right)^2 \right\}. \tag{38}$$

The first-order condition yields the Phillips curve:

$$\log(1+\pi_t) = \kappa \left(MC_t - \frac{\eta - 1}{\eta}\right) + \mathbb{E}_t \frac{1}{R_{t+1}} \left[\log(1+\pi_{t+1}) \frac{Y_{t+1}}{Y_t}\right]. \tag{39}$$

[16] As a robustness check, I have entertained different specifications for the discount factor. Results remain robust.

Additionally, managers obtain profits from adjusting the aggregate capital stock subject to adjustment costs:

$$K_{t+1} = K_t + I_t - \frac{\phi}{2}\left(\frac{K_{t+1} - K_t}{K_t}\right)^2 K_t, \tag{40}$$

where there I_t denotes net aggregate investment.[17]

Since there is perfect competition in the capital market, managers will adjust the capital stock until the following first-order condition holds:

$$q_t = 1 + \phi \frac{K_{t+1} - K_t}{K_t}. \tag{41}$$

As managers have measure zero in the economy, all profits from non-financial firms go to entrepreneurs.

3.6 Government

The government is composed of a fiscal authority and a central bank. The central bank sets the nominal interest rate paid on deposits according to the following Taylor rule:

$$\frac{1 + i_{t+1}}{1 + \bar{i}} = \left(\frac{1 + i_t}{1 + \bar{i}}\right)^{\rho_i} \left(\frac{1 + \pi_t}{1 + \bar{\pi}}\right)^{\theta_\pi (1 - \rho_i)}, \tag{42}$$

where ρ_i captures monetary policy inertia, θ_π determines the response of the central bank to inflationary pressures, $1 + \bar{i}$ is the steady-state gross nominal interest rate, and $1 + \bar{\pi}$ the gross inflation rate in steady state.

On the fiscal side, I abstract from government debt. This ensures that all liquid assets in the model are an endogenous result of the intermediation activity of banks. More in detail, the fiscal authority adjusts government expenditures G_t to balance the budget every period, where revenue comes proportional taxes on income: [18]

$$G_t = \tau(w_t N_t + \Xi_t). \tag{43}$$

3.7 Market Clearing

The labor market clears if the condition (36) holds. The market for deposits clears if the following equation holds:

$$D_{t+1} = \mathbb{E}_t \left[\nu d^*_{a,t} + (1 - \nu) d^*_{n,t}\right], \tag{44}$$

[17] Note that adjustment costs in (40) only apply to new capital created. Therefore, gross investment equals $I_t + \delta K_t$.

[18] In the appendix C I show that results remain robust to the alternative assumption where the government instead adjusts taxes.

where D_{t+1} denotes the aggregate supply of deposits from the financial system, and $d^*_{a,t}$ and $d^*_{n,t}$ denote the optimal demand of deposits from adjusters and non-adjusters, respectively. These policies depend on the idiosyncratic and aggregate states of the economy, as well as on current and future prices. Expectations in the right-hand side of (44) are taken with respect to the joint distribution $\Theta_t(d, k^h, h)$.

The market for capital claims clears if the aggregate claims on capital held by the household sector, K^h_t, and the financial sector, K^b_t, equals the aggregate stock of capital, K_t:

$$K_t = K^b_t + K^h_t. \tag{45}$$

The goods' market clears due to Walras' law if the markets for labor services, capital claims and deposits clear.

3.8 Equilibrium

A *sequential equilibrium with recursive planning* is a set of policy functions for households $\left\{d^*_{a,t}, d^*_{n,t}, k^{h*}_{a,t}, k^{h*}_{n,t}, x^*_{a,t}, x^*_{n,t}\right\}$ and banks $\left\{k^b_t, d_t\right\}$, a set of value functions for households $\{V^a_t, V^n_t\}$ and banks $\left\{V^b_t\right\}$, pricing functions $\left\{r^k_t, w_t, 1+i_t, \pi_t, \Xi_t\right\}$, aggregate capital and labor supply functions $\{K_t, N_t\}$, distributions Θ_t over individual asset holdings and productivity, and a perceived law of motion Γ, such that:

1. Given prices, households' and banks' policy and value functions solve their decision problems.

2. The labor, the final goods, the deposit, the capital claims and the intermediate good markets clear, i.e., (36), (39), (44), and (45) hold.

3. The actual law of motion and the perceived law of motion Γ coincide, that is, $\Theta_{t+1} = \Gamma(\Theta_t)$.

4 Numerical Implementation and Calibration

The dynamic problem of households, characterized by (12) and (13), and therefore the recursive equilibrium, are not computable because it involves the infinite-dimensional object Θ_t. Instead, I discretize the distribution Θ_t and represent it by its histogram, that is a finite-dimensional object. The household problem is solved using the endogenous grid method developed by Carroll (2006) and extended by Hintermaier and Koeniger (2010). The idiosyncratic productivity process is approximated by a Markov chain with 11 states. The time-varying probabilities of this Markov chain are obtained using the Tauchen (1986) method. I use 80 grid points for capital claims and deposits to solve the household problem.

The model is written such that the leverage constraint may be binding only occasionally. However, solving the model with heterogeneous agents, two assets, and an occasionally binding constraint is beyond the scope of the current paper. Instead, I entertain two distinct scenarios: one where the leverage constraint always binds and one where the leverage constraint never binds. Specifically, I solve the model by perturbation methods. I use first-order perturbation around the non-stochastic steady state of the model. I rely on the method proposed in Bayer and Luetticke (2020) to reduce the dimensionality of the problem. This method approximates the joint distribution Θ_t over idiosyncratic states with a distribution with time-varying marginals and a fixed copula. Moreover, the value functions of the household problem are approximated by sparse polynomials around their steady-state solutions.

4.1 Calibration

I calibrate the model to the US economy. All targets correspond to a data sample covering the period between 1983 and 2015. One period in the model is a quarter. As a baseline, the calibrated parameters imply that the leverage constraint is always binding in equilibrium. Table 1 contains the parameter values, where I use letters with bars to denote the steady-state variables.

4.1.1 Households

The relative risk aversion of households is set to $\xi = 4$ as in Kaplan and Violante (2014). The Frisch elasticity γ is set to 1, in line with the estimates of Chetty et al. (2011). The time discount factor $\beta = 0.97$ and the participation frequency $\nu = 0.13$ are jointly calibrated to match the ratio of aggregate capital to output and the ratio of liquid assets to aggregate output. I target a quarterly capital-to-output ratio of 11.4 following Bayer et al. (2019). Following Kaplan et al. (2018) and Bayer et al. (2019) I target a ratio of aggregate liquidity to aggregate quarterly output of 1.04. [19]

I set the quarterly long-run standard deviation of persistent shocks to idiosyncratic income, σ_h, to 0.06 and its persistence, ρ_h, to 0.98, as estimated in Bayer et al. (2019). The persistence of innovations to the variance of shocks and its quarterly autocorrelation is set to the estimated values from Bayer et al. (2019). These values are consistent with the estimated shocks to income uncertainty used in the empirical specification discussed section 2. The probability of dropping out of the entrepreneurial state, ι, is set to match

[19] Liquid assets are measured using the Survey of Consumer Finances and are composed of deposits in financial institutions (checking, saving, call, and money market accounts), government bonds, and corporate bonds net of revolving consumer credit. Deposits account for almost 89% of liquid assets (see Kaplan et al. 2018). As a robustness check, I have entertained an alternative calibration where liquid assets in the model were only matched to deposits. Results remain unaffected. Illiquid assets are equated to all capital goods in the NIPA tables, net of non-housing durable consumption goods (Bayer et al., 2019).

Table 1: Calibrated parameters.

Parameter	Description	Value	Target / Source
Households			
ξ	Risk aversion	4	Kaplan and Violante (2014)
ν	Adj. probability	0.13	$\bar{D}/\bar{Y} = 1.04$
β	Discount factor	0.97	$\bar{K}/\bar{Y} = 11.4$
γ	Inverse Frisch elasticity	1	Chetty et al. (2011)
ρ_h	Persistence productivity	0.98	Bayer et al. (2019)
σ_h	Std. shocks	0.06	Bayer et al. (2019)
ρ_s	Persistence innovations	0.84	Bayer et al. (2019)
σ_s	Std. shocks to variance	0.54	Bayer et al. (2019)
ι	Trans. prob. from E. to W.	1/16	Guvenen et al. (2014)
ζ	Trans. prob. from W. to E.	0.0005	Gini = 0.78
Non-Financial Intermediaries			
δ	Depreciation	1.35 %	NIPA
α	Labor share	0.7	Labor Income Share 66%
η	Elasticity substitution	20	Markup 5%
κ	Slope Philips curve	0.05	Calvo price duration 5 quarters
ϕ	Capital adj. costs	10	std(I)/std(Y) = 3
ρ_A	Persistence TFP	0.90	Standard value
σ_A	Std. TFP shocks	0.01	Standard value
Financial Intermediaries			
θ	Divertible assets	0.4	Binding Leverage Constraint
σ	Life bank	0.97	Gertler and Karadi (2011)
$\bar{\omega}$	Proportional startup transfer	0.002	Leverage of 4
ς	Utility cost intermediation	0	
Government			
ρ_i	Inertia Taylor Rule	0.8	Standard value
θ_π	Response to Inflation	1.25	Standard value
$1 + \bar{i}$	Nominal Rate	1.0091	$\bar{R}^k - \bar{R} = 100$ bps p.a.
$1 + \bar{\pi}$	Inflation	1	0% p.a.
τ	Tax Rate	0.27	$\bar{G}/\bar{Y} = 0.20$

Notes: Letters with bars capture steady-state variables. The main text provides further details.

the probability that a household falls out of the top 1% of the income distribution reported in Guvenen et al. (2014). The probability of entering the entrepreneurial state ζ is calibrated to match a Gini coefficient of total wealth of 0.78, a value corresponding to the average Gini coefficient in the Survey of Consumer Finances over the calibration period.

4.1.2 Financial Intermediaries

The bank survival probability σ is set to 0.97, as in Gertler and Karadi (2011). The proportional transfer to newborn banks $\bar{\omega}$ is set to match a steady-state leverage ratio of 4, as in Gertler and Karadi (2011). The fraction of divertible assets θ is set to 0.4, implying that the leverage constraint binds. The utility cost of intermediating assets ς is set to zero in my baseline.

4.1.3 Production

I set the labor share α to match a labor income share of 2/3. The slope of the Phillips curve κ implies a price duration of 5 quarters in a Calvo setting. The elasticity of substitution η is calibrated to match a steady-state markup of 5%, a common value in the literature. The adjustment cost of capital ϕ is calibrated to match a relative volatility of investment of 3 conditional on a TFP shock. The autocorrelation of TFP is set to $\rho_A = 0.9$, and the standard deviation of TFP shocks to $\sigma^A = 0.01$, standard values in the literature.

4.1.4 Government

I set the steady-state tax rate on income τ to match a government-spending-to-output ratio of 20%. The steady-state inflation rate is set to zero, and the real return on deposits is set to 3.6% per year to target an excess return of capital over liquid assets of 100 basis points, as in Gertler and Karadi (2011). The monetary policy inertia parameter ρ_i and the response to inflation θ_π are set to conventional values in the literature.

5 Results

The empirical findings of section 2 are suggestive of the state of the financial system being fundamental for the aggregate consequences of an income risk shock (and the consequent shift in the demand for liquid savings). I seek to understand next the role played by banks' endogenous liquidity provision to households, and how this is impaired by financial frictions, in driving these findings. Towards this end, I assess next the effects of an increase in labor income risk. This increase raises households' demand for liquid savings, shifting the desired liquidity of their portfolios. I first consider the baseline economy with banks and a binding leverage constraint. Then I contrast it with a counterfactual economy where the leverage constraint is not binding. This allows me to isolate how banking frictions impair liquidity transformation, and how this affects aggregate activity.[20]

5.1 The Aggregate Consequences of Liquidity Transformation

Figure 3 shows the impulse response functions to a one standard-deviation increase in household income risk. The shock itself is depicted in panel (a). Blue solid lines show

[20] I adjust the utility costs of bank asset intermediation, ς, to match the same steady-state excess return between capital and deposits as in my baseline. This ensures that the steady state of both economies is exactly the same.

the aggregate effects of this shock in the baseline economy where the leverage constraint of financial intermediaries is binding. Red dashed lines display the response to the same shock in the counterfactual economy where the leverage constraint does not bind.[21]

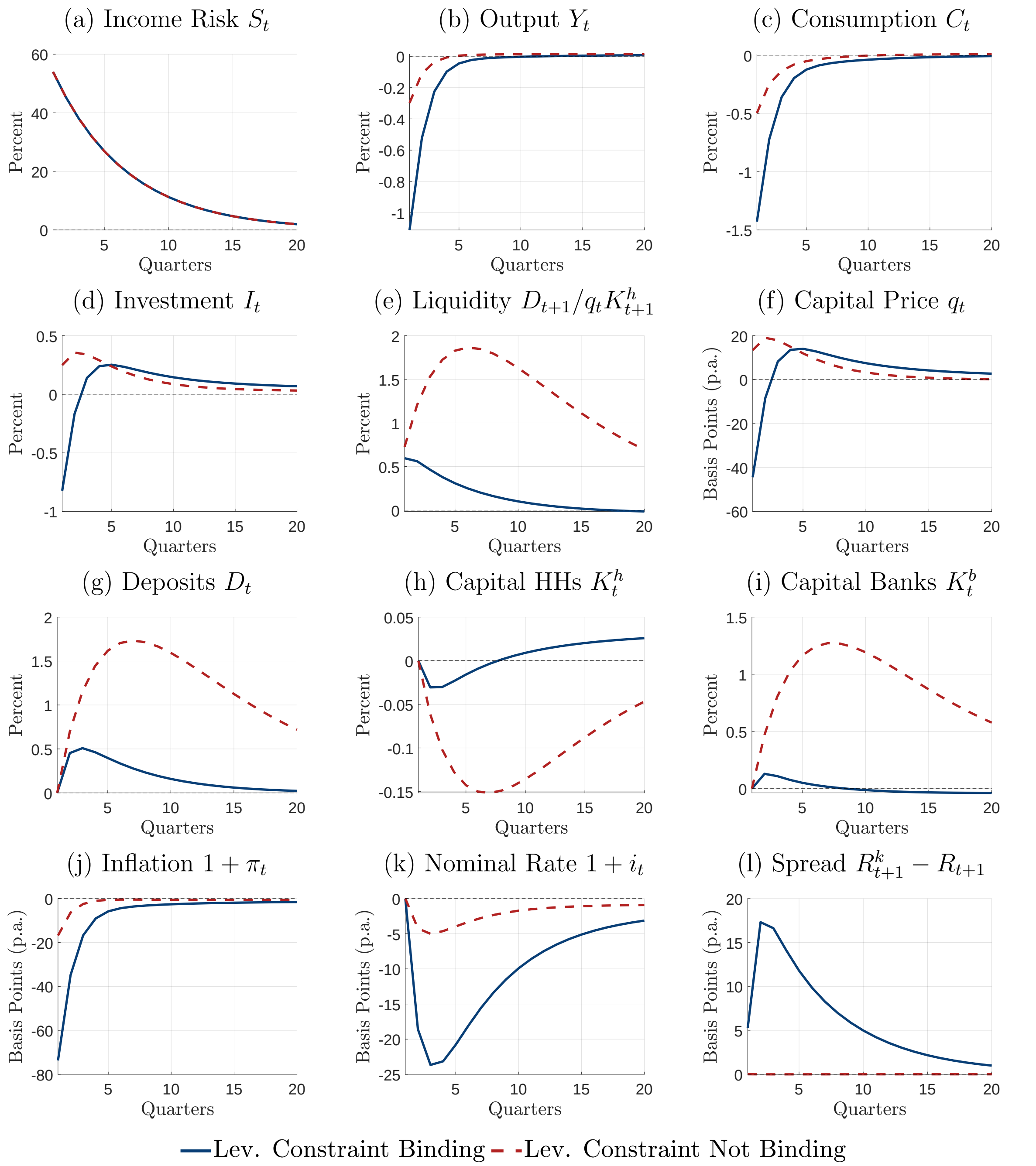
Focus first on the economy where the leverage constraint does not bind; the dashed red lines. Recall that in this case the supply of deposits is fairly elastic (Figure 2, panel a). The increase in idiosyncratic income risk induces households to reduce consumption (panel c) to build a buffer of precautionary savings. Next to this, households seek to rebalance their portfolios away from illiquid claims on capital to liquid bank deposits. Banks are able to meet the increase in demand for liquid savings, leading to a peak increase in deposits of almost 2% (panel g). This tilts households' portfolios towards the liquid asset (panel e). Banks use deposits to increase loans to non-financial firms (panel i). That is, while the household sector backs on investment (panel h), banks take over instead. As a consequence, there is no increase in excess returns (panel l). With the economy-wide savings increasing, overall investment rises by almost 0.5% (panel d). The effect of the shock on aggregate output is rather mild, it falls by only 0.3% (panel b). In sum, an unconstrained financial system makes the economy resilient to shocks that shift the desired liquidity composition of households' portfolios.

The solid blue lines in Figure 3, instead, show the case when the leverage constraint binds. Recall that if the financial system is constrained, banks cannot easily issue more deposits. As a result, the supply of liquid savings is rather inelastic (cf. panel (b) in Figure 2). In this case, banks cannot meet the households' increased demand for deposits. Figure 2 focused on the deposit market only. There, equilibrium was achieved through a fall in the interest rate. At the same time, Figure 2 assumed that the demand for deposits moves exogenously and that the real rate can flexibly fall. The case here is more complicated, however. On the one hand, the rise in demand for deposits goes in hand with a fall in aggregate demand (and incomes). On the other hand, monetary policy shapes the response of the real interest rate. The Taylor rule (42) used here is meant to capture a conventional monetary response. Monetary policy does not explicitly account for the rise in income risk. Thereby, and combined with sticky prices, the real interest rate does not fall enough to clear the market for deposits at given incomes. Instead, other quantities and prices move. On the one hand, the excess demand for deposits translates into low aggregate demand, leading incomes to fall. On the other hand, the excess demand for deposits is mirrored by a lack of demand for illiquid assets. In equilibrium, then the price of these assets falls sharply as well. Falling household incomes and falling asset prices weaken households' demand for liquid savings, restoring equilibrium.

More precisely, heightened income risk induces households to increase their demand for a more liquid portfolio and to reduce consumption. An impaired financial system cannot provide the household sector with enough liquid savings. Sticky prices imply that

[21] Figure B.1 in appendix B provides impulse responses of additional variables.

Figure 3: Impulse Response Functions to an Income Risk Shock



Notes: Impulse response functions to one standard-deviation increase in the variance of income shocks. Blue solid lines show the response in the baseline model, where the leverage constraint of financial intermediaries is binding. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding.

inflation (panel j), and hence the nominal interest rate (panel k), moves little. As a result, the real rate remains too high. Thus, households further reduce demand for consumption goods, amplifying the fall in aggregate consumption to almost 1.5% (panel c). With sticky prices the supply of goods is demand-determined: the fall in demand for goods induces firms to cut back on production, and hence households' income drops. This weakens households' desire to increase savings. Next to this, the binding leverage constraint mutes the response of bank credit (panel i). Consequently, now investment falls more than 0.5% (panel d). As a result, the price of capital falls markedly (panel f), leading to a rise in expected excess returns (panel l). Higher spreads discourage households from saving in the liquid asset, inducing them to hold a more illiquid portfolio (panel e). In sum, a decline in income and an increase in expected excess returns of illiquid assets dampen households' demand for liquid savings. Thus, markets clear with a muted creation of liquid deposits, that now only increase by 0.5% (panel g). The limited supply of liquid assets, however, comes with marked falls in both consumption and investment, amplifying the drop in aggregate output to 1%.

Overall, the dynamics observed in Figure 3 capture the gist of the empirical findings discussed in section 2. The aggregate consequences of an increase in households' demand for liquid savings, resulting from higher income risk, crucially depend on the state of the financial system. When the banking sector is unconstrained, the creation of liquid savings in equilibrium is ample. Furthermore, the intermediation of deposits into lending helps to stabilize investment. A binding leverage constraint, instead, impairs banks' liquidity transformation: the response of liquid deposits and credit are muted and much lower than if banks are unconstrained. This leads to marked falls in aggregate consumption and investment, amplifying the recessionary impact of the shock.

It bears noting that the financial frictions do not amplify all shocks to the same extent. Rather, they amplify in particular shocks that induce households to shift their portfolios towards liquid savings. Appendix B.3, for example, shows that financial frictions do not amplify a shock to the discount factor β. This shock makes households more patient, inducing them to reduce consumption and increase savings in all assets. In this case, liquidity creation is also lower when the leverage constraint binds. Households, however, meet their higher desire to increase overall savings by increasing their holdings of the illiquid asset, even if this means that the liquidity of their portfolios falls.

5.2 The Role of Liquidity Transformation

The current model gives a dual role to banks: they intermediate funds between households and firms, and they provide liquid savings to the household sector. At the same time, financial frictions impair both lending to firms and liquidity transformation. As we have seen, banking frictions crucially shape the aggregate consequences of a shock to household income risk that shifts the demand for liquid savings. I seek to understand and quantify next each of the roles of the financial system in driving the amplification to such shock. Towards this end, I analyze two counterfactuals that allow me to isolate the role of liquidity transformation, the focus of this paper.

5.2.1 An Economy With a Fixed Supply of Liquid Assets

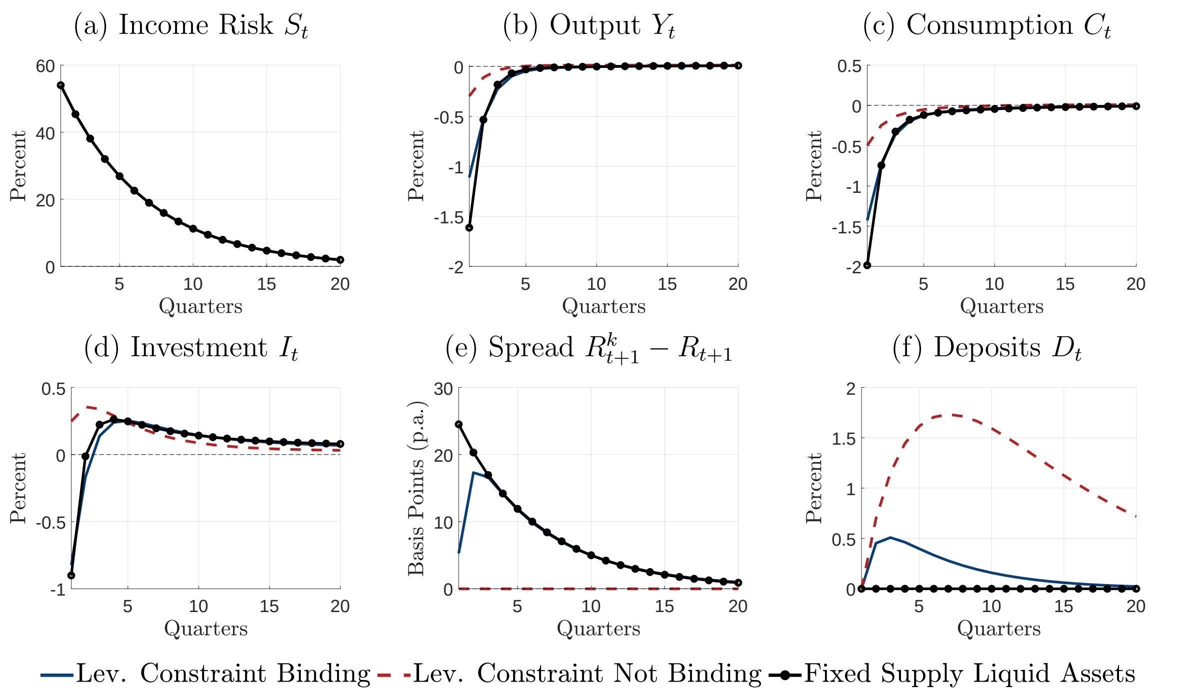
For the household sector, the banking system is the main supplier of liquid assets. The previous section has shown that banking frictions are fundamental in shaping how a shock to household income risk (and the ensuing shift in the demand for liquid assets) propagates to economic activity. In order to obtain a better understanding of the role played by banks' liquidity transformation, this section abstracts from liquidity creation. In particular, I entertain the same two-asset model as above but assuming that the supply of liquid deposits and bank credit are in fixed supply, at the steady-state levels of the baseline economy. See appendix D for details on the set up.

Figure 4 shows with solid black lines with circles the responses to an increase in income risk in the economy without liquidity transformation. It also displays the responses of the baseline economy with a binding and non-binding constraint, discussed above. If the supply of liquid assets is fixed, and there is no liquidity transformation, the recession is deeper still.[22] Output falls around 1.5% on impact, observe panel (b). This amplification is driven by a larger initial drop in consumption (panel c), that falls 2% on impact. What is more, the larger contraction of consumption is not explained by a deeper fall in investment: investment falls just as much as when the supply of deposits is not exogenous. Instead, the reason for this result is a fixed supply of liquid assets (panel f). Recall that households seek to hold more liquid portfolios. With the supply of liquidity fixed, however, the supply curve is entirely vertical (an extreme case of the right panel in Figure 2). Thus, any shift in demand for deposits cannot be an equilibrium outcome. Instead, the demand for liquid savings is curbed by increasing excess returns (panel e) and falling household income, amplifying the drop in consumption. This suggests that the limited supply of liquid savings is central for the larger contraction in consumption observed in Figure 3.

Figure 4 shows that, overall, the presence of the financial system can be stabilizing: it provides households with the liquid store of value that they demand, using these assets to provide credit for the economy. Furthermore, it suggests that banking frictions that impair liquidity transformation are central for the amplification of consumption and output, over and beyond constraints on lending. In the next counterfactual, I explicitly quantify the contribution of each of the roles of the banking sector in driving the amplification of the recession.

[22]Note that this result contrasts with the financial accelerator literature (e.g. Bernanke et al. 1999, Gertler and Kiyotaki 2010) that generally finds that removing the financial system together with financial frictions is stabilizing. In my model, however, financial intermediaries also have the central role of endogenously creating the liquid assets that households demand to self-insure.

Figure 4: Comparison to an Economy Without Liquidity Transformation



Notes: Impulse response functions to 1 standard-deviation increase in the variance of income shocks. Blue solid lines show the response in the baseline model, where the leverage constraint is binding. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding. Black lines with circles show the responses in the economy with an exogenous supply of liquid assets.

5.2.2 Stabilization Policy and the Role of Liquidity Transformation

My second counterfactual quantifies the role of liquidity provision through looking at unconventional monetary policy. More precisely, I consider a credit policy that attempts to mimic the quantitative easing policies conducted by the Federal Reserve during the last financial crisis. I model this credit policy following Gertler and Karadi (2011). The literature has emphasized the effects on asset prices and credit of these policies. Instead, I highlight the liquidity consequences of the monetary intervention. In particular, I consider two ways of financing the credit policy. One with issuance of reserves, that increases the supply of liquid savings; the other without reserves, that does not. Two findings arise from this counterfactual. First, impaired banks' liquidity provision can explain around half of the amplification of a shock to household income risk observed in Figure 3. Second, and related, liquidity creation is an important channel of the monetary intervention, over and beyond the effects on credit.[23]

[23] Cui and Sterk (2021) also discuss the liquidity consequences of quantitative easing in a model without banking frictions and limited household heterogeneity.

5.2.2.1 Credit Policy

The stabilization policy works as follows. The central bank purchases claims on physical capital from financial intermediaries. Contrary to banks, the monetary authority is only constrained by its balance sheet, and contrary to households the central bank can adjust its asset holdings every period. Let K_t^{CB} denote the total amount of claims on capital purchased by the central bank. Then, under this policy, the market clearing condition for claims on capital (45) is now given by,

$$K_t = K_t^h + K_t^b + K_t^{CB}. \tag{46}$$

Recall that a tightening of the leverage constraint goes in hand with a rise in spreads. The central bank purchases capital claims when banks' leverage constraint is binding in an attempt to reduce expected excess returns. In particular, I assume that central bank's capital purchases obey the following rules:

$$K_{t+1}^{CB} = \psi_t^{CB} K_{t+1}, \tag{47}$$

$$\psi_t^{CB} = \theta^{CB} \mathbb{E}_t \left[(R_{t+1}^k - R_{t+1}) - (\bar{R}^k - \bar{R}) \right], \tag{48}$$

that is, the monetary authority increases asset purchases when expected excess returns are above their steady-state value. By purchasing claims on capital, the central bank eases the leverage constraint (26). This stimulates lending and investment, inducing an increase in asset prices and a fall in excess returns. How this policy is financed is crucial here, however, because it affects the creation of liquid deposits. I look at two financing schemes that allow me to disentangle the effects of liquidity provision.

Central bank intervention with issuance of reserves. In the first financing scheme, the central bank entirely finances asset purchases by issuing interest-bearing reserves M_t^{CB} to banks. Contrary to claims on capital, I assume that banks cannot divert reserves. Therefore, they do not enter directly in the leverage constraint (26). As a result, by non-arbitrage, the real interest rate paid on reserves is the same as on deposits.

The swap of claims on capital for reserves in the balance sheet of banks is non-neutral to the extent that banks are constrained. The central bank, by purchasing assets from banks, directly relaxes the leverage constraint (26). Note that central for this is the assumption that reserves (that banks obtain in exchange for selling the claims on capital) do not enter in the leverage constraint. This allows banks to purchase new claims. This has two consequences. First, the monetary intervention stimulates lending and, therefore, the demand for investment goods. What is more, this policy expands the supply of liquid assets. In order to finance the new purchases of capital claims, banks issue more liquid deposits to households. Therefore, this unconventional monetary policy not only supports investment but also increases the supply of liquid assets. Finally, following Gertler and Karadi (2011), I assume that any capital gains or losses incurred by the monetary authority are rebated to the fiscal authority.

Central bank intervention without issuance of reserves. Above, liquidity creation and asset purchases go hand in hand. In order to tell these two roles apart, I also entertain a tax-financed scheme. This second financing scheme assumes that the central bank does not issue reserves $M_t^{CB} = 0$. Instead, asset purchases are financed through lump-sum taxes on the shareholders of banks, entrepreneurs.[24] Entrepreneurs, being wealthy households, have low marginal propensities to consume and are hence less likely to respond strongly to lump-sum taxes.

More precisely, the monetary authority obtains funds from taxing entrepreneurs. Then the central bank uses these funds to purchase capital claims from banks. This, again, relaxes the leverage constraint of banks. Therefore, the policy still stimulates lending and investment. Now, however, banks do not have to issue more deposits to increase lending. Instead, banks purchase new claims on capital using the funds obtained from selling their assets to the central bank. Thus, this policy does not command a direct increase in the supply of liquid assets. This is so because this policy does not involve a swap of assets. As a consequence, comparing this financing scheme to the previous one allows me to gauge the effects of liquidity provision. Finally, in order to avoid large fiscal distortions, I assume here that any capital losses or gains are rebated to the entrepreneurs in form of lump-sum transfers.[25]

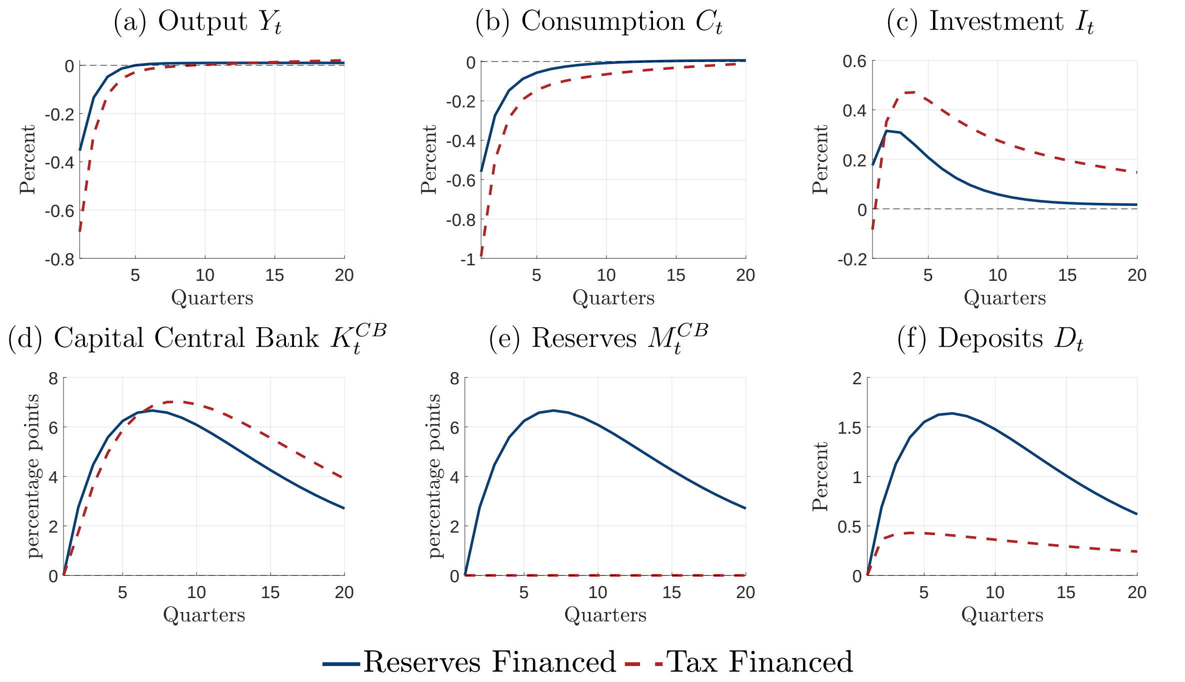
5.2.2.2 The Liquidity Consequences of Credit Policy

Figure 5 shows the impulse responses under the credit policy to a one-standard deviation income risk shock when the leverage constraint is binding. Blue solid lines show the case where the credit policy is financed by issuing reserves to banks. In this case, I set the response of the central bank to fluctuations in expected excess returns equal to $\theta^{CB} = 100$. This implies that, in this scenario, the central bank almost eliminates fluctuations in expected excess returns entirely – not shown –, replicating the dynamics observed when the leverage constraint does not bind (cf. red dashed lines, panel 1 in Figure 3). Red dashed lines show the responses in the situation where asset purchases are financed through lump-sum taxes on entrepreneurs, the shareholders of banks. Here, I set the response to fluctuations in expected excess returns to target a similar increase in the balance sheet of the central bank as in the case of a reserve-financed scheme. This implies $\theta^{CB} = 17$. Recall that tax-financed asset purchases have limited effects on the

[24]This second financing scheme does not attempt to model an actual policy conducted by central banks. Instead, it is a useful device to disentangle the channel of liquidity provision.

[25]Fiscal consequences can be large here because the government does not have to pay interest rates on reserves. Rebating capital gains to entrepreneurs avoids this.

Figure 5: Stabilization Policy: The Role of Liquidity



Notes: Impulse responses to a one-standard deviation income risk shock when the leverage constraint is binding under credit policy. Blue solid lines shows the case where the central bank finances asset purchases by issuing reserves to banks. In this case, I set the response of the monetary authority to fluctuations in excess returns to $\theta^{CB} = 100$, see equations (47) and (48). Red dashed lines show the situation where, instead, asset purchases are financed through lump-sum taxes on entrepreneurs. In this case, I set the response to excess returns to target a similar increase in the balance sheet of the central bank as in the case of a reserves-financed scheme. This implies $\theta^{CB} = 17$.

supply of liquid assets, but similar effects on lending. This allows me to disentangle the consequences of impaired liquidity transformation.

Under the reserves-financed scheme (solid blue lines), the central bank completely eliminates the amplification arising from a binding leverage constraint (cf. Figure 3). The central bank purchases claims on capital from banks (panel d), in exchange for reserves (panel f). This relaxes the leverage constraint, allowing banks to increase lending. As a result, aggregate investment increases (panel c) by about 0.3%. Importantly, the monetary intervention expands the supply of liquid assets. In order to finance new asset purchases, banks issue more deposits (panel f), that now increase more than 1.5%. Therefore, now, banks satisfy households' increased demand for liquid savings, arising from heightened income risk. Since now households achieve the desired liquidity of their portfolios, consumption is stabilized (panel b). The increase in investment and the muted consumption response dampen the contraction in output (panel a). Thus, the central bank, by stimulating lending and the supply of liquid assets, stabilizes the economy and replicates the dynamics observed when the leverage constraint does not bind (compare to red dashed lines in Figure 3).

Liquidity provision is essential for stabilizing the economy, observe red dashed lines. In this case, a similar increase in the balance sheet of the central bank (panel d) is now financed through lump-sum taxes on entrepreneurs. Again, the central bank, by purchasing assets from banks, relaxes the leverage constraint. This allows banks to extend more loans, increasing investment (panel c). The increase in investment is now even larger than with a reserves-financed scheme. The response of investment is stronger because, without liquidity provision, excess returns remain higher – not shown–, inducing banks to lend more. Recall that this financing scheme has weaker effects on the supply of liquid assets. As a result, the expansion in deposits is now three times smaller (panel f). Although investment expands more, consumption (panel b), and hence output (panel a), still fall twice as much as with a reserves-financed scheme: without liquidity creation, the effectiveness of policy halves. Figure B.3 in appendix B.2 makes this point even starker. There, I show that without the expansion in liquid assets the central bank has to double asset purchases, relative to a reserves-financed policy, in order to stabilize expected excess returns.

In other words, liquidity transformation is central for an economy to be resilient to shocks that shift the demand for liquid savings. A policy that increases both lending and the supply of liquid assets entirely eliminates the amplification arising from banking frictions. In contrast, a policy that only stimulates investment but does not improve liquidity provision is only able to reduce the amplification by a half. The implications of this finding are twofold. First, liquidity provision is an important channel of the monetary intervention. Second, impaired banks' liquidity transformation can explain around half of the amplification of a shock to household income risk when the leverage constraint binds. Thus, banking frictions not only amplify shocks by constraining lending to firms, but also by hampering the supply of liquid assets to households.

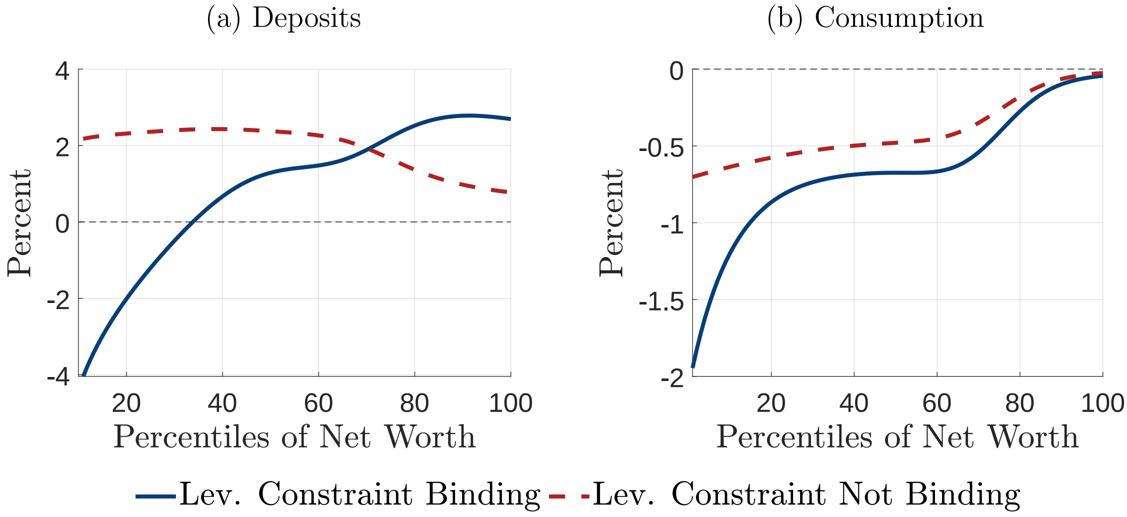
5.3 The Role of Heterogeneity and Inequality

Banking frictions, by impairing liquidity transformation, amplify shifts in the demand for liquid assets. Beyond the aggregate consequences, financial frictions also affect households to different extents, depending on their wealth and portfolio composition, and have marked implications for inequality. This section first discusses how the state of the financial system affects the heterogeneous responses of households to an increase in income risk and, second, its implications for wealth inequality.

5.3.1 Heterogeneous Household Responses to Income Risk

Figure 6 shows the equilibrium response of households' deposits and consumption over the net worth distribution. It focuses on the response two quarters after the shock to household income risk. Blue solid lines show the case when the leverage constraint binds.

Figure 6: Change in Deposits and Consumption by Percentile of Net Worth



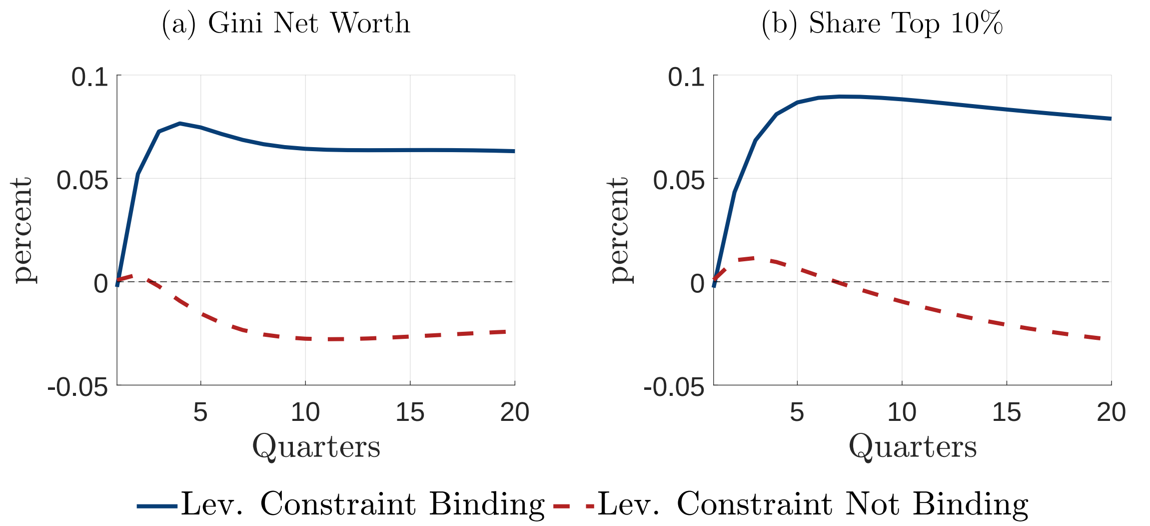
Notes: Left panel displays the equilibrium change in deposits over the net worth distribution two quarters after the household income risk shock. The bottom 10% of the distribution is not shown since some households hold zero deposits. The right panel shows the equilibrium change in consumption two quarters after the household income risk shock. Red dashed lines show the case of non-binding leverage constraint. Blue solid lines show the scenario with a binding leverage constraint. Changes computed using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1.

Red dashed lines show the case of a non-binding leverage constraint.

When the financial system is unconstrained, all households increase their holdings of liquid deposits in response to the shock to household income risk, observe the red dashed line in panel (a). Households at the bottom half of the wealth distribution increase their savings in bank deposits particularly strongly. They hold little wealth to begin with and, therefore, are poorly insured against the surge in income risk. The mirror image of this is that households at the bottom of the wealth distribution cut their consumption by around 0.7%, while wealth-rich households are able to smooth the fall in income arising from the recession, see the red dashed line in panel (b). Recall that in this case the supply of liquid assets was relatively elastic (cf. panel (a) in Figure 2).

This picture changes dramatically when the leverage constraint prevents banks from issuing deposits. This case is shown by the solid lines in Figure 6. In this situation, the financial system is not able to meet the increase in households' demand for deposits. Instead, households have to be discouraged from demanding deposits through a larger fall in income. Not all households are equally affected by this larger contraction in income, however. Households at the bottom of the wealth distribution are unable to smooth the larger decline in aggregate income when the leverage constraint binds. As a consequence, their consumption drop more than doubles, to almost 2%. This is so although they run down their liquid savings in an attempt to smooth consumption, observe the solid line in panel (a). Consequently, wealth-poor households not only cut consumption more when

Figure 7: Consequences of a Household Income Risk Shock on Wealth Inequality



Notes: Impulse responses of the Gini index for net worth (left panel) and the wealth share of the top 10% of the net worth distribution (right panel) to a household income risk shock. Blue solid lines: leverage constraint binding. Red dashed lines: leverage constraint not binding. A 0.1% increase in the Gini coefficient for net worth, implies that the Gini indexes increases from its steady-state value of 0.78 to 0.7808.

the financial system is impaired, but they become more exposed to the increase in income uncertainty too.

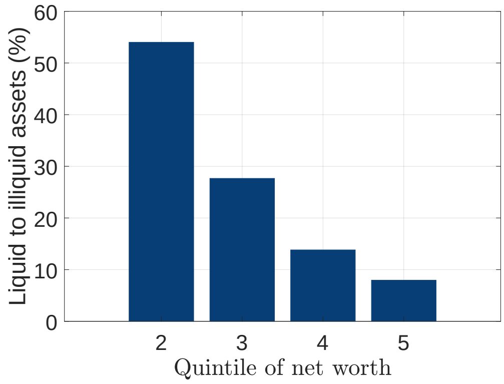
The consumption decline of households at the middle of the wealth distribution does not exhibit such a marked amplification. Still, also the middle class accumulates less liquid deposits than when the leverage constraint is not binding. This contrasts with the behavior of households at the top of the distribution, who barely see their consumption affected by the deeper recession. These households even increase their holdings of bank deposits by more. This is so because many households at the top of the wealth distribution are entrepreneurs that receive profit income. Markups are countercyclical due to sticky prices.[26] Recessions, thus, mean windfall gains to this group of households. As a consequence, it is particularly costly for them to become workers in a deeper recession, when labor income is lower, and they self-insure against this event by accumulating even more liquid assets.

5.3.2 Response of Wealth Inequality to Income Risk

The different saving decisions of households induced by the deeper recession when the financial system is impaired have marked implications for wealth inequality. This can be observed in Figure 7, that displays the response of the Gini coefficient for net worth, panel (a), and the response of the wealth share of the top 10%, panel (b), after the

[26]The impulse response of aggregate profits is provided in Figure B.1 in appendix B.

Figure 8: Liquid Deposits over Illiquid Assets at the Steady State by Wealth Quintile



Notes: Holdings of liquid deposits relative to estimated illiquid assets by quintile of the net worth distribution at the steady state. Computed using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1.

shock to household income risk. Blue solid lines show the case of a constrained financial system, and the dashed red lines the situation where the leverage constraint does not bind. Although effects on wealth inequality are not large, the dynamics of inequality crucially depend on the state of the financial system. When the leverage constraint is not binding, inequality falls after the first quarters, since wealth-poor households are the ones that accumulate precautionary savings more strongly, as discussed previously.

Wealth inequality increases in response to the shock to household income risk when the leverage constraint binds, however. At first glance, this is surprising since the desired shift in the portfolio allocation sharply reduces the price of capital when the leverage constraint binds. Heterogeneity in households portfolios implies that wealth-rich households lose the most from falling asset prices. To understand this, Figure 8 shows the estimated holdings of liquid deposits relative to illiquid capital by quintile of the net worth distribution in the steady state. The bottom quintile is not reported since some of these households hold non-positive amounts of capital. The liquidity of household portfolios is clearly declining with wealth. [27] Therefore, falling asset prices hurt the wealth-rich the most, that hold more illiquid portfolios. Yet, as shown previously, when the financial system is impaired, wealth-poor households reduce their liquid savings in response to the fall in aggregate income, while rich households still increase their liquid savings.[28] Therefore, this second channel dominates over the change in asset prices. This leads to an overall increase in wealth inequality when the financial system is constrained.

[27] This pattern is consistent with the data, see Bayer et al. (2019) and Luetticke (2021).

[28] In appendix B.1 I provide the change in total savings and capital holdings, see Figure B.2.

6 Conclusion

This paper investigates how financial frictions, by impairing banks' liquidity transformation, affect the propagation of shocks that shift the desired liquidity of households' portfolios. I first provide novel empirical evidence that one such shock, a shock to household income uncertainty, is more recessionary when financial frictions are tight. Second, I study the drivers behind these findings in a two-asset New Keynesian model with heterogeneous households and banks that perform liquidity transformation, subject to a leverage constraint.

At the empirical level, I find that the state of the financial system is fundamental for the aggregate consequences of a shock to household income risk. If financial conditions are loose, the creation of liquid deposits is ample, and the recessionary consequences of the shock mild. On the contrary, if financial conditions are tight, the economy sees a deep recession and a muted creation of liquid savings.

Next, at the theoretical level, I study how financial frictions and liquidity transformation affect the propagation of swings in the demand for liquid savings in a formal business-cycle model with heterogeneous agents. Next to sticky prices, I incorporate portfolio choice between liquid bank deposits and illiquid claims on capital. Banks perform liquidity transformation, subject to a leverage constraint. I use the model to study the interaction between shifts in the demand for liquid savings and the ability of the financial system to perform liquidity transformation. I do so through looking at a household income risk shock. I find that a binding leverage constraint amplifies the aggregate consequences of such shock, capturing the gist of the empirical findings. A limited supply of liquid assets from the banking sector when the leverage constraint binds is central for this. Constrained banks cannot meet the households' increased demand for liquid deposits. With sticky prices, the deposit market clears through falling household income and falling asset prices, amplifying the drop in consumption. I show that the impaired ability of the financial system to perform liquidity transformation can account for half of the amplification when the leverage constraint binds. The other half being accounted by a muted response of bank credit. Thus, banking frictions not only matter because they constrain lending, but also because they restrict the supply of liquid savings to the household sector.

There are fruitful areas for future research. This paper highlights that the financial system, through the provision of liquid deposits, is an important source of insurance for households that can be hampered by financial frictions. The work on the optimal design of both, insurance policies, as unemployment benefits (McKay and Reis, 2021), and macro-prudential regulation (Elenev et al., 2021), could be extended to account for this feature. Financial frictions usually come with highly non-linear dynamics (Brunnermeier and Sannikov, 2014, Bocola, 2016). In future work, it could be interesting to extend the model to examine the non-linear interaction between precautionary savings and an occasionally binding leverage constraint, using recent advances in global solution methods for economies with heterogeneous agents (Fernández-Villaverde et al., 2019).

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A Empirical Appendix

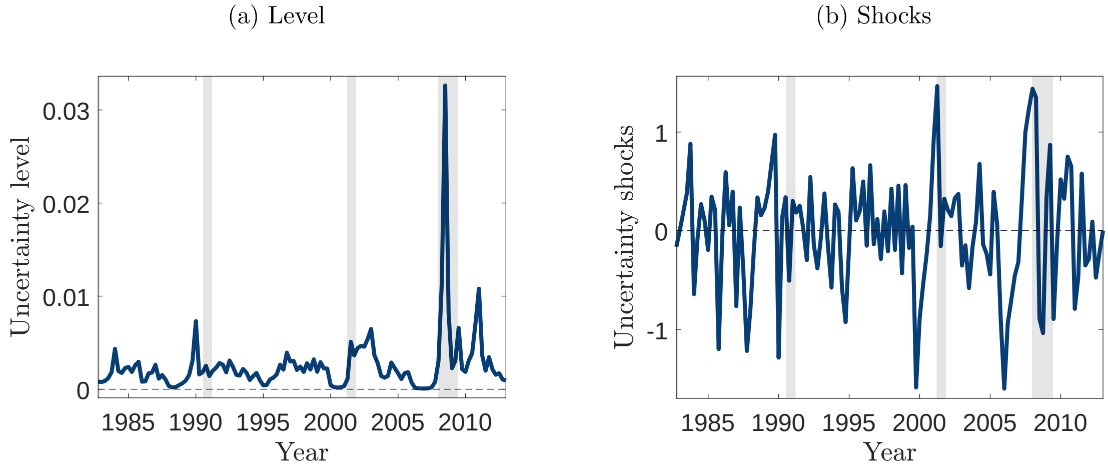
This appendix regards the empirical analysis discussed in section 2. I first provide the exact source and definition of variables used in the analysis. Next, I show the empirical response to a household income risk shock of further variables and the difference between tight and loose financial condition. Finally, I provide the details regarding robustness checks discussed in the main text.

A.1 Data

Unless otherwise noted, all data are taken from the FRED, Federal Reserve of Saint Louis. Nominal variables are deflated using the Consumer Price Index for All Urban Consumers: All Items.

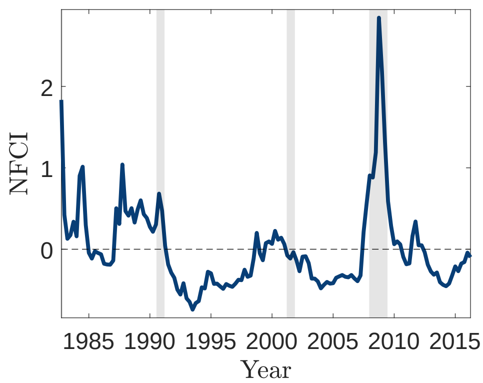
- Output; Real Gross Domestic Product, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate
- Consumption: Real Personal Consumption Expenditures, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate
- Investment: Real Gross Private Domestic Investment, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate
- Unemployment: Unemployment Rate, Percent, Quarterly, Seasonally Adjusted
- Nominal interest rate: 3-Month Treasury Bill: Secondary Market Rate, Percent, Quarterly, Not Seasonally Adjusted
- Income risk shocks: Bayer et al. (2019)
- Credit: Bank Credit, All Commercial Banks, Billions of U.S. Dollars, Quarterly, Seasonally Adjusted
- Deposits: Households and Nonprofit Organizations; Total Currency and Deposits Including Money Market Fund Shares; Asset, Level, Billions of Dollars, Quarterly, Not Seasonally Adjusted minus Households and Nonprofit Organizations; Money Market Fund Shares; Asset, Level, Billions of Dollars, Quarterly, Not Seasonally Adjusted
- NFCI: Chicago Fed National Financial Conditions Index, Index, Monthly, Not Seasonally Adjusted. Aggregated to quarterly frequency by averaging over the quarter.

Figure A.1: Estimated level of household uncertainty and income risk shocks



Notes: Panel (a): Estimated standard-deviation of persistent income shocks. Panel (b): Shocks to income risk. Both series have been estimated in Bayer et al. (2019). NBER recession dates are displayed with gray areas.

Figure A.2: National Financial Conditions Index (NFCI)



Notes: Time series of the National Financial Conditions Index (NFCI) from 1983 to 2013. Weekly data aggregated to quarterly observations by averaging over the period and demeaned such that positive values indicate tighter financial conditions than average. NBER recession dates are displayed with gray areas.

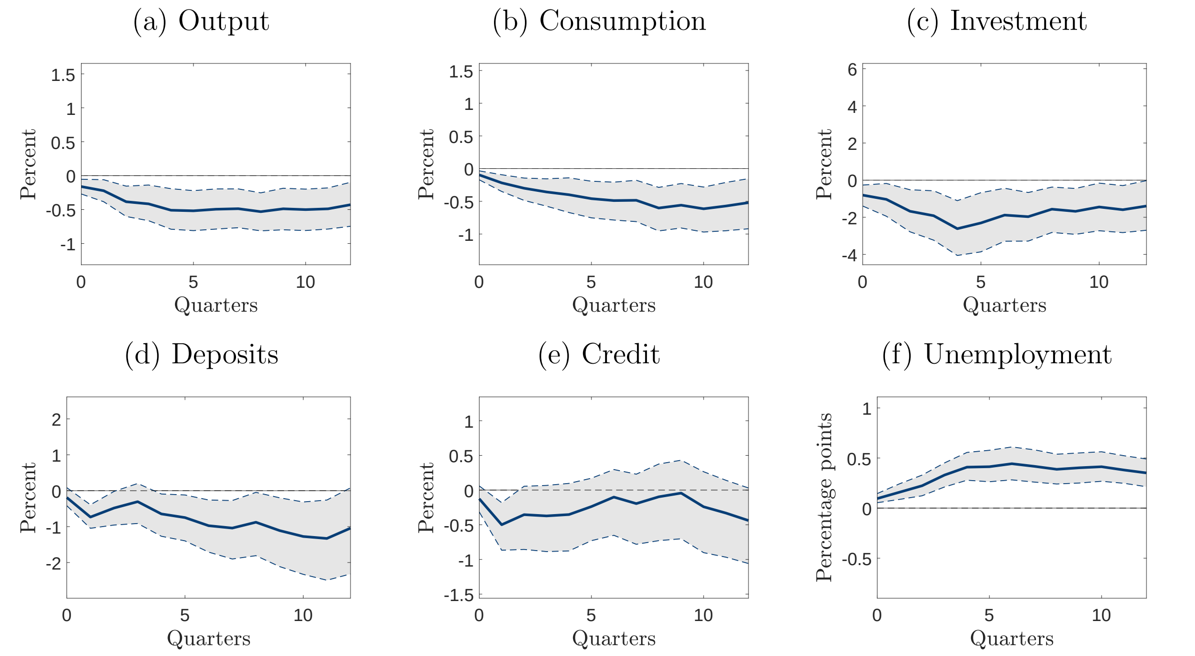
A.2 Baseline Empirical Responses

This appendix provides further empirical responses to a household income risk shock, complementary to those discussed in section 2.2. Figure A.3 provides the empirical responses to a household income risk shock when financial conditions are tight (top panel) and when financial conditions are loose (bottom panel). Furthermore, Figure A.4 shows the estimated difference between the response during times of tight and loose financial conditions. In both cases, gray areas delimited by dashed lines show block bootstrapped 66% confidence bounds.

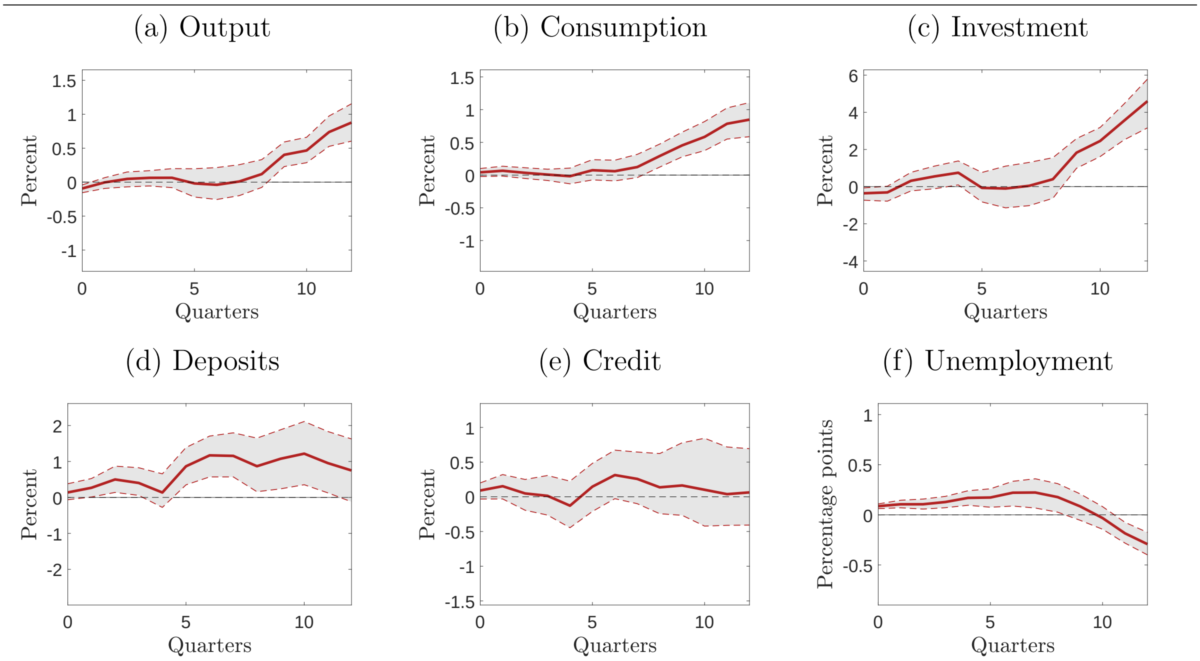
Figure A.3 makes clear that the aggregate consequences of shock to household income risk crucially depend on the state of the financial system. Output drops nearly five times more when financial conditions are tight and remains depressed for a longer period, relative to periods of loose financial conditions, observe panels (a). This is driven by a larger fall in both aggregate consumption and investment. In times of tight financial conditions, consumption drops by about 0.5% and investment contracts by around 3%. These responses contrast with the muted responses observed in periods of benign financial conditions, observe the bottom panel of Figure A.3. Consumption barely falls and aggregate investment tends to increase after eight quarters, leading to an increase in both output and consumption. These different responses impact the labor market too, see panels (f). Unemployment persistently increases with tight financial conditions, reaching a maximum increase of about 0.5 percentage points, while it barely moves when financial conditions are loose. The behavior of household deposits and bank credit markedly depend of the state of the financial system. During periods of tight financial conditions, despite the increase in household income uncertainty, the overall contraction in output leads to a drop of aggregate deposits of nearly one percent, while bank credit contracts by almost 0.5%. This contrasts with the marked increase in households deposits during periods of benign financial conditions, while credit does not fall in this case, as observed in times of tight financial conditions. Moreover, Figure A.4 shows that the differences just highlighted are statistically significant.

Figure A.3: Empirical response to a household income risk shock

Tight Financial Conditions

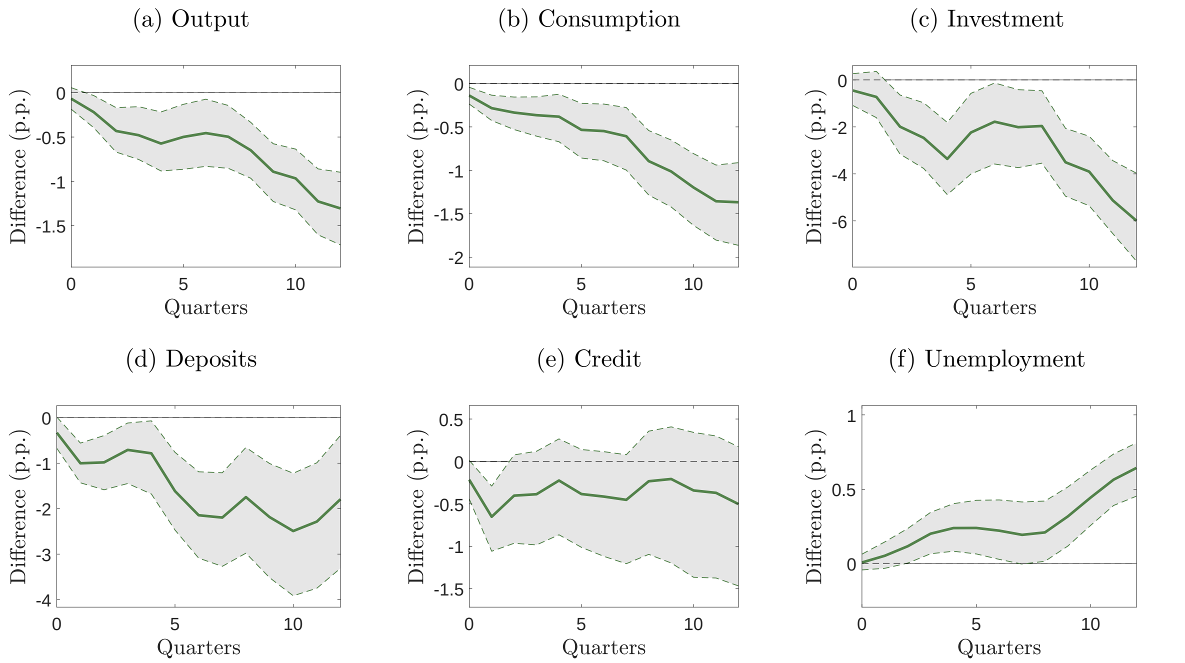


Loose Financial Conditions



Notes: Estimated responses to one standard-deviation shock to household income risk, as identified in Bayer et al. (2019). The top panel shows the empirical responses when financial conditions are tight as measured by the National Financial Condition Index (NFCI). The bottom panel shows the responses when financial conditions are loose. Block bootstrapped 66% confidence bounds are shown in gray areas delimited by dashed lines. The unemployment rate is expressed in percentage points, the rest of variables in percents.

Figure A.4: Difference Between Times of Tight and Loose Financial Conditions



Notes: Difference in the empirical response to a household income-risk shock, identified in Bayer et al. (2019), between times of tight financial conditions and times of loose financial conditons. For example, a value of -1 in panel (d), deposits, means that the response of deposits to a household income-risk shock during times of tight financial conditions is 1 percentage point smaller than during periods of loose financial conditions. Block bootstrapped 66% confidence bounds are shown in gray areas with dashed lines.

A.3 Robustness of Empirical Results

This appendix provides several robustness checks for the empirical results discussed in section 2. First, I show that results are similar after controlling for the business cycle. Next, I show that similar results are obtained if I use leverage as a measure for financial conditions. Finally, I discuss the results based on an alternative identification scheme that controls for the contemporaneous response of aggregate variables.

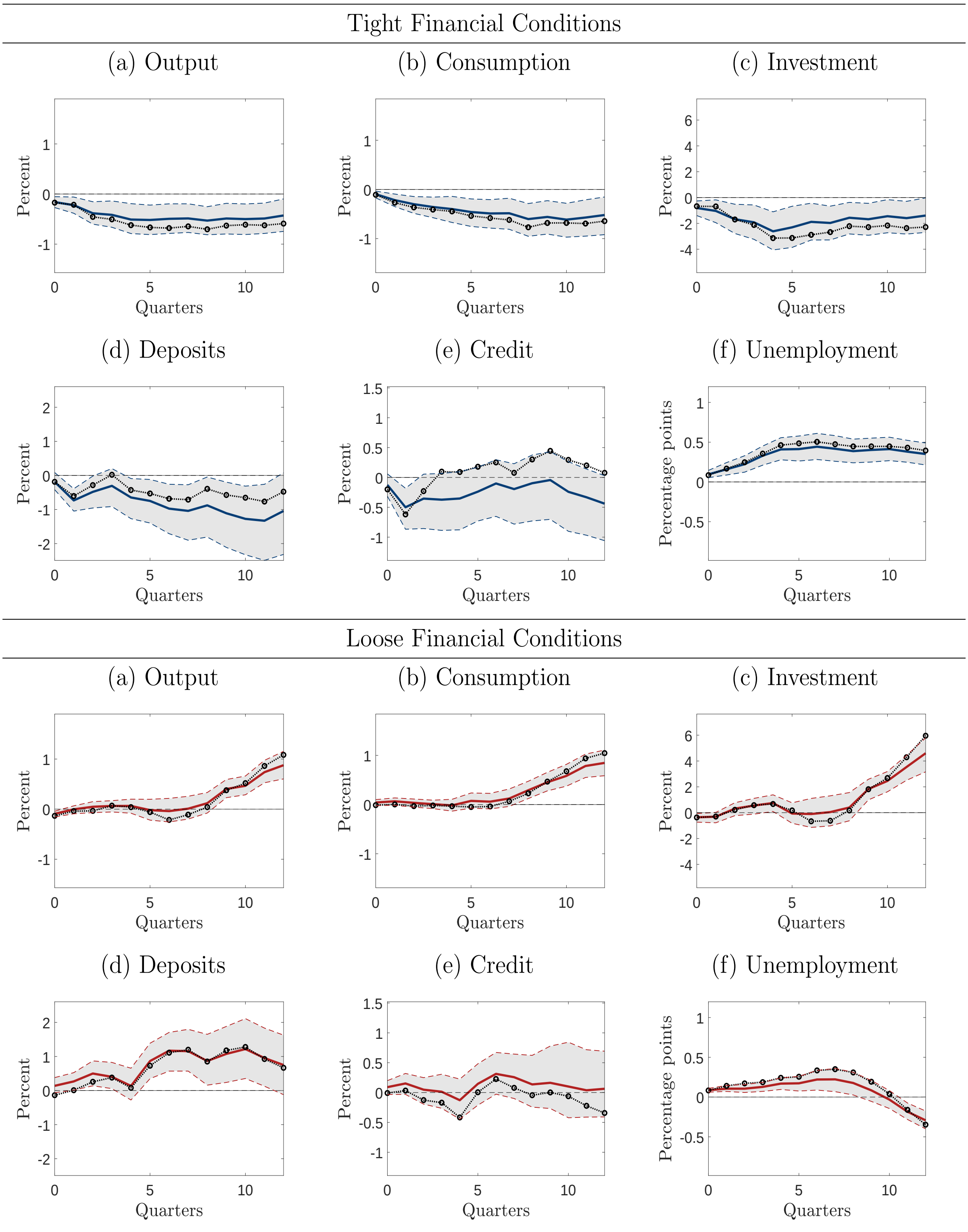
A.3.1 Controlling for the state of the business cycle

As can be observed in Figure A.2, times of tight financial conditions sometimes coincide with economic slumps, the last financial crisis being a salient example of this. Therefore, a potential concern is that the empirical findings presented in section 2.2 are driven by state-dependent responses between expansions and recessions, and not by the state of the financial system. In order to address this issue, I extend my baseline specification (1) in order to control for the state of the business cycle too. Towards this end, I first construct an indicator for the state of the business cycle, $\mathbb{I}^{BC}$, by using the unemployment rate. More precisely, I define the business cycle to be in an expansion $\mathbb{I}^{BC} = 1$ when the unemployment rate is above its mean over the period, and in a recession otherwise $\mathbb{I}^{BC}=0$. Using this indicator, I consider the following specification:

$$\begin{aligned} y_{t+l} =& \mathbb{I}^{FT}_{t-1}\left[\alpha_{FT,l} + \phi_{FT,l}(L)\mathbf{x}_t + \beta_{FT,l}\frac{\varepsilon^s_t}{\sigma_s} + \mathbb{I}^{BC}_{t-1}\beta_{FTBC,l}\frac{\varepsilon^s_t}{\sigma_s}\right] \\ &+ (1-\mathbb{I}^{FT}_{t-1})\left[\alpha_{FNT,l} + \phi_{FNT,l}(L)\mathbf{x}_t + \beta_{FNT,l}\frac{\varepsilon^s_t}{\sigma_s} + \mathbb{I}^{BC}_{t-1}\beta_{FNTBC,l}\frac{\varepsilon^s_t}{\sigma_s}\right] \\ &+ \gamma_l \text{trend}_t + \nu_{t+l} \ , \ l \geq 0. \end{aligned} \tag{49}$$

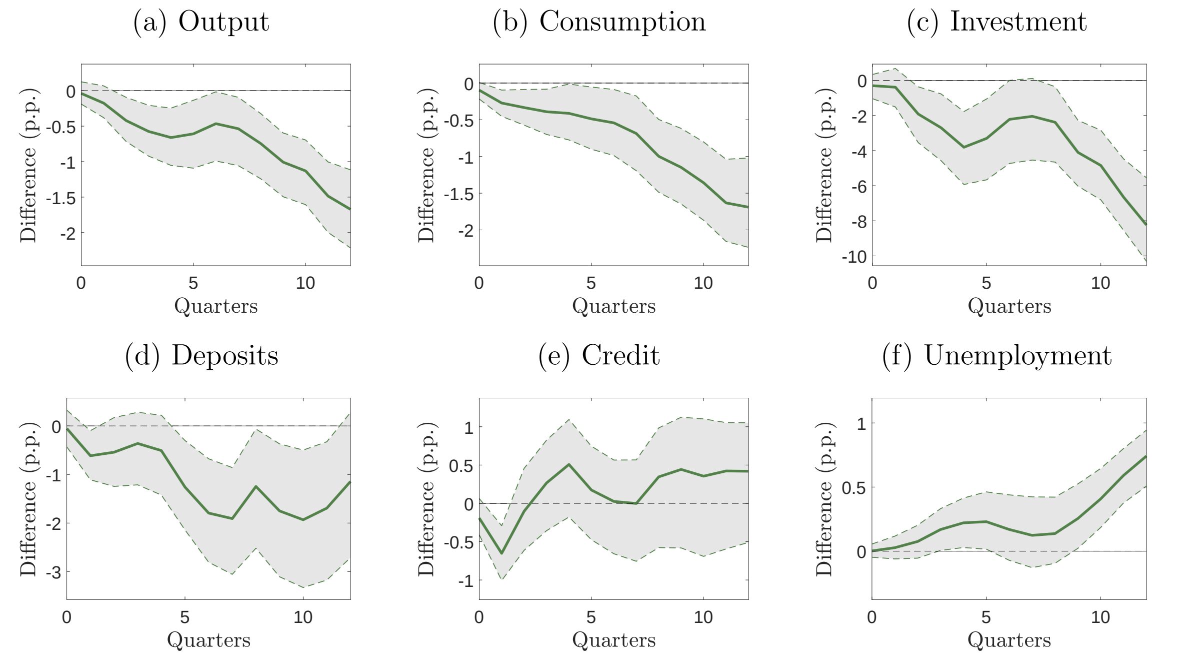
Therefore, now $\beta_{FT,l}$ ($\beta_{FNT,l}$) provides the response of variable y_{t+l}, at horizon l, to a household income risk shock when financial conditions are tight (loose) outside of recessions, while $\beta_{FTBC,l}$ ($\beta_{FNTBC,l}$) measures the additional effects of a period with tight (loose) financial conditions and a high unemployment rate $\mathbb{I}^{BC}_{t-1}=1$. Figure A.5 shows the estimated coefficients $\beta_{FT,l}$ and $\beta_{FNT,l}$ under specification (49) with black lines with circles, along the baseline estimated responses. As can be observed, results remain quite similar. Figure A.6 shows the difference between responses during times of tight and loose financial conditions after controlling for the state of the business cycle.

Figure A.5: Aggregate consequences of an increase in income risk - Controlling for the state of the business cycle



Notes: Empirical response to a household income-risk shock. The top panel shows with blue lines the empirical responses when financial conditions are tight. The bottom panel shows with red lines the responses when financial conditions are loose. Black lines with circles show the response when financial conditions are tight (top panel) or loose (bottom panel) after controlling for the state of the business cycle. The economy is defined to be in a recession if the unemployment rate is above its average over the period. Block bootstrapped 66% confidence bounds are shown in gray areas delimited with dashed lines.

Figure A.6: Difference between times of tight financial conditions and loose financial conditions - Controlling for the state of the business cycle



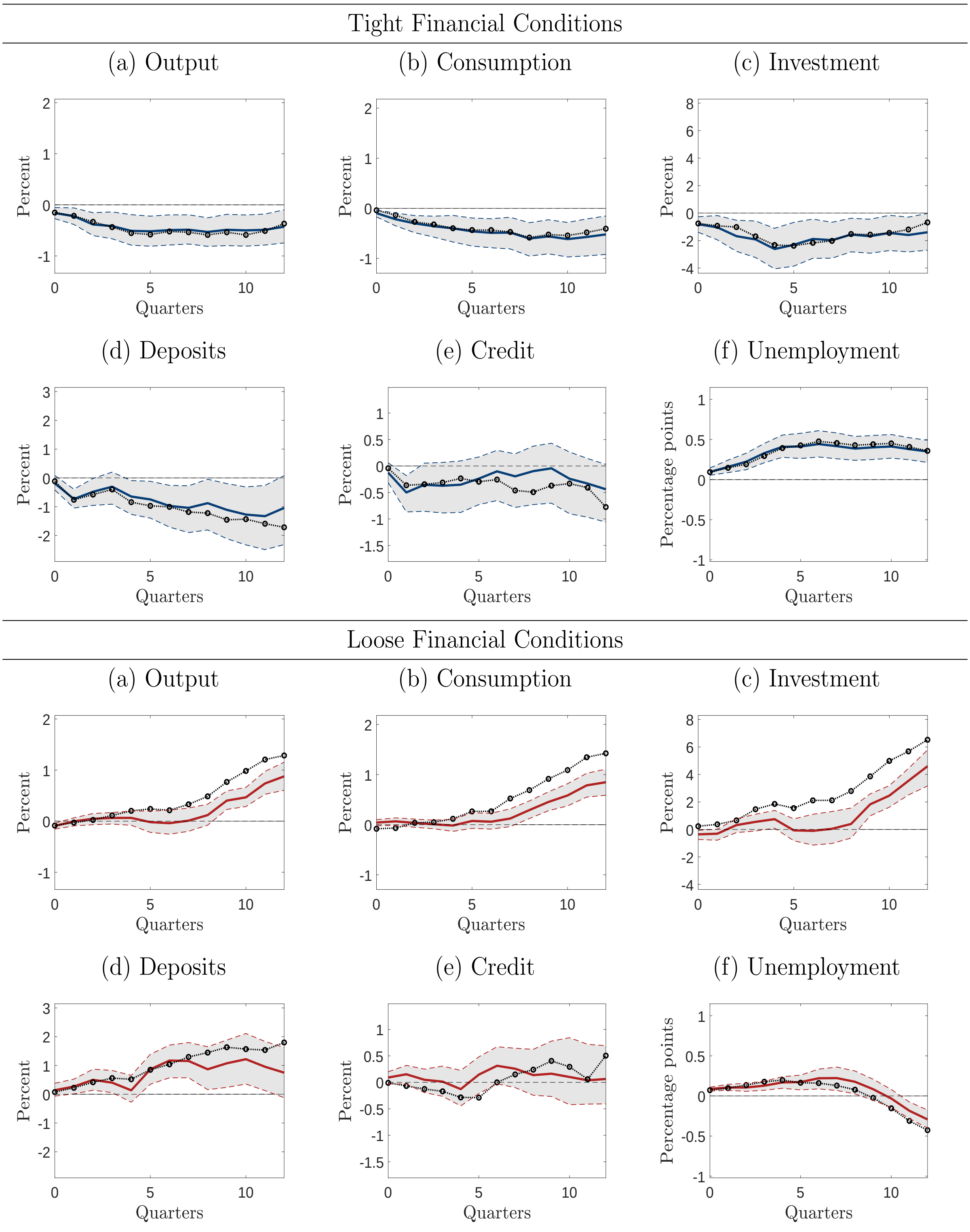
Notes: Difference in the empirical response to a household income-risk shock between times of tight financial conditions and times of loose financial conditons after controlling for the state of the business cycle. The economy is defined to be in a recession if the unemployment rate is above its average over the period. Block bootstrapped 66% confidence bounds are shown in gray.

A.3.2 Leverage as state variable

In the model presented in section 3, the state of the financial system is tightly linked to leverage in the financial sector. Yet, my indicator of financial conditions in the empirical results in section 2, the National Financial Conditions Index (NFCI), is composed by a leverage subindex, a risk subindex and a credit subindex. In order to ensure that leverage in my model is a good proxy for the financial conditions in the data, I use here the leverage subindex in my baseline specification (1) to measure financial conditions. More precisely, I define financial conditions to be tight, $\mathbb{I}_{t-1}^{FT} = 1$, if the leverage subindex of the NFCI is above its average over the period and to be loose otherwise.

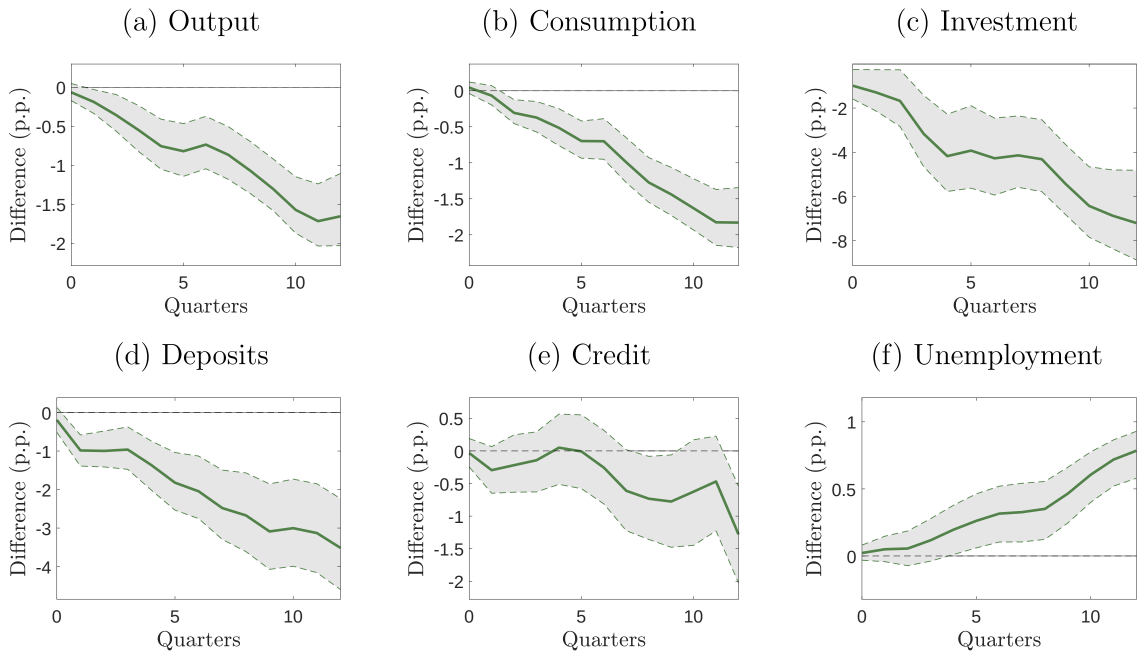
Figure A.7 displays the estimated responses to an increase in household income risk when the leverage subindex is used to measure financial conditions with black lines with circles, along with the baseline responses discussed in section 2.2. As it can be observed, the state-dependent nature of the responses becomes even more pronounced, and the differences remain statistically significant as shown in figure A.8.

Figure A.7: Aggregate consequences of an increase in income risk - Leverage as state variable



Notes: Empirical response to a household income-risk shock. The top panel shows the empirical responses when financial conditions are tight. The bottom panel shows the responses when financial conditions are loose. Black solid lines with circles show the responses when financial conditions are measured according to the leverage subindex of the NFCI. Block bootstrapped 66% confidence bounds are shown in gray areas delimited with dashed lines.

Figure A.8: Difference between times of tight financial conditions and loose financial conditions - Leverage as state variable



Notes: Difference in the empirical response to a household income-risk shock between times of tight financial conditions and times of loose financial conditons as measured by the leverage subindex of the NFCI. Block bootstrapped 66% confidence bounds are shown in gray.

A.3.3 Alternative Identification Scheme

An important assumption in the baseline regression (1) is that the estimated shocks to household income risk identified in Bayer et al. (2019) are purely exogenous and orthogonal to other structural shock ν_{t+l} in the economy. Despite that by focusing on shocks to the variance of the persistent component of income, the uncertainty shocks that I employ are less likely to be contaminated by transitory fluctuations in the economy, I present additional empirical evidence in this appendix based on an alternative identification scheme.

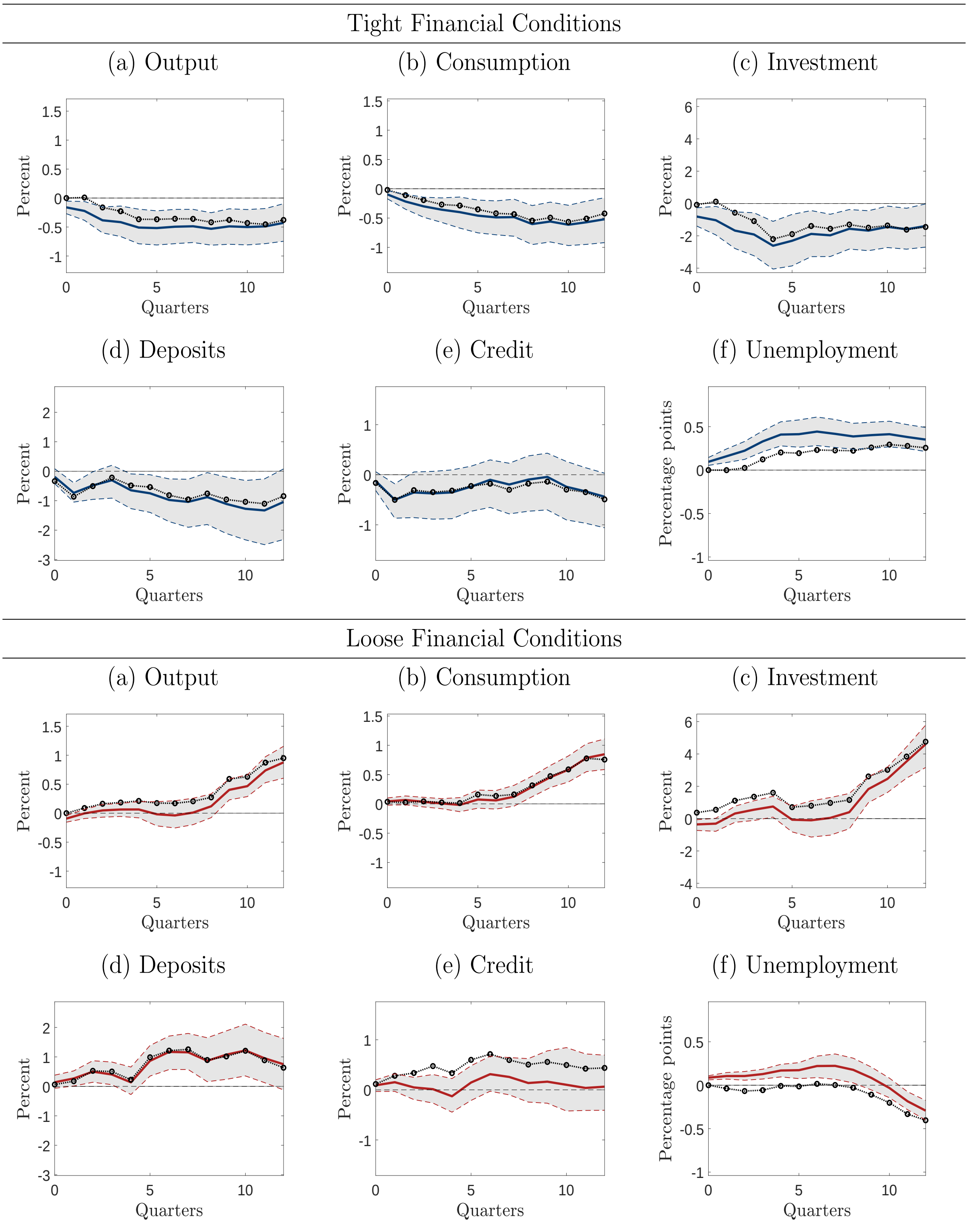
My baseline specification can be understood as an Cholesky identified SVAR where income risk is ordered first. Here, I take opposite extreme assumption and control for all contemporaneous controls, except for income uncertainty itself. More precisely, I estimate:

$$\begin{aligned} y_{t+l} = \mathbb{I}^{FT}_{t-1} \left[\alpha_{FT,l} + \phi_{FT,\tilde{x}_t,l} \tilde{\mathbf{x}}_t + \phi_{FT,x_{t-1},l} \mathbf{x}_{t-1} + \beta_{FT,l} \frac{\varepsilon^s_t}{\sigma_s} \right] \\ + (1 - \mathbb{I}^{FT}_{t-1}) \left[\alpha_{FNT,l} + \phi_{FNT,\tilde{x}_t,l} \tilde{\mathbf{x}}_t + \phi_{FNT,x_{t-1},l} \mathbf{x}_{t-1} + \beta_{FNT,l} \frac{\varepsilon^s_t}{\sigma_s} \right] \\ + \gamma_l \text{trend}_t + \nu_{t+l} \ , \ l \geq 0, \end{aligned} \tag{50}$$

where $\tilde{\mathbf{x}}_t$ is a set of contemporaneous controls that include the unemployment rate, the log of real output, and the 3-month Treasury Bill. The lagged controls $\mathbf{x_{t-1}}$ additionally include a lag of income uncertainty and a lag of the variable of interest y.

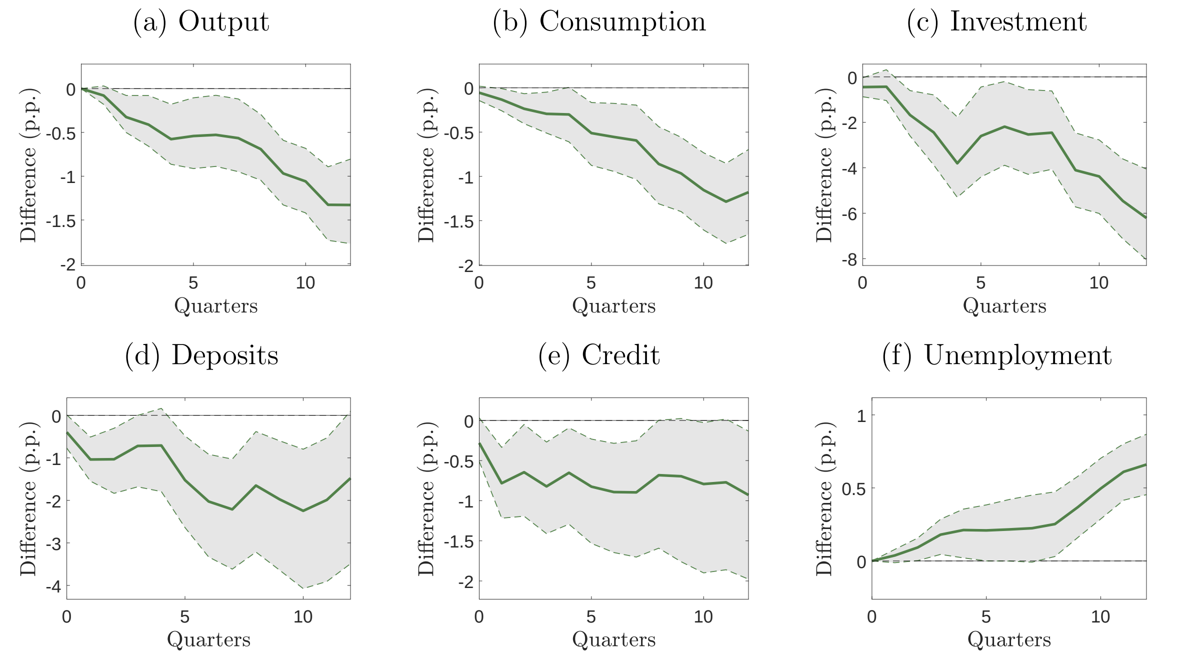
Figure A.9 shows with black lines with circles the aggregate impulse responses under the alternative identification scheme (50), along with the baseline results discussed in section 2.2. Overall, the responses are close to the ones obtained under the baseline specification.

Figure A.9: Aggregate consequences of an increase in income risk - Alternative Identification Scheme



Notes: Empirical response to a household income-risk shock. The top panel shows the empirical responses when financial conditions are tight. The bottom panel shows the responses when financial conditions are loose. Black solid lines with circles show the responses in a specification that includes contemporaneous controls, except income uncertainty itself. Block bootstrapped 66% confidence bounds are shown in gray areas delimited with dashed lines.

Figure A.10: Difference between times of tight financial conditions and loose financial conditions under alternative identification scheme



Notes: Difference in the empirical response to a household income-risk shock between times of tight financial conditions and times of loose financial conditons in a specification that controls for contemporaneous controls, except for income uncertainty itself. Bootstrapped 66% confidence bounds are shown in gray.

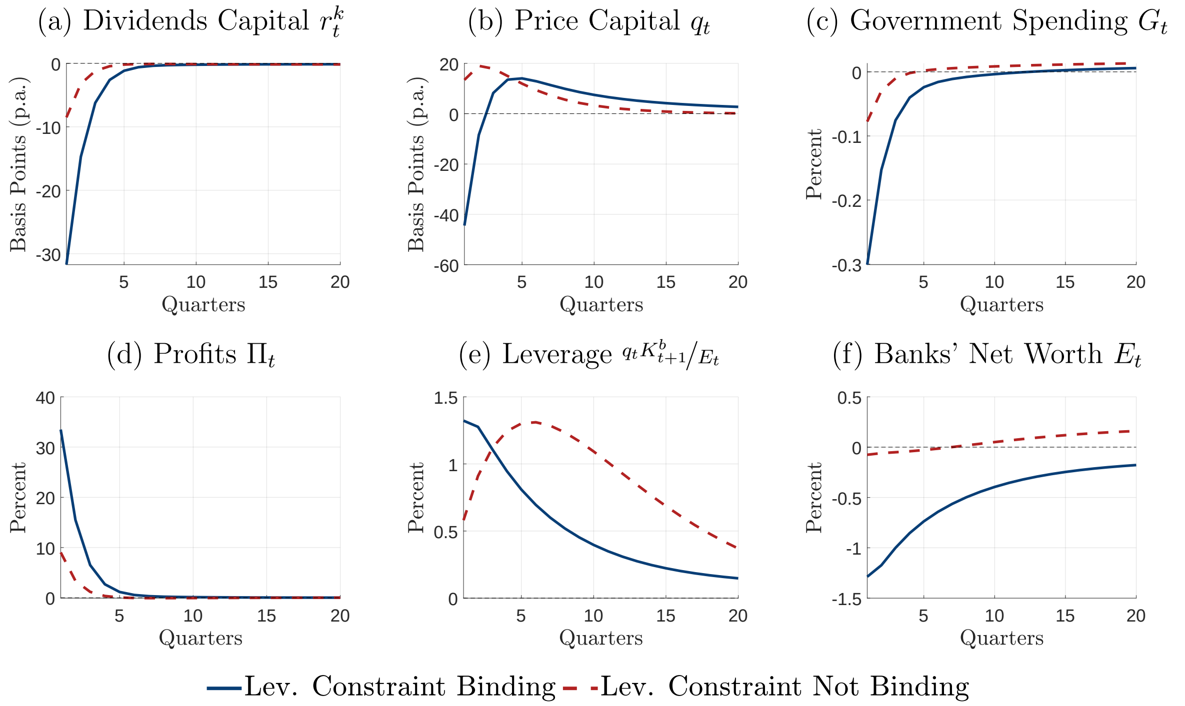
B Additional Impulse Responses

This section contains complementary impulse responses to those shown in the main text. I first provide the response of additional variables to a household income risk shock. I next provide the aggregate consequences of a discount factor shock.

B.1 Aggregate and Heterogeneous Consequences

Figure B.1 shows the response of additional variables to the household income risk shock considered in section 5.1. Blue solid lines show the impulse response functions when the leverage constraint is binding. Red dashed lines display the impulse response functions when the leverage constraint is not binding. Since capital and investment fall substantially more when the leverage constraint binds (see Figure 3), the dividends on this asset (panel a) and the price of capital (panel b) drop markedly. The larger contraction in output with an impaired financial system has a larger impact on tax revenues, and hence the government cuts government spending more strongly to balance the budget (panel c). A common feature of New Keynesian models with sticky prices is that profits are countercyclical to inflation (panel d), and they increase more when the leverage constraint binds, as a consequence of larger fall in output and, hence, inflation. Bank leverage increases in both situations, but substantially more when the financial system is unconstrained (panel e).[29]. This is so despite that banks' net worth markedly drops with a binding leverage constraint (panel f), as a consequence of the drop in asset prices (panel b).

Figure B.1: Impulse Response Functions to an Income Risk Shock

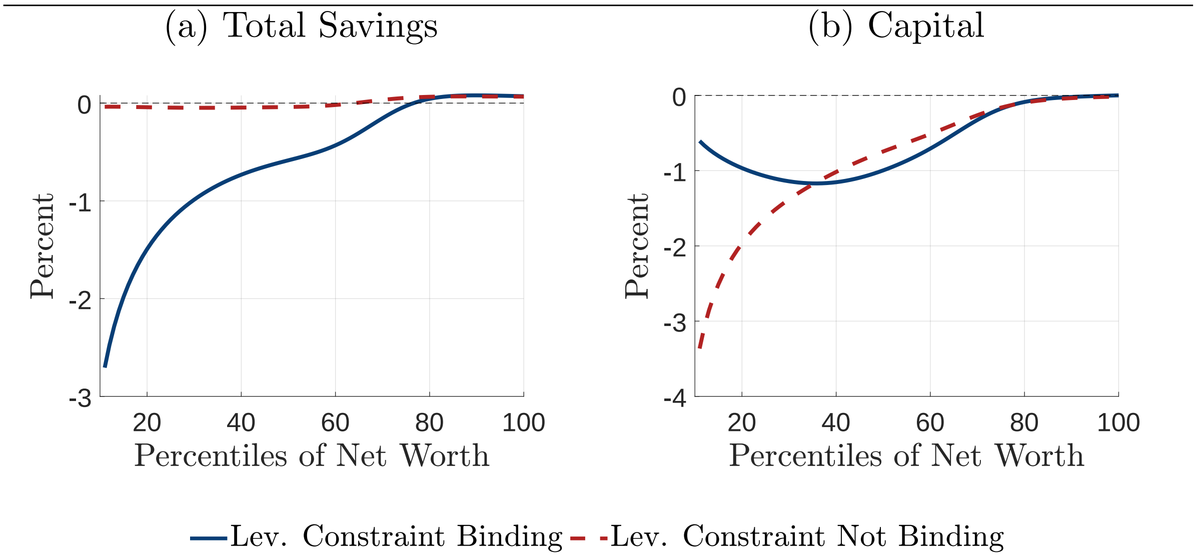


Notes: Impulse response functions to one standard-deviation increase in the variance of income shocks. Blue solid lines show the response in the baseline model, where the leverage constraint of financial intermediaries is binding. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding.

Figure B.2 shows the equilibrium response of total savings, $d_{i,t+1} + q_t k_{i,t+1}^h$, and illiquid claims on physical capital, $k_{i,t+1}^h$ along the net worth distribution two quarters after the shock to household income risk. Blue solid lines display the change when the leverage constraint binds. Red dashed lines show the case of a non-binding leverage constraint. In both cases, households reduce their holdings of illiquid claims on physical capital (panel b). This reduction is more pronounced when the leverage constraint is not binding, since excess returns do not increase (see Figure 3 in the main text). The difference is more pronounced for wealth-poor households. When the leverage constraint binds, these households already run down their savings in liquid deposits (see Figure 6 in the main text), and it is, therefore, more costly for them to further reduce their savings even in form of illiquid assets. Yet, because wealth-poor households hold most of their savings

[29]Leverage increases more on impact when the leverage constraint is binding because asset prices fall (see panel (b) in Figure B.1). Leverage quickly takes over with an unconstrained financial system, since the expansion in credit is larger in this case (see Figure 3).

Figure B.2: Change in individual total savings and capital



Notes: Left panel displays the equilibrium change in individual total savings $d_{i,t+1} + q_t k^h_{i,t+1}$ over the net worth distribution two quarters after the household income risk shock. The right panel shows the equilibrium change in capital holdings $k^h_{i,t}$ two quarters after the household income risk shock. The bottom 10% of the distribution is not shown since some households hold zero assets. Red dashed lines show the case of non-binding leverage constraint. Blue solid lines show the scenario with a binding leverage constraint. Changes by net worth percentile are computed using a local linear regression technique with a Gaussian kernel and a bandwidth of 0.1.

in form of liquid deposits, their total savings markedly fall when the leverage constraint binds (panel a). In the case of a non-binding leverage constraint, overall savings move little at all percentiles of the wealth distribution, as the fall in claims on physical capital (panel b) is largely offset by the increase in savings in form of liquid bank deposits (see Figure 6).[30]

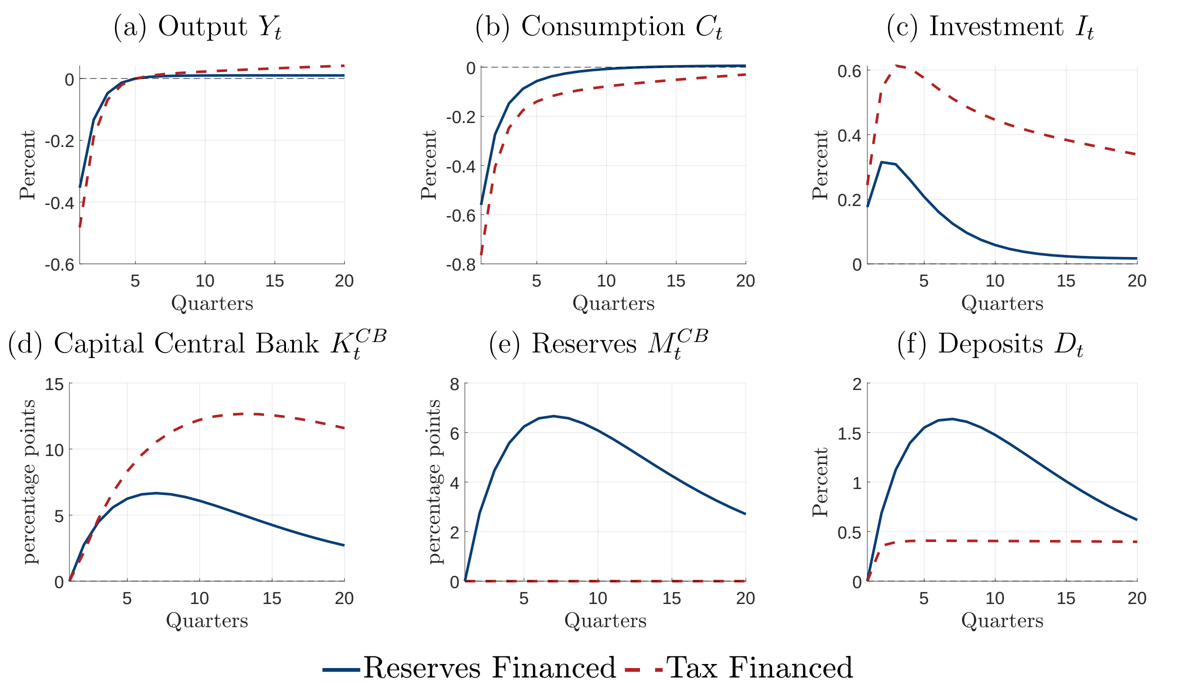
B.2 Stabilization Policy

Figure B.3 shows the impulse responses under the credit policy to a one-standard deviation income risk shock that increases households' demand for liquid savings when the leverage constraint is binding. Blue solid lines show the case where credit policy is financed by issuing reserves to banks. Red dashed lines show the responses in the situation where asset purchases are financed through lump-sum taxes on entrepreneurs, the shareholders of banks. In both situations I assume that the responses of the central bank to expected excess returns is equal to $\theta^{CB} = 100$. This implies that in both cases the central

[30] The small changes in total savings when the leverage constraint is not binding (dashed line in panel (a) of Figure B.2) is consistent with the muted response on impact of wealth inequality (dashed lines, Figure 7 in the main text). The response of individual total savings a few quarters later – not reported here – does show an larger build up of precautionary savings by wealth-poor households when the leverage constraint does not bind. This is consistent with the later fall in wealth inequality observed in Figure 7 for the case of an unconstrained financial system.

bank almost eliminates fluctuations in expected excess returns – not shown. As it can be observed in panel (d), the central bank has to double the size of its balance sheet when asset purchases are financed through lump-sum taxes (red dashed line) in order to achieve a similar stabilization to the case where the policy increases liquid assets (blue solid line).

Figure B.3: Stabilization Policy



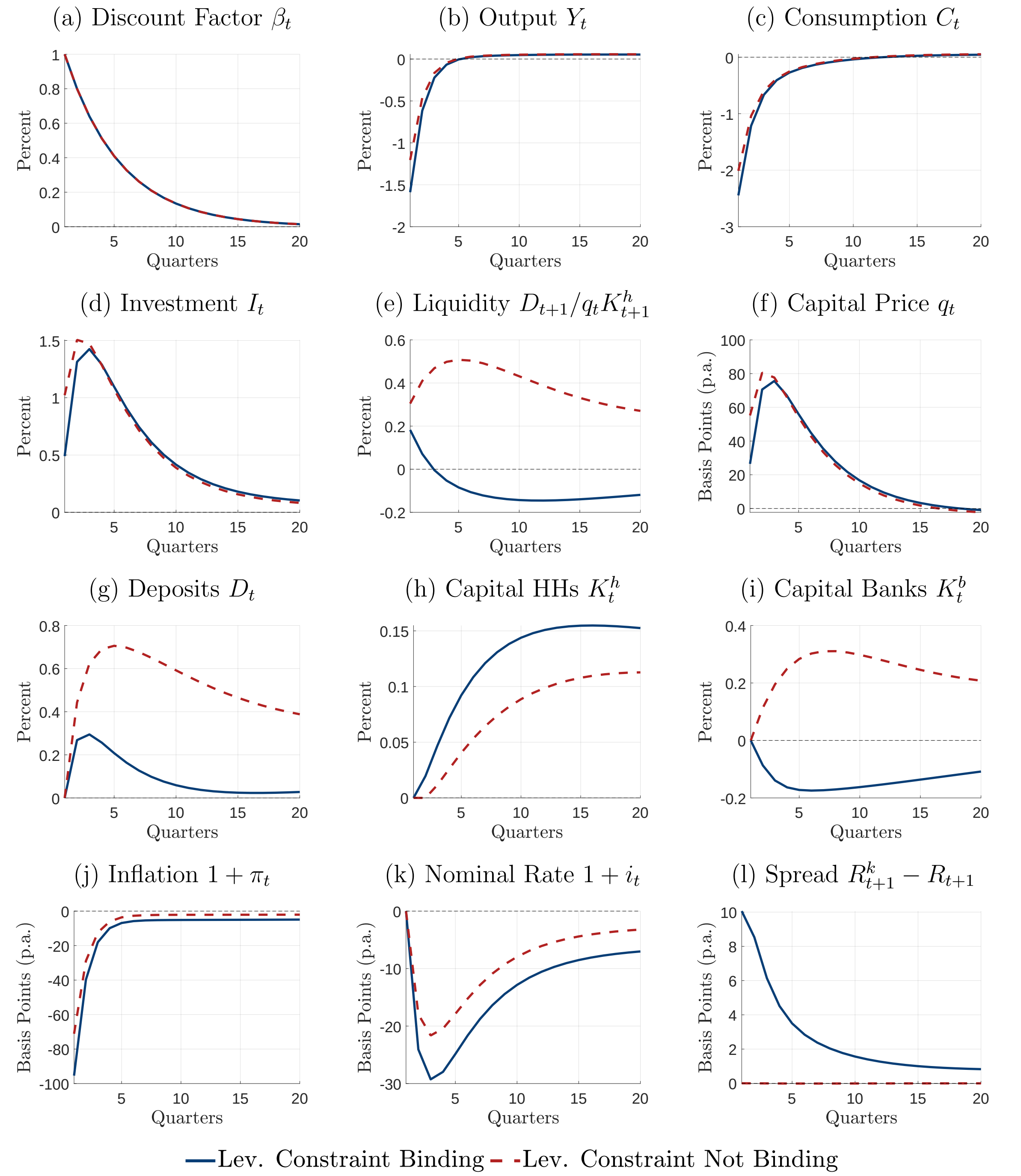
Notes: Impulse responses to a one-standard deviation income risk shock when the leverage constraint is binding under credit policy. Blue solid lines shows the case where the central bank finances asset purchases by issuing reserves to banks. Red dashed lines show the situation where, instead, asset purchases are financed through lump-sum taxes on entrepreneurs. In both cases, I set the response of the monetary authority to excess returns to $\theta^{CB} = 100$, see equations (47) and (48).

B.3 Discount Factor Shock

Figure B.4 shows the effects of a shock that increases the discount factor of households β by 1%. The shock is assumed to follow a $AR(1)$ process with persistence equal to 0.8. Blue solid lines show the responses when the leverage constraint is binding. Red dashed lines display the responses when the leverage constraint is not binding.

The increase in the discount factor makes households more patient, inducing them to reduce consumption and increase savings. More precisely, households seek to increase savings in all assets: both in the illiquid and liquid asset. Therefore, this shock does not increase the preference of households for a more liquid portfolio. As a result, financial frictions do not amplify the aggregate consequences of an increase in the discount factor, observe panels (b), (c) and (d). This is so although the financial system creates less liquid deposits when the leverage constraint binds (panel g). In this case, since households only seek to increase overall savings, they simply accumulate more illiquid claims on physical capital (panel h).

Figure B.4: Impulse Response Functions to a Discount Factor Shock

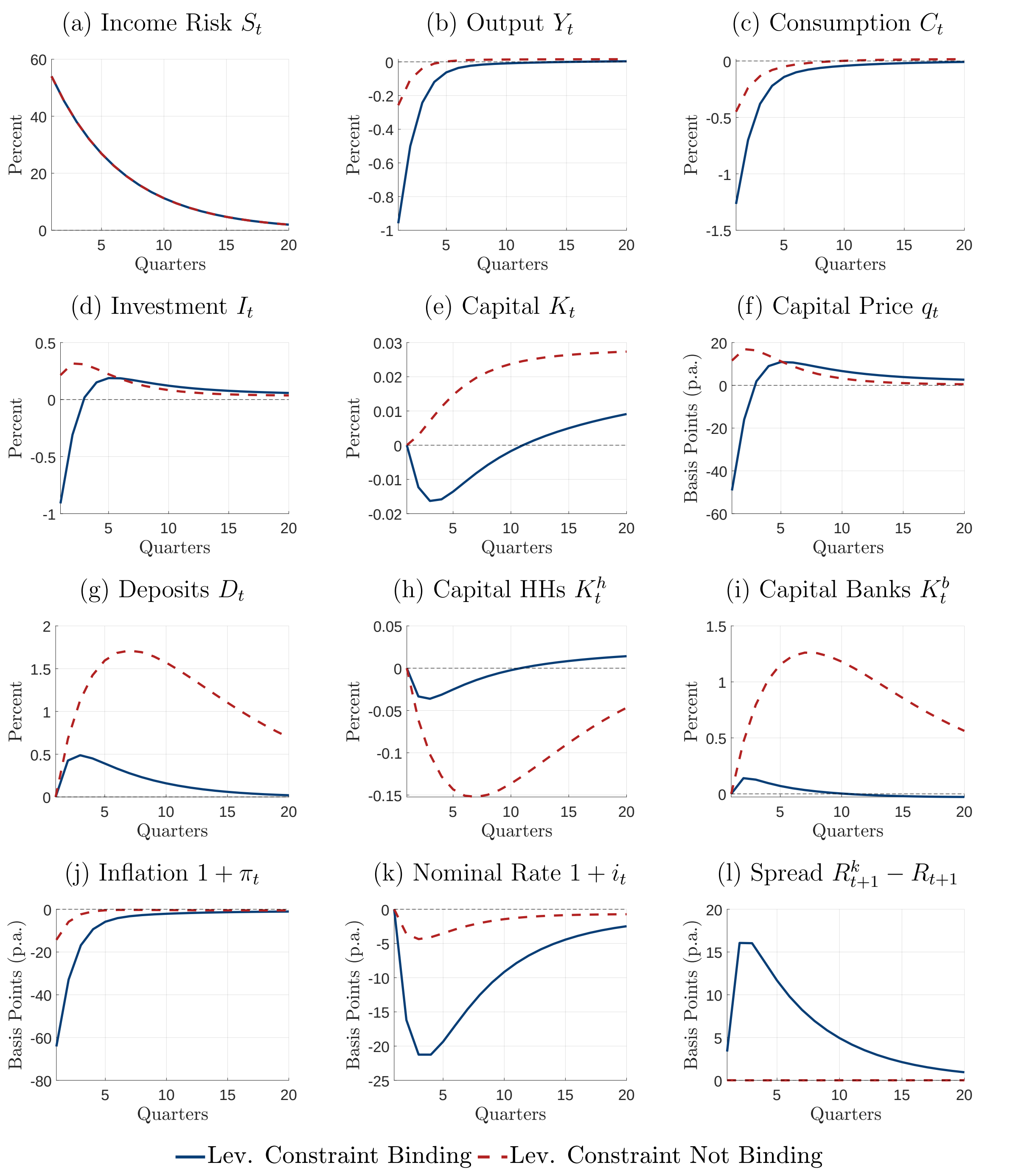


Notes: Impulse response functions to one percent increase in the discount factor β with persistence 0.8. Blue solid lines show the response in the baseline model, where the leverage constraint of financial intermediaries is binding. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding.

C Robustness Model Results

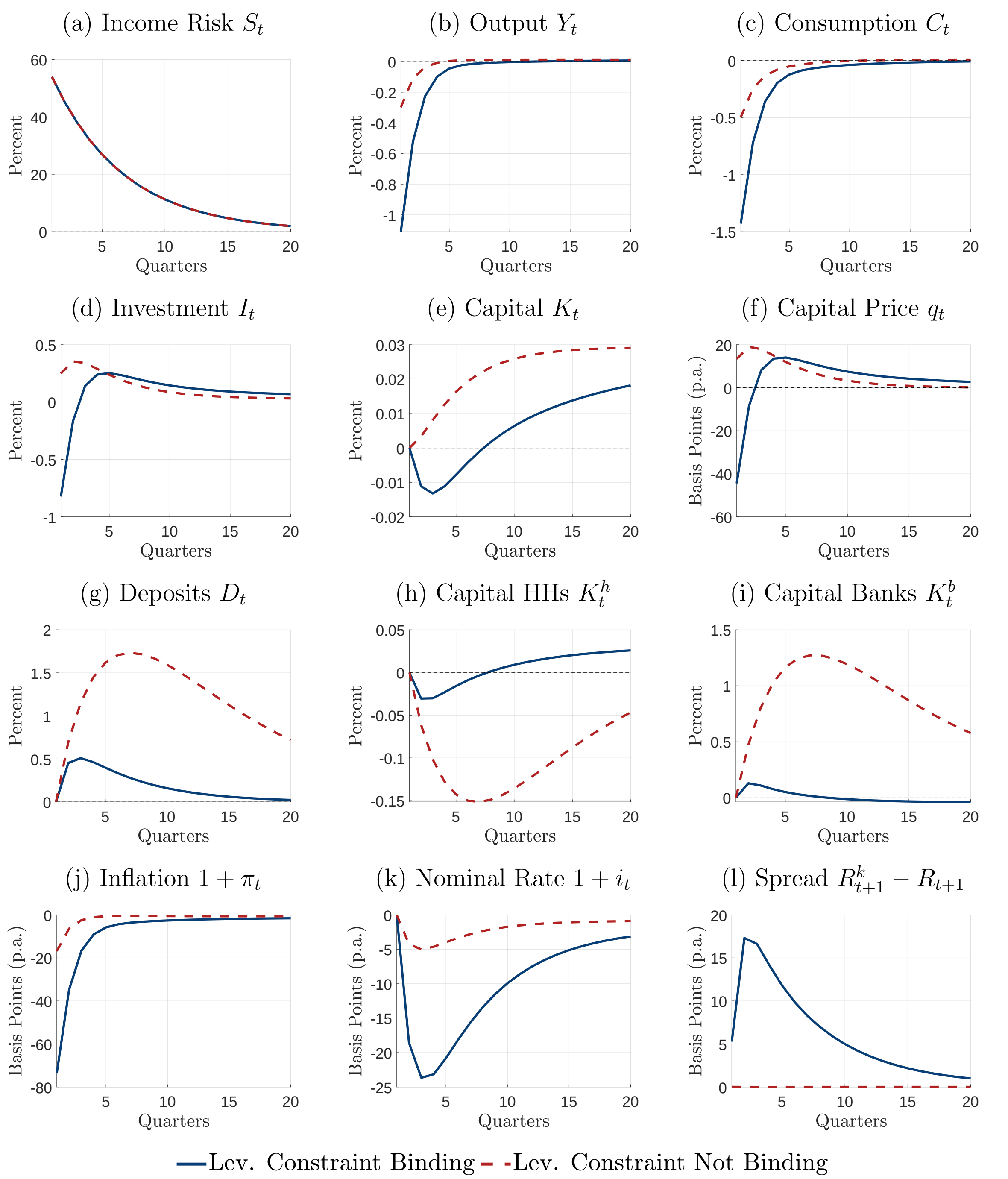
This section provides robustness checks regarding the main quantitative results of the paper. Figure C.1 shows dynamics of aggregate variables following an increase in income risk when the government adjusts the tax rate on income τ_t instead of government spending to balance the budget. In Figure C.2 I consider an scenario with more flexible prices $\kappa = 0.09$, implying an average price duration of four quarters. Finally, Figure C.3 entertains an scenario with a stronger response on the nominal interest rate to inflation $\theta_\pi = 1.5$. The amplification of idiosyncratic income risk shocks when financial frictions bind remain robust in all these scenarios.

Figure C.1: Aggregate consequences of an increase in income risk - τ_t adjusts



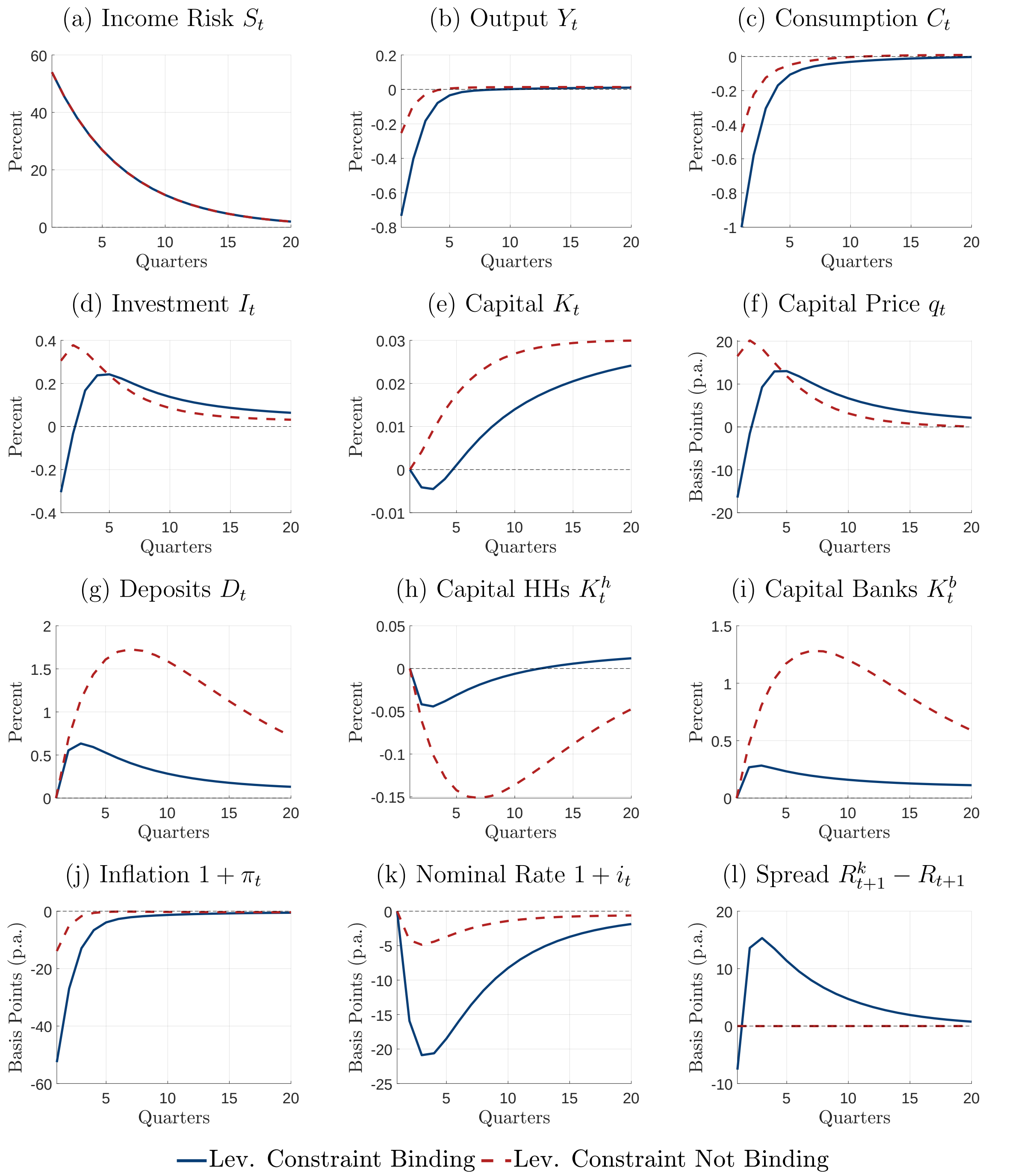
Notes: Impulse response functions to 1 standard-deviation increase in the variance of income shocks, when the income tax τ_t adjusts. Blue solid lines show the response in the baseline model. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding.

Figure C.2: Aggregate consequences of an increase in income risk - More flexible prices



Notes: Impulse response functions to 1 standard-deviation increase in the variance of income shocks, with $\kappa = 0.09$ impliying an average calvo duration of prices of 4 quarters. Blue solid lines show the response in the baseline model. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding.

Figure C.3: Aggregate consequences of an increase in income risk - Stronger response of monetary policy



Notes: Impulse response functions to 1 standard-deviation increase in the variance of income shocks, with a stronger response of the central bank to inflation $\theta_\pi = 1.5$. Blue solid lines show the response in the baseline model. Red dashed lines show the response in a counterfactual economy where the leverage constraint is not binding.

D Model With a Fixed Supply of Liquid Assets

This appendix contains the details regarding the two-asset model with a fixed supply of liquid assets discussed in section 5.2.1.

In this economy, the leverage constraint is not binding. More precisely, I assume that financial intermediaries always keep their supply of deposits, D_t, fixed at the steady-state level $\bar{D}$. Similarly, financial intermediaries are also assumed to keep their capital holdings fixed at the steady-state level $K_t^b = \bar{K^b}$. This assumption, effectively renders banks irrelevant for aggregate dynamics. I further assume that any capital gains or losses incurred by financial intermediaries are rebated to shareholders, the entrepreneurs. This ensures that the steady state of this economy without an active financial sector is the same as in my baseline, presented in section 3. The market clearing conditions for capital, (45), and deposits, (44), now read:

$$K_t = K_t^h + \bar{K^b}, \tag{51}$$

$$\bar{D} = \mathbb{E}_t \left[\nu d_{a,t}^* + (1-\nu) d_{n,t}^* \right]. \tag{52}$$