Bank Liquidity and Capital Regulation

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Abstract

We develop a nonlinear dynamic general equilibrium model with a banking sector and use it to study the macroeconomic impact of introducing a minimum liquidity standard for banks on top of existing capital adequacy requirements. The model generates a distribution of bank sizes arising from differences in banks' ability to generate revenue from a given quantity of loans and from occasionally binding capital and liquidity constraints. In equilibrium, the buffers of capital and liquidity above the required minimums are also endogenous. Under our baseline calibration, imposing a liquidity requirement would lead to a steady-state decrease of about 5 percent in the amount of loans made, an increase in banks' securities holdings of at least 12 percent, a fall in the interest rate on securities of about 25 basis points, and declines in output and consumption of about 1.0 percent and 0.6 percent, respectively. However, introducing a minimum liquidity requirement increases risk-based capital ratios, allowing banks to better withstand the impact of shocks to capital. Finally, our results are sensitive to the supply of safe assets. In particular, the larger the supply of securities, the smaller the macroeconomic impact of introducing a minimum liquidity standard for banks, all else being equal.

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1 Introduction

During times of financial stress, such as the recent crisis, financial intermediaries may experience rapid and large withdrawals of funds, motivated by investors' own funding needs as well as their concern about the intermediaries' solvency. If the intermediary either does not have sufficient funds on hand to accommodate the demand for withdrawals, or is (falsely) perceived to not have enough funds, demand for withdrawals may accelerate, leading to a run. In order to reduce the likelihood of such runs, the Basel III regulatory requirements have introduced rules on banks such at the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR). Roughly speaking, these new regulations require banks to hold sufficient liquid assets to accommodate expected demand for withdrawals of certain types of liabilities over different time intervals.

Although such liquidity requirements may reduce the likelihood of bank runs, and of financial crises more generally, they likely come with some cost. By forcing banks to hold a higher fraction of their assets as low-risk, highly liquid securities, these regulations may reduce the quantity and price of loans. These regulations may also interact with previously existing regulations such as capital requirements. Since such regulations are new to most countries, it is difficult to do empirical analysis of the effects of their imposition.[1]

In this paper, we develop a nonlinear dynamic general equilibrium model and use it to study the macroeconomic impact of introducing a minimum liquidity standard for banks on top of existing capital adequacy requirements. The liquidity standard requires banks to hold a certain portion of their portfolio in assets that either have a zero or relatively low risk weight. The model generates a distribution of bank size arising from heterogeneity in bank productivity—that is, some banks are able to obtain more revenue from a given quantity of loans made—and from *occasionally binding* capital and liquidity constraints. In equilibrium, the amount of capital and liquidity above the required minimums—the capital and liquidity "buffers"—are also endogenous. We present partial equilibrium and general equilibrium results as well as transitional dynamics between steady states.[2]

Under a liquidity standard, and based on a scenario assuming a 30 percent fall in deposits,

[1]There is a substantial theoretical literature on the nature of liquidity, but its focus is on the financial sector more broadly. See, for example, Holmström and Tirole [1996], Farhi, Golosov, and Tsyvinski [2009], Holmström and Tirole [2001], Holmström and Tirole [2011], Brunnermeier and Pedersen [2009], and Bolton, Santos, and Scheinkman [2011]. Diamond and Rajan [2011] and Freixas, Martin, and Skeie [2010] discuss the role of liquidity in the banking sector more specifically.

[2]In general equilibrium, market prices—interest rates on loans and securities, the return on capital, and the wage rate—are allowed to adjust to their new equilibrium values.

we find that, in general equilibrium, loans would decline by about 5 percent and securities would increase by over 12 percent in the new steady state on the assets side of banks' balance sheets. On the liabilities side, deposits are little changed and bank equity rises. The introduction of a liquidity standard prevents the most productive banks from fully exploiting their profit opportunities, which reduces the supply of bank loans and increases the cost of funds. As a result, aggregate output falls by about 1 percent and consumption drops by about 0.6 percent in the new steady state. In addition, the introduction of a liquidity requirement induces the bank to finance a larger portion of its assets with equity, resulting in a rise in the capital buffer above the minimum requirement by 1 percentage point. We also show that our results are somewhat sensitive to the supply of safe assets in our economy. In particular, we study the sensitivity of our results to the availability of securities that are not explicitly modeled in our framework, such as debt securities with the backing of the U.S. Government. Overall, we find that the macroeconomic impact of introducing a liquidity requirement in our economy is mitigated as the availability of safe assets increases.

We also analyze the responses in our economy to an increase in capital requirements from 6 to 10 percent. The increase in capital requirements acts as a tax on assets with non-zero risk-weights, so bankers' portfolios become slightly more concentrated in securities, which carry a zero risk-weight. However, the increase in capital requirements also makes it more difficult for the banker to smooth its dividend stream, which increases the desire for the banker to reduce risk and increase its securities holdings even more. The increase in demand for securities leads to a decrease in the equilibrium return on securities. If the precautionary effect is sufficiently strong, the reduction in loans induced by the increase in capital requirements could be offset by the asset pricing effects. Indeed, in general equilibrium we report that the stock of loans is about unchanged as the increase in the demand for securities leads to a substantial reduction in its rate of return making loans relatively more attractive despite the increase in risk weights. On the liabilities side, bank deposits are little changed, while equity holdings increase by over 33 percent.

In our framework, the general equilibrium effects on the banking variables are considerably smaller than the partial equilibrium effects. This illustrates the importance of using general equilibrium modeling to estimate the macroeconomic impact of these regulatory changes; an alternative approach of using models of the banking sector to estimate the impact of banking variables, and then applying that impact to other macroeconomic variables, would be misleading. However, the large difference between the partial and general equilibrium models also means that the results are sensitive to potential misestimates of the general equilibrium effects of banking choices on prices.

Finally, we also study the effects of a wealth transfer from bankers to workers and entrepreneurs both in the case where there is just a capital requirement and in the case where there are both capital and liquidity requirements. Our exercise uses a wealth transfer of the size comparable to bank losses reported in the 2009 U.S. stress tests. We find that in the case with just capital requirements, loan spreads would increase by about 100 basis points in response to a wealth transfer equivalent to 7.5 percent of U.S. gross domestic product. In the case where there are both capital and liquidity requirements, loan spreads increase by about 80 basis points because under the liquidity requirement banks have a slightly larger capital buffer, allowing them to better withstand the impact of the capital shortfall shock.

The model developed in this paper is closely related to the papers by Covas [2006] and Angeletos [2007]. These two papers augment the standard model with uninsurable labor income risk, as in Bewley [1986], Imrohoroğlu [1992], Huggett [1993], and Aiyagari [1994], with an entrepreneurial sector subject to uninsurable investment risk. We expand those models and augment the standard Bewley model with both an entrepreneurial and banking sectors. The bankers in our economy are subject to uninsurable profitability risk and the regulatory capital constraint faced by bankers in our model corresponds to a borrowing constraint faced by workers and entrepreneurs. The main difference is that we assume a lower degree of risk aversion for bankers and a considerably larger borrowing capacity to enhance the realism of the model. In order to study the response of our economy to changes in regulatory requirements we focus on transitional dynamics between steady states, as in Kitao [2008]. In addition, the problem solved by the banker in our paper is somewhat similar to the problem analyzed by De Nicolò, Gamba, and Lucchetta [2013], although unlike in that paper our results are obtained under general equilibrium.

This paper is also closely related to the literature on the macroeconomic impact of banking frictions in otherwise standard macroeconomic models. Van den Heuvel [2008] studies the welfare costs of capital requirements in a general equilibrium model with moral hazard. He and Krishnamurthy [2010] develop a model in which bankers are risk-averse and bank capital plays an important role in the determination of equilibrium prices. Finally, there is an emerging literature on macro-prudential regulation including the work by Gertler and Karadi [2011], Gertler and Kiyotaki [2011], Kiley and Sim [2011], and Gertler, Kiyotaki, and Queralto [2011] which is also important to our work, although that research proceeds from different modeling assumptions.[3]

[3] There is also an empirical literature on the role of capital and capital regulations in the trans-

The remainder of the paper proceeds as follows. Section 2 describes the model. Section 3 presents the model calibration. Section 4 discusses the baseline economy and policy experiments and section 5 analyzes the transitional dynamics between steady states. Section 6 discusses the effects of a capital shortfall in the banking sector with and without a liquidity requirement. Section 7 concludes.

2 The Model

We construct a general equilibrium model with agents that face uninsurable risks.[4] We consider three types of agents: (i) workers; (ii) entrepreneurs; and (iii) bankers. Agents are not allowed to change occupations. Workers supply labor to entrepreneurs and face labor productivity shocks which dictates their earning potential. Entrepreneurs can invest in their own technology and face investment risk shocks which determine their potential profitability. Bankers play an intermediation role in this economy by accepting deposits from workers and making loans to entrepreneurs. In addition, bankers can also invest in riskless securities. Bankers are subject to revenue shocks that determine their potential profitability. An important feature of the banker's problem is the presence of occasionally binding capital and liquidity constraints.

The model generates real effects of changes in capital and liquidity requirements through two violations of the Modigliani-Miller theorem. First, banks are not indifferent to their form of finance due to both the presence of capital requirements and the absence of outside equity. Second, entrepreneurs are assumed to be dependent on bank loans.[5]

Workers. As in Aiyagari [1994] workers are heterogeneous with respect to wealth holdings and earnings ability. Since there are idiosyncratic shocks, the variables of the model will differ across workers. To simplify notation, we do not index the variables to indicate this

mission of macroeconomic shocks. See, for example, Peek and Rosengren [1995b], Peek and Rosengren [1995a], Berrospide and Edge [2010], Blum and Hellwig [1995], Concetta Chiuri, Ferri, and Majnoni [2002], Cosimano and Hakura [2011], Francis and Osborne [2009], Hancock and Wilcox [1993], Hancock and Wilcox [1994], Kishan and Opiela [2006], Kishan and Opiela [2000], and Repullo and Suarez [2013].

[4] Examples of similar models include Aiyagari [1994] and Quadrini [2000] for workers and entrepreneurs, respectively.

[5] The assumption of bank-dependence for the entrepreneurial sector is in accordance with the literature on the credit channel of monetary policy, which also assumes that some firms, particularly smaller ones, do not have the same amount of access to other forms of finance. See, for, example, Bernanke and Blinder [1988], Peek and Rosengren [2000], Gertler and Gilchrist [1993], Kashyap and Stein [2000], Kashyap and Stein [1994], Driscoll [2004], and Ashcraft [2005].

cross-sectional variation. Let c_t^w denote the worker's consumption in period t, d_t^w denote the deposit holdings and a_t^w denote the worker's asset holdings in the same period, and ϵ_t is a labor-efficiency process which follows a first-order Markov process. Workers choose consumption to maximize expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta_w^t u(c_t^w, d_{t+1}^w)$$

subject to the following budget constraint:

$$c_t^w + d_{t+1}^w + a_{t+1}^w = w\,\epsilon_t + R^D d_t^w + R\,a_t^w,$$

where $0 < \beta_w < 1$ is the worker's discount factor, w is the worker's wage rate, and R^D is the gross rate on deposits and R is gross return on capital. We assume workers are subject to a borrowing constraint; that is $a_{t+1}^w \geqslant \underline{a}$, where $\underline{a} \leqslant 0$. The wage and the return on capital are determined in general equilibrium such that labor and corporate capital markets clear in the steady state. Also, note that we have introduced a demand for deposits by assuming that its holdings bring utility to the worker. However, the deposit rate is assumed to be exogenous since, as described later, bankers take as given the stock of deposits.

Let $v^w(z, x_w)$ be the optimal value function for a worker with earnings ability ϵ and cash on hand x_w.[6] The entrepreneur's optimization problem can be specified in terms of the following dynamic programming problem:

$$\begin{aligned} v^w(\epsilon, x_w) &= \max_{c_w, d'_w, a'_w} u(c_w) + \beta_w E[v(\epsilon', x'_w)|\epsilon], \qquad (1)\\ \text{s.t.} \quad c_w + d'_w + a'_w &= x_w, \\ x'_w &= w\,\epsilon' + R^D d'_w + R\,a'_w, \\ a'_w &\geqslant \underline{a}. \end{aligned}$$

The full list of parameters of the worker's problem is shown at the top of Table 1.

Entrepreneurs. Entrepreneurs are also heterogeneous with respect to wealth holdings and productivity of the individual-specific technology that they operate. Entrepreneurs choose

[6]Because the worker's problem is recursive, the subscript t is omitted in the current period, and a prime denotes the value of the variables one period ahead.

consumption to maximize expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta_e^t u(c_t^e),$$

where $0 < \beta_e < 1$ is the entrepreneur's discount factor. Each period, the entrepreneur can invest in an individual-specific technology (risky investment), or invest its savings in securities. The risky technology available to the entrepreneur is represented by

$$y_t = z_t f(k_t, l_t),$$

where z_t denotes productivity, k_t is the capital stock in the risky investment and l_t is labor. This investment is risky because the stock of capital is chosen before productivity is observed. The labor input is chosen after observing productivity. The idiosyncratic productivity process follows a first-order Markov process. As is standard, capital depreciates at a fixed rate δ.

In addition, the entrepreneur is allowed to borrow to finance consumption and the risky investment. Let b_{t+1}^e denote the amount borrowed by the entrepreneur and R^L denote the gross rate on bank loans. The loan rate is determined in general equilibrium. Borrowing is constrained, for reasons of moral hazard and adverse selection that are not explicitly modeled, to be no more than a fraction of entrepreneurial capital:

$$b_{t+1}^e \geqslant -\kappa\, k_{t+1},$$

where κ represents the fraction of capital that can be pledged at the bank as collateral. Entrepreneurs that are not borrowing to finance investment can save through a riskless security, denoted by s^e with a gross return R^S which will also be determined in general equilibrium.

Under this set of assumptions, the entrepreneur's budget constraint is as follows:

$$c_t^e + k_{t+1} + b_{t+1}^e + s_{t+1}^e = x_t^e,$$
$$x_{t+1}^e = z_{t+1} f(k_{t+1}, l_{t+1}) + (1 - l_{t+1})w + (1-\delta)k_{t+1} + R^L b_{t+1}^e + R^S\, s_{t+1}^e,$$

where x_t^e denotes the entrepreneur's period t wealth. It should be noted that the entrepreneur can also supply labor to the corporate sector or other entrepreneurial businesses.

Let $v^e(z, x_e)$ be the optimal value function for an entrepreneur with productivity z and wealth x_e.[7] The entrepreneur's optimization problem can be specified in terms of the following dynamic programming problem:

$$v^e(z, x_e) = \max_{c_e, k', b'_e, s'_e} u(c_e) + \beta_e E[v(z', x'_e)|z], \tag{2}$$

$$\begin{aligned} \text{s.t.} \quad c_e + k' + s'_e + b'_e &= x_e, \\ x'_e &= \pi(z', k'; w) + (1-\delta)k' + R^L b'_e + R^S s'_e, \\ 0 \geqslant b'_e &\geqslant -\kappa\, k', \\ s'_e &\geqslant 0, \\ k' &\geqslant 0, \end{aligned}$$

where $\pi(z', k'; w)$ represents the operating profits of the entrepreneur's and incorporates the static optimization labor choice. From the properties of the utility and production functions of the entrepreneur, the optimal levels of consumption and the risky investment are always strictly positive. The constraints that may be binding is the choice of bank loans, b'_e and security holdings s'_e. The full list of parameters of the entrepreneur's problem is shown in the middle panel of Table 1.

Bankers. Bankers are heterogeneous with respect to wealth holdings, loan balances, deposit balances and productivity. Bankers choose consumption to maximize expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta_b^t u(c_t^b)$$

where $0 < \beta_b < 1$ is the banker's discount factor.

Bankers hold two types of assets—risky loans (b) and riskless securities (s)—and fund those assets with deposits (d) and equity (e). Loans can also be funded by short-selling securities—implying s can be negative if the amount of such wholesale funding is greater than the holdings of such assets.

Each period, the banker chooses the amount of loans it makes to the entrepreneurs, denoted by b_{t+1}. Loans, which are assumed to mature at a rate $\bar{\delta}$, yield both interest- and noninterest-income (the latter, for example, through fees, which are a substantial part of bank income). Banks may differ in their ability to extract net revenue from loans due to (unmodeled) differences in ability to screen applicants, monitor borrowers, or in market

[7] Because the entrepreneur's problem is recursive, the subscript t is omitted in the current period, and we let the prime denote the value of the variables one period ahead.

power. For analytical convenience, we represent net revenue in period t from the existing stock of loans b_t as:

$$y_t^b = (R^L - \phi_b)b_t + \theta_t g(b_t)$$

where θ_t denotes the idiosyncratic productivity of the bank, the function $g(b_t)$ exhibits decreasing returns to scale, and ϕ_b is the cost of operating the loan technology.

The banks also face adjustment costs in changing the quantity of loans, which allows us to capture the relative illiquidity of such assets. In particular, the adjustment costs are parameterized by

$$\Psi(b_{t+1}, \bar{\delta}b_t) \equiv \frac{\nu_t}{2}\left(\frac{b_{t+1} - \bar{\delta}b_t}{b_t}\right)^2 b_t,$$

where

$$\nu_t \equiv \nu^+ 1_{\{b_{t+1} \geqslant \bar{\delta}b_t\}} + \nu^- 1_{\{b_{t+1} < \bar{\delta}b_t\}}.$$

In our calibration, we will assume that the cost of adjusting the stock of loans downwards is much greater than the cost of adjusting it upwards—reflecting the idea that calling in or selling loans is more costly than originating loans.

Net returns from the bank's securities holdings is given by:

$$y_t^s = R^S s_t,$$

which may be negative if the bank is short-selling securities.[8] The banker's budget constraint is written as follows:

$$\begin{aligned} c_t^b + b_{t+1} + s_{t+1} + d_{t+1} &= x_t^b - \Psi(b_{t+1}, \bar{\delta}b_t), \\ x_{t+1}^b &= (R^L - \phi_b)b_{t+1} + \theta_{t+1}g(b_{t+1}) + R^S s_{t+1} + R^D d_{t+1}. \end{aligned}$$

where x_t^b denotes the banker's period t wealth and d_{t+1} the stock of deposits. The bank borrows through deposits that it receives from the workers, but can also borrow by selling securities to other bankers or entrepreneurs. For simplicity, we assume the share of deposits received by each bank is exogenous and follows a four-state first-order Markov Chain (see appendix). However, the borrowing that is funded by entrepreneurs and other bankers is endogenous and it is constrained due to the existence of capital requirements. Letting e_{t+1}

[8]A more realistic formulation would differentiate between securities as asset holdings and wholesale deposits and other types of wholesale funding. This additional realism would come at considerable computational cost, which is why we have pursued the current approach.

denote banks' equity, the capital requirement may be written as:

$$e_{t+1} \geqslant \chi b_{t+1},$$

which is equivalent to a risk-based capital requirement, giving a zero risk weight to securities. The capital requirement may in turn be rewritten as (since $e_{t+1} = x_t^b - \Psi(b_{t+1}, \bar{\delta} b_t) - c_t^b$):

$$s_{t+1} \geqslant (\chi - 1) b_{t+1} - d_{t+1}.$$

We also impose a liquidity requirement, in which we assume that cash on hand—which consists of the return on existing securities holdings and the net revenue from paydowns on existing loans—must be sufficient to satisfy demand for deposit withdrawals under a liquidity stress scenario and interest payments on deposits. This can be represented as:

$$R^S s_{t+1} + \bar{\delta} b_{t+1} \geqslant (d_{\{s-1,1\}^+} - R^D d_{t+1}) \tag{3}$$

where $d_{\{s-1,1\}^+}$ represents a decline in the stock of deposits (note that $d < 0$). Since d_t follows a Markov Chain, if in period t the bank is in state s then deposit withdrawals correspond to state $\{s-1, 1\}^+$. The stringency of the liquidity requirement is given by the assumption about the relative size of the bad deposits realization. It will be calibrated through an assumption of how quickly deposits would run off in a crisis situation.[9]

Let $v^b(\theta, x^b, b, d')$ be the optimal value function for a banker with wealth x^b, loans b, deposits d', and productivity θ. The banker's optimization problem can be specified in terms of the following dynamic programming problem:

$$v^b(\theta, x_b, b, d') = \max_{c_b, b', s'} u(c^b) + \beta_b E[v^b(x_b', b', d'', \theta') | \theta, d'], \tag{4}$$

$$\begin{aligned} \text{s.t.} \quad c_b + b' + s' + d' &= x_b - \Psi(b', \bar{\delta} b) \\ x_b' &= (R^L - \phi_b) b' + \theta' g(b') + R^S s' + R^D d' \\ e' &\geqslant \chi b', \\ R^S s' + \bar{\delta} b' &\geqslant (d_{\{s-1,1\}^+} - R^D d') \end{aligned}$$

[9] In the sensitivity analysis section below we also explore the possibility of involuntary drawdowns on loan commitments that are usually observed during financial crisis. For example, according to Santos [2011] the average drawdown rate for nonfinancial borrowers is 23 percent, and those are significantly higher during recessions and financial crisis.

Corporate sector. In this economy there is also a corporate sector that uses a constant-returns-to-scale Cobb-Douglas production function, which uses the capital and labor or workers and entrepreneurs as inputs. The aggregate technology is represented by:

$$Y_t = F(K_t, L_t),$$

and aggregate capital, K_t is assumed to depreciate at rate δ.

Definition 1 summarizes the steady-state equilibrium in this economy.

Definition 1 *The steady-state equilibrium in this economy is: a value function for the worker, $v^w(\epsilon, x^w)$, for the entrepreneur $v^e(z, x^e)$, and for the banker, $v^b(\theta, x_b, b, d')$; the worker's policy functions $\{c^w(\epsilon, x^w), d^w(\epsilon, x^w), a^w(\epsilon, x^w)\}$; the entrepreneur's policy functions $\{c^e(z, x_e),\ k(z, x_e), l(z, x_e), b^e(z, x_e), a^e(z, x_e)\}$; the banker's policy functions $\{c^b(x_b, b, \theta, d'),$ $b^b(x_b, b, \theta, d'), s(x_b, b, \theta, d'), d(x_b, b, \theta, d')\}$; a constant cross-sectional distribution of worker's characteristics, $\Gamma_w(\epsilon, x^w)$ with mass η; a constant cross-sectional distribution of entrepreneur's characteristics, $\Gamma_e(z, x^e)$ with mass ν; a constant cross-sectional distribution of banker's characteristics, $\Gamma_b(x_b, b, \theta, d')$, with mass $(1 - \eta - \nu)$; and prices (R^D, R^L, R, w), such that:*

1. *Given R^D, R, and w, the worker's policy functions solve the worker's decision problem (1).*

2. *Given R, R^L, and w, the entrepreneur's policy functions solve the entrepreneur's decision problem (2).*

3. *Given R^D, R^L, R^S, the banker's policy functions solve the banker's decision problem (4).*

4. *The loan, securities, and deposit markets clear:*

$$\nu \int b^e \, d\Gamma_e = (1 - \eta - \nu) \int b^b \, d\Gamma_b, \qquad \text{(Loan market)}$$

$$\bar{S} = \nu \int s^e \, d\Gamma_e + (1 - \eta - \nu) \int s^b \, d\Gamma_b, \qquad \text{(Securities market)}$$

$$\eta \int d^w \, d\Gamma_w = (1 - \eta - \nu) \int d^b \, d\Gamma_b. \qquad \text{(Deposit market)}$$

5. *Corporate sector capital and labor are given by:*

$$K = \eta \int a^w \, d\Gamma_w$$
$$L = (\eta + \nu) - \nu \int l \, d\Gamma_e.$$

6. *Given K and L, the factor prices are equal to factor marginal productivities:*

$$R = 1 + F_K(K, L) - \delta,$$
$$w = F_L(K, L).$$

7. *Given the policy functions of workers, entrepreneurs, and bankers, the probability measures of workers, Γ_w, entrepreneurs, Γ_e, and bankers, Γ_b, are invariant.*

3 Calibration

The properties of the model can be evaluated only numerically. We assign functional forms and parameters values to obtain the solution of the model and conduct comparative statics exercises. We choose one period in the model to represent one year.

Workers' and entrepreneurs' problems. The parameters of the workers' and entrepreneurs' problems are fairly standard, with the exception of the discount factor of entrepreneurs, which is chosen to match the loan rate. The period utility of the workers is assumed to have the following form:

$$u(c_e, d'_w) = \omega \left(\frac{c_w^{1-\gamma_w}}{1 - \gamma_w} \right) + (1 - \omega) \ln(d'_w),$$

where ω is the relative weight on the marginal utility of consumption and deposits and γ_w is the risk aversion parameter. We set γ_w to 2, a number often used in representative-agent macroeconomic models. We set ω equal to 0.915 to match the ratio of banking assets relative to output. The discount factor of workers is set at 0.96, which is standard.

We adopt a constant relative risk-aversion (CRRA) specification for the utility function of entrepreneurs:

$$u(c_e) = \frac{c_e^{1-\gamma_e}}{1 - \gamma_e}.$$

Table 1: Parameter Values Under Baseline Calibration

Parameter	Description	Value
Worker's parameters:		
β_w	Discount factor	0.96
γ_w	Coefficient of relative risk aversion	2.0
ω	Weight on consumption	0.92
ρ_ϵ	Persistence of earnings risk	0.70
σ_ϵ	Unconditional s.d. of earnings risk	0.22
$\underline{a}$	Borrowing constraint	0.0
η_w	Mass of workers	0.66
Entrepreneur's parameters:		
β_e	Discount factor	0.95
γ_e	Coefficient of relative risk aversion	2.0
ρ_z	Persistence of productivity risk	0.70
σ_z	Unconditional s.d. of productivity risk	0.25
κ	Borrowing constraint	0.70
α	Capital share	0.46
ν	Labor share	0.35
δ	Depreciation rate	0.08
η_e	Mass of entrepreneurs	0.33
Banker's parameters:		
β_b	Discount factor	0.95
γ_b	Coefficient of Relative Risk Aversion	1.0
$\underline{\chi}$	Capital requirements	0.06
$\bar{\delta}$	Loan maturity	0.24
α_b	Curvature of loan revenues	0.55
ρ_θ	Persistence of shock to loan revenues	0.85
σ_θ	Unconditional s.d. of shock to loan revenues	0.10
ρ_d	Persistence of shock to deposits	0.80
σ_d	Unconditional s.d. of shock to deposits	0.08
ϕ_b	Intermediation cost	0.13
ν^-	Adjustment cost for decreasing loans	0.04
ν^+	Adjustment cost for increasing loans	0.02
Corporate sector's parameters:		
α_c	Capital share	0.36
δ_c	Depreciation rate	0.08

We set γ_e to 2, close to that of Quadrini [2000]. The idiosyncratic earnings process of workers is first-order Markov and—as in Aiyagari [1994]—the serial correlation parameter ρ_ϵ is set to 0.70, and the unconditional standard deviation σ_ϵ set to 0.22. Although we lack direct information to calibrate the stochastic process for entrepreneurs, we make the reasonable assumption that the process should be at least as persistent as the one of workers. Doing so is also consistent with the evidence provided by Hamilton [2000] and Moskowitz and Vissing-Jørgensen [2002] that the idiosyncratic risk facing entrepreneurs is larger than the idiosyncratic risk facing workers. Hence we set the serial correlation of entrepreneurs to 0.70 and the unconditional standard deviation to 0.25.

As is standard in the business cycle literature, we choose a depreciation rate δ of 8 percent for the entrepreneurial as well as the corporate sector. The degree of decreasing returns to scale for entrepreneurs is equal to 0.81—slightly less than Cagetti and De Nardi [2006]—with a capital and labor shares of 0.46 and 0.35, respectively. As in Aiyagari [1994] we assume workers are not allowed to have negative assets, and let the maximum leverage ratio of entrepreneurs to be at about 70 percent, which corresponds to κ set to 0.7.[10]

The discount factor of entrepreneurs is chosen to match the average loan rate between 1997 and 2012. Based on bank holding company and call report data the weighted average real interest rate charged on loans of all types was 4 percent. By setting β_e to 0.95 we obtain this calibration.

Bankers' problem. We divide the set of parameters of the bankers' problem into two parts: (i) parameters set externally, and (ii) parameters set internally. The parameters set externally are taken directly from outside sources. These include the loan maturity, $\bar{\delta}$, and the capital constraint parameter, χ. In addition, we assume the banker has log utility to minimize the amount of precautionary savings induced by occasionally binding capital and liquidity constraints. The remaining nine parameters of the banker's problem are determined so that a set of nine moments in the model are close to a set of nine moments available in the bank holding company and commercial bank call reports. The lower panel in Table 1 reports the parameter values assumed in the parametrization of the model.

We now describe the parameters set externally. For the capital constraint we assume that the minimum capital requirement in the model is equal to 6 percent, which corresponds to the minimum tier 1 ratio a bank must maintain to be considered well capitalized. Thus, χ equals 0.06. The loan maturity parameter, $\bar{\delta}$, is set to 0.24 so that the average maturity

[10]Leverage is defined as debt to assets, that is $-b/k$. At the constraint $b = -\kappa k$, the maximum leverage in the model is equal to $\kappa = 0.70$.

Table 2: Selected Moments

Moment	Data	Model
Tier 1 capital ratio	10.0	9.7
Share of constrained banks	0.1	0.3
Leverage ratio	7.0	6.3
Adjusted return-on-assets	2.9	3.4
Cross-sectional volatility of adjusted return-on-assets	1.3	1.4
% Safe assets held by banks	33.2	34.4
Share of interest income in revenues	0.6	0.3
Share of noninterest expenses	3.0	8.5
Return on securities	0.5	0.5
Loan rate	4.0	4.1
Consumption to output	0.7	0.7
Banking assets to output	1.2	1.2
Safe-to-total assets	0.3	0.3
Memo: Deposit rate	0.1	0.1
% Labor in entrepreneurial sector	—	58.5
% Labor in corporate sector	—	41.5
% Output of entrepreneurial sector	—	63.8
% Output of corporate sector	—	24.7
% Output of banking sector	—	11.5

NOTE: Moments are based on sample averages using quarterly observations between 1997:Q1 and 2012:Q3, with the exception of the percentage of safe assets held by banks which is only available starting in 2001:Q1, and averages for share of interest income in revenues and banking assets to output are calculated only for the period after the fourth quarter of 2008 when investment banks became bank holding companies. The adjusted return on assets is defined as net income excluding income taxes and salaries and employee benefits. The percentage of safe assets held by banks includes all assets with a zero and with a 20 percent risk weight. The sample includes all bank holding companies and commercial banks that are not part of a BHC, or that are part of a BHC which does not file the Y-9C report. The share of constrained banks is estimated using banks' responses in the Senior Loan Officer Opinion Survey and reported by Bassett and Covas [2013]. The safe-asset share is obtained from Gorton, Lewellen, and Metrick [2012].

of loans is 4.2 years.

The parameters set internally—namely the banker's discount factor, the intermediation cost, the parameters of the banker's loan technology, the persistence and standard deviation of a shock to deposits, and the adjustment cost parameters—are chosen to match a set of nine moments calculated from regulatory reports. The moments selected are: (i) tier 1 capital ratio, (ii) the fraction of capital constrained banks, (iii) leverage ratio, (iv) adjusted return-on-assets, (v) the cross-sectional volatility of adjusted return on assets, (vi) the share of assets with a zero or 20 percent Basel I risk-weight, (vii) the share of interest income relative to total revenues, (viii) the share of noninterest expenses, and (ix) the return on securities. The upper panel of Table 2 presents a comparison between the data and the model for this selected set of moments.

As discussed above, certain types of safe assets such as U.S. Treasury securities, Agency debt and municipal bonds are not directly modeled in our framework. We capture the supply of these assets using the parameter $\overline{S}$. As shown in Section 4, our results are somewhat sensitive to the choice of this parameter. Thus, we calibrate the parameter $\overline{S}$ using the estimates of the share of safe assets provided by Gorton, Lewellen, and Metrick [2012]. Specifically, that paper estimates that during the postwar period the safe-asset share has fluctuated between 30 and 35 percent. In the model we define the safe-asset share as follows. The numerator includes bank deposits, the exogenous amount of safe assets, $\overline{S}$, and the amount of borrowing by banks in the securities' market. The denominator includes all assets in the economy for each of the three types of agents. Namely, workers' deposits and corporate sector assets; entrepreneurs' capital and securities; and bankers' loans and securities. By setting $\overline{S}$ to 7, we obtain a safe-asset share of 33.6 percent in our calibrated model. The solution of the model is obtained via computational methods and additional details are provided in the Appendix.

4 Analysis of the Baseline Economy

We first present results for a partial equilibrium version of the model, in which prices (interest rates and wages) are taken as given, in order to gain intuition regarding the different constraints of the model. We then present general equilibrium results in which we let all prices adjust.

Partial Equilibrium. The macroeconomic effects of the capital and liquidity requirements will depend on the extent to which such requirements are binding. That in turn will depend on the distribution of the banker's wealth (or net worth). We thus first show information on bankers' wealth distribution; we next present information on how capital and liquidity constraints vary in the cross-section; we then show how loan and securities holdings vary with net worth, as affected by the capital and liquidity constraint; and we finally present the steady-state effects on the banking variables of imposing or altering the requirements.

Table 3 shows the percentage of wealth held at each quintile and the level of loan pro-

Table 3: Bankers' Wealth Distribution

	% wealth held by				
	0 − 20%	20 − 40%	40 − 60%	60 − 80%	80 − 100%
Low revenue	0.4	0.0	0.0	0.0	0.0
Medium revenue	5.1	10.0	13.7	22.0	39.4
High revenue	–	–	–	0.1	9.1

NOTE: All figures are in percent. The stochastic process for the noninterest income technology is discretized into a markov-chain with 5 states. The "low revenue" state corresponds to the first state of the markov chain, the "medium revenue" state to the next three states and the "high revenue" state to the last state. Results are based on the invariant distribution of bankers. In addition to the parameters reported in Table 1, the steady state distribution is obtained assuming a loan rate of 4.1 percent and a return on securities of 0.5 percent.

ductivity. As shown in the Table, low productivity bankers in the first quintile of the wealth distribution hold about 0.4 percent of the entire wealth of the banking sector. Conversely, the most productive bankers in the top quintile hold more than 9 percent of the wealth of the banking sector. We did not parametrize the model with the objective of matching the high degree of concentration of banking assets that exists in the U.S. However, as suggested by the results below the impact of an increase in liquidity requirement would likely be strengthened in a model in which a larger share of assets is held by the top quintile.[11]

Table 4 shows the share of capital constrained (Panel A) and liquidity constrained (Panel B) bankers in equilibrium. Within each productivity (revenue) level, smaller banks are more likely to be capital constrained than larger banks. For the liquidity constraint we observe the opposite. Larger banks are more likely to be liquidity constrained than smaller banks. Banks that are more productive in terms of loan revenue would like to maximize the share of assets devoted to loans, and therefore hold smaller shares as securities. If the concentration of assets in the top quintiel was higher in the model, the impliciations of a binding liquidity constraint would be potentially more relevant since larger banks are more likely to be liquidity constrained.

Figure 1 plots the policy rules for bank loans and securities as a function of net worth for a bank with the highest revenue shock. The solid line represents the decision rule of bankers in the absence of a liquidity requirement, while the dashed line depicts the banker's decision rule in the presence of one.[12] In the absence of a liquidity requirement, as net worth (and

[11]In our calibration the share of wealth held by the top quintile is slightly less than 50 percent. In the data, the average between 1997-2006 was more than 90 percent.

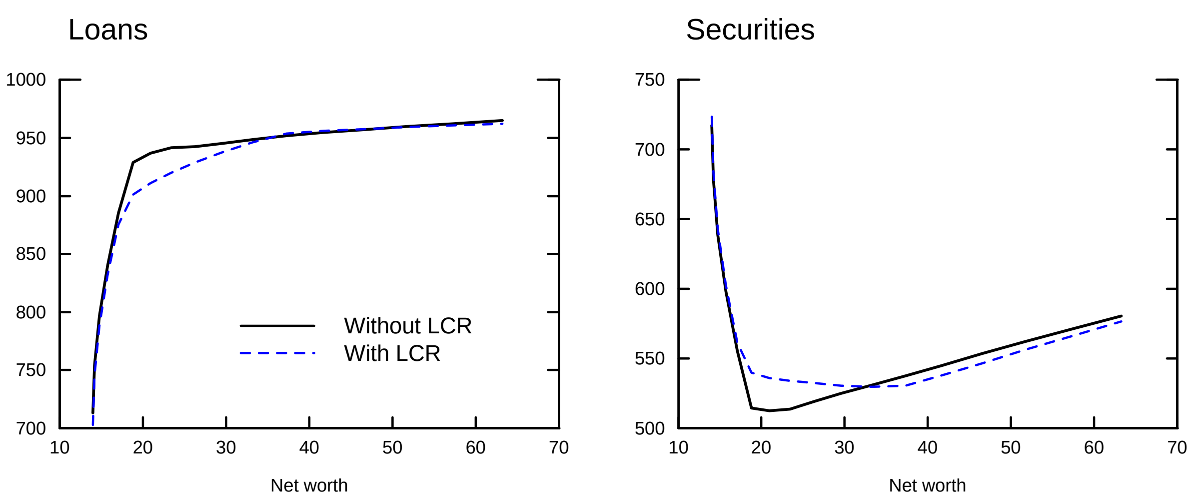
[12]In both cases, there is a capital requirement.

Table 4: Share of Bankers with Binding Constraints

	Panel A: Binding capital constraint				
	0 – 20%	20 – 40%	40 – 60%	60 – 80%	80 – 100%
Low revenue	55.8	0.0	0.0	0.0	0.0
Medium revenue	81.8	72.6	72.6	13.7	0.0
High revenue	–	–	–	10.4	0.1
	Panel B: Binding liquidity constraint				
	0 – 20%	20 – 40%	40 – 60%	60 – 80%	80 – 100%
Low revenue	0.0	0.0	0.0	0.0	0.0
Medium revenue	0.0	0.0	0.8	39.6	72.0
High revenue	–	–	–	96.7	100.0

NOTE: Each entry in panel A reports the share of bankers with a binding capital constraint in each wealth/loan revenue bucket. Each entry in panel B reports the fraction of agents with a binding liquidity constraint in each wealth/loan revenue bucket. Results are based on the invariant distribution of bankers assuming a loan rate of 4.1 percent and a return on securities of 0.5 percent.

Figure 1: The Effect of the LCR constraint on bankers' policy rules



Notes: Policy rules for the bankers under the highest productivity state $\theta = \bar{\theta}_5$, average level of deposits $d = \bar{d}_2$ and stock of loans $l = 50$.

equity) increases from low levels banks initially substitute securities for loans as the capital requirement is relaxed due to the increase in equity. As wealth continues to increase, banks cease to be capital constrained and the choice of loans no longer varies with the bank's

Table 5: Partial Equilibrium Analysis of the Banking Sector

	Baseline	Δ's relative to Baseline		
Capital requirements	6%	6%	10%	10%
Liquidity requirements	No	Yes	No	Yes
1. Securities	590.3	25.7%	15.3%	34.9%
2. Loans	1123.6	-14.0%	-5.5%	-16.4%
3. Assets (=1+2)	1713.8	-0.3%	1.7%	1.3%
4. Deposits	1605.0	0.0%	0.0%	0.0%
5. Equity	108.8	-4.6%	26.3%	19.8%
6. Securities-to-Assets (%)	34.4	43.4	39.1	45.9
7. Liquidity coverage ratio (%)	207.2	242.3	229.4	256.1
8. Liquidity constraint binds (%)	—	0.0	—	0.0
9. Capital ratio (%)	9.7	10.7	12.9	13.9
10. Capital constraint binds (%)	31.6	31.1	35.1	35.3
11. Leverage ratio (%)	6.3	6.1	7.9	7.5
12. Return-on-assets (%)	3.4	3.3	3.3	3.2

NOTE: Results are based on the invariant distribution of bankers. The baseline economy is one in which capital requirements are equal to 6 percent ($\chi = 0.06$) and there are no liquidity requirements. The rate on loans and the return on securities are set at 4.1 and 0.5 percent, respectively.

equity. At that point, banks also start to borrow less in the securities market.

The presence of a liquidity requirement affects both of these dynamics. The binding nature of the requirement reduces the bank's ability to invest in loans and borrow by short-selling securities. Note that the effect of the liquidity requirement on the banker's policy rules is only present when the shock to revenues is sufficiently high, such as the one shown in Figure 1. For lower revenue shocks the region in which the liquidity constraint would bind is above the banker's optimal loan choice and the policy rules with liquidity requirements overlap with the ones that are only subject to capital requirements. Finally, the presence of a liquidity requirement also makes lending less sensitive to increases in net worth and equity.

These effects are reflected in the solution to the partial equilibrium version of the banker's model, given in Table 5. The first column of the table reports the baseline solution under the presence of a capital requirement, but not a liquidity requirement. The second column reports the impact of introducing liquidity requirements on model outcomes. The third column reports the model outcomes in response to an increase in the capital requirement from 6 to 10 percent, and the last column reports the impact of simultaneously increasing the capital requirement and imposing a liquidity requirement.

The introduction of a liquidity requirement (second column) leads to a substantial increase in the stock of securities and a decrease in the stock of loans, leaving total assets about flat. Although the bank's equity falls somewhat, the more substantial fall in loans boosts the capital ratio. Though the liquidity requirement only binds for a relatively small share of banks, since these are the largest banks in our model the effect of imposing a liquidity requirement is quite significant.

An increase in capital requirements from 6 to 10 percent (third column) would increase the stock of equity at banks by more than 25 percent, decrease loans by over 5 percent, and increase securities holdings by about 15 percent. As higher capital requirements make it more difficult for the banker to smooth consumption, it increases his desire to invest more in securities which are riskless.

The last column of Table 5 combines the increase in capital and liquidity requirements. The overall net impact on equity is positive and both the capital ratio and the liquidity coverage ratio increase significantly relative to the baseline specification. The balance sheet size of banks expands modestly, while loans shrink and securities holdings increase substantially.

General Equilibrium. The first column of Table 6 reports the baseline general equilibrium solution of the full model without a liquidity requirement. In general equilibrium prices (R^L, R^S, R, w) have to adjust to clear the loan, securities, the asset and the labor markets. In addition, we will be able to make statements about aggregate consumption and output.

The second column of Table 6 reports the impact on banking and macroeconomic variables in response to the introduction of a liquidity standard. Securities, loans, assets and equities (rows 1-3 and 5) behave similarly to the partial equilibrium case, though the magnitudes are attenuated. This reduction in magnitude comes from the impact of changes in the loan rate and the return on securities. Specifically, the equilibrium loan rate increases 18 basis points in response to the reduction in the supply of loans. This, in turn, makes loans more attractive and attenuates the effect of the liquidity requirement on loan supply. In contrast, the equilibrium return on securities falls substantially—from 48 basis points to 21 basis points—in response to the increase in securities holdings. The decrease in the riskless return makes securities less attractive to hold, thus, relative to the partial equilibrium case the increase in securities holdings is reduced in half. Nonetheless, the impact of imposing a

Table 6: General Equilibrium Analysis

	Baseline	Δ's relative to Baseline		
Capital requirements	6%	6%	10%	10%
Liquidity requirements	No	Yes	No	Yes
1. Securities	590.3	11.5%	6.3%	16.6%
2. Loans	1123.6	-4.8%	0.0%	-4.4%
3. Assets (=1+2)	1713.8	0.8%	2.1%	2.8%
4. Deposits	1605.0	0.2%	0.0%	0.2%
5. Equity	108.8	8.9%	33.6%	41.4%
6. Securities-to-Assets (%)	34.4	38.1	35.8	39.1
7. Liquidity coverage ratio (%)	207.2	222.6	217.1	230.7
8. Liquidity constraint binds (%)	—	23.2	—	20.5
9. Capital ratio (%)	9.7	11.1	12.9	14.3
10. Capital constraint binds (%)	31.6	27.3	36.7	34.9
11. Leverage ratio (%)	6.3	6.9	8.3	8.7
12. Return-on-assets (%)	3.4	3.3	3.2	3.1
12. Loan rate (%)	4.07	4.25	4.07	4.24
13. Return on securities (%)	0.48	0.21	0.31	0.05
14. Output	3.2	-1.0%	0.0%	-0.9%
15. Excl. banking sector	2.8	-0.5%	0.0%	-0.5%
16. Entrepreneurial sector	2.0	-1.6%	0.0%	-1.4%
17. Corporate sector	0.8	2.2%	0.0%	1.9%
18. Consumption	2.1	-0.6%	-0.3%	-0.9%

NOTE: Results are based on the invariant distributions of bankers, workers and entrepreneurs. The baseline economy is one in which capital requirements are equal to 6 percent ($\chi = 0.06$) and there are no liquidity requirements. For stock variables, the numbers reported in lines 1–5 and 14–18 in columns 2-4 represent percentage changes relative to the baseline specification.

minimum liquidity standard on banks on output and consumption is non-negligible. In particular, aggregate output falls by about 1 percent (one-half of a percent outside the banking sector), and consumption declines by about 0.6 percent.

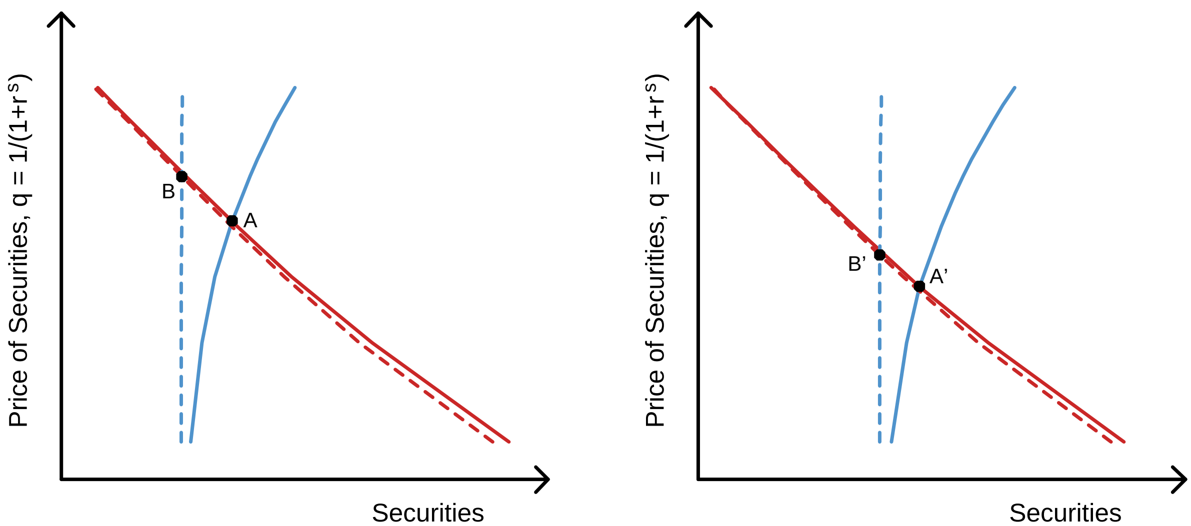
The third column of Table 6 reports the general equilibrium results when capital requirements increase from 6 to 10 percent. In this case the results are quite a bit different from the partial equilibrium case. Specifically, loans are about unchanged, while securities increase a lot less relative to the partial equilibrium case. In large part, the increase in demand for securities leads to a substantial reduction in the equilibrium rate of return on securities (row 13). Consequently, making loans becomes relatively more attractive and, as calibrated here, the precautionary savings effect is strong enough to offset the negative impact on loans reported in the partial equilibrium case. Although aggregate output is now flat this case, consumption still falls in large part because banks need to pay less dividends to sustain the higher capital ratios. Were banks' increased holdings of securities to have a smaller effect on the returns of securities, the net effects on loans would be the same as in the partial equilibrium case.

Finally, the last column in Table 6 reports the combined effects of an increase in capital and liquidity requirements. The model suggests that a simultaneous increase in capital and liquidity requirements would cause output and consumption to both decline by about 0.9 percent.

Supply of Safe Assets. We now analyze the comparative statics in our economy when the supply of safe assets—controlled by the parameter $\overline{S}$—increases. The availability of safe assets has important implications for the liquidity requirement in our model—as defined in equation (3)—since banks are required to invest a share of their liabilities in liquid assets. In our calibration, the parameter $\overline{S}$ represents the "exogenous" amount of safe assets available in our economy. This parameter represents liquid assets available in the economy that are not explicitly modeled in our framework, such as debt securities that have the explicit or implicit backing of the U.S. Government. Therefore, it is important to understand how the equilbrium changes in response to an exogenous variation in the supply of safe assets and for reasons not related to the introduction of a liquidity requirement in the banking sector.

The left panel of Figure 2 plots the steady state equilibrium in the securities market under the baseline calibration before the introduction of the liquidity requirement (solid lines). The supply of securities is positively sloped (blue line) and corresponds to the sum of an exogenous component—defined by the parameter $\overline{S}$—and an endogenous component determined by banks that are supplying safe assets to the market (i.e., those with $s' < 0$). The demand for securities by bankers and entrepreneurs is represented by the red solid line and it is negatively sloped. The equilibrium in the securities market before the introduction of a liquidity requirement is represented by the dot labeled 'A' in the left panel. The dashed lines represent the supply and demand of securities after the introduction of the liquidity requirement. As shown by the blue lines in the left panel, the introduction of the liquidity requirement shifts the supply curve to the left and makes it very inelastic. This happens because one way for banks to ease the liquidity requirement constraint is to reduce their amount of borrowing in the securities' market, making the supply of securities almost exclusively determined by the parameter $\overline{S}$. Meanwhile, the demand for securities remains about unchanged in large part due to the following offsetting effects. The introduction of the liquidity requirement increases banks' demand for securities at the expense of bank loans. However, that implies that the equilibrium loan rate is also higher, increasing the opportunity cost of investing in securities. Thus, the decrease in the supply of securities induced by the introduction of the liquidity requirement reduces its return and the new steady state equilibrium moves to point 'B'. Although bankers' holdings of securities increases by about 12 percent (as shown in row 1 of Table 6), the *sum* of securities' holdings of bankers and entrepreneurs *decreases* after the introduction of the liquidity requirement.

Figure 2: The Effects of Changes in the Supply of Safe Assets



NOTE: The solid lines represent the demand and supply curves of securities before the introduction of a liquidity requirement. The dashed lines depict the demand and supply curves of securities after the introduction of a liquidity requirement.

The panel to the right displays the demand and supply curves under a higher level of safe assets, namely by increasing $\overline{S}$ from 7 to 8. The increase in securities corresponds to a 14 percent increase in the exogenous supply of safe assets. Because the exogenous share of safe assets is now larger, the introduction of the liquidity requirement has a smaller impact on the equilibrium price level of securities (the change from A' to B' in the right panel of Figure 2). Specifically, the return on securities declines 19 basis points, about one-third less relative to the changes reported under the baseline calibration (as shown in the second column of row 13 in Table 6). As a result, loans outstanding and aggregate output decline about 20 and 10 basis points less relative to the ones reported under the baseline calibration, respectively. Overall, the macroeconomic impact of introducing a liquidity requirement in our economy is mitigated as the share of safe assets *exogenous* to the change in policy increases.

5 Transitional Dynamics

In this section, we illustrate the transitional dynamics of introducing liquidity requirements and compare those to the responses to an increase in capital requirements. In contrast to the results of the previous section, we assume a gradual increase in the liquidity requirement over a five year horizon and report the responses of all sectors in our economy. In addition, we also compare these responses to the case in which the increase in capital requirements is also done gradually over a five year horizon.

Introduction of a liquidity requirement. Figure 3 shows the transitional dynamics of the banking sector in response to the introduction of a liquidity standard to bankers. The liquidity standard is increased gradually over a five-year period. Specifically, the liquidity requirement is anounced in year 1 and it is introduced in year 2 at 20 percent and then rises linearly until it reaches 100 percent in year 6. Bankers respond to the introduction of a liquidity standard by decreasing the supply of loans (top right panel) and increasing their holdings of securities (middle right panel). This triggers an immediate increase in the loan rate from 4.06 to 4.20 percent (top left panel) and a sharp decrease in the return of securities (middle left panel). The liquidity coverage ratio also increases sharply (bottom right panel) as the more profitable banks shift their portfolio allocation from loans into securities. The reduction in loans also boosts the risk-based capital ratio of banks, in part because securities have a zero risk-weight, but also because the liquidity requirement penalizes banks' dependence on deposits and as a result bankers' increase their desire to fund themselves with retained earnings.

Figure 4 displays the responses of workers, entrepreneurs and aggregate output and consumption. On the worker and entrepreneurial sectors, the reduction in lending leads to a decline in entrepreneurial output and consumption (middle panels). The decreased demand of labor from the entrepreneurial sector leads to a reallocation of labor to the corporate sector. Since capital and labor are complements in the corporate sector, this reallocation increases the demand for capital which in turn boosts workers' holdings of corporate assets (top left panel) and (eventually) worker consumption (top right panel). However, as shown in the bottom two panels of Figure 4 aggregate output and consumption decline throughout the transition period and fall by about 1 and 0.6 percent in the long-run, respectively.

Figure 5 compares the transitional dynamics of increasing capital requirements with those of imposing a liquidity requirement. The effects of increasing the liquidity requirement are the same as those presented in Figures 3 and 4. Regarding the increase in capital requirements we assume those rise linearly from 6 to 10 percent over a period of 5 years. The effects from imposing a higher capital requirement are different from those of introducing a liquidity requirement since the capital and liquidity constraints bind for a different set of banks and operates through a different mechanism. Specifically, an increase in capital requirements implies that for a given level of profitability risk, it becomes harder to smooth divident payouts for bankers. As a result, bankers would like to accumulate more securities (precautionary buffer) and would substitute out of loans into securities. However, in general equilibrium this portfolio reallocation of bankers leads to a decrease in the rate of return of securities and an increase in the rate of return of loans. This in turn makes loans more attractive and if the precautionary effect is strong in equilibrium the return on securities could decrease considerably and the investment of bankers in loans be little changed in response to the increase in capital requirements.

Indeed, under our calibration we find that in response to the increase in capital requirements loan rates increase by less than 10 basis points in the near term but subsequently rebound to their baseline value (top left panel). Similarly, outstanding loans on banks' books fall by about 1 percent during the period in which requirements are increased but in the long-run are little changed (top right panel). In response to higher capital requirements, the most affected banks are the ones with the lowest levels of equity and the least profitability. As a result, the increase in capital requirements increases their precautionary desire to hold securities which leads to a substantial decrease in the return on those assets (not shown). Consequently, loans become relatively more attractive for banks, offsetting the initial negative effect on lending. In addition, since the supply of loans to bank dependent borrowers is little changed the overall effects of increasing capital requirements on aggregate output are relatively small (bottom left panel).

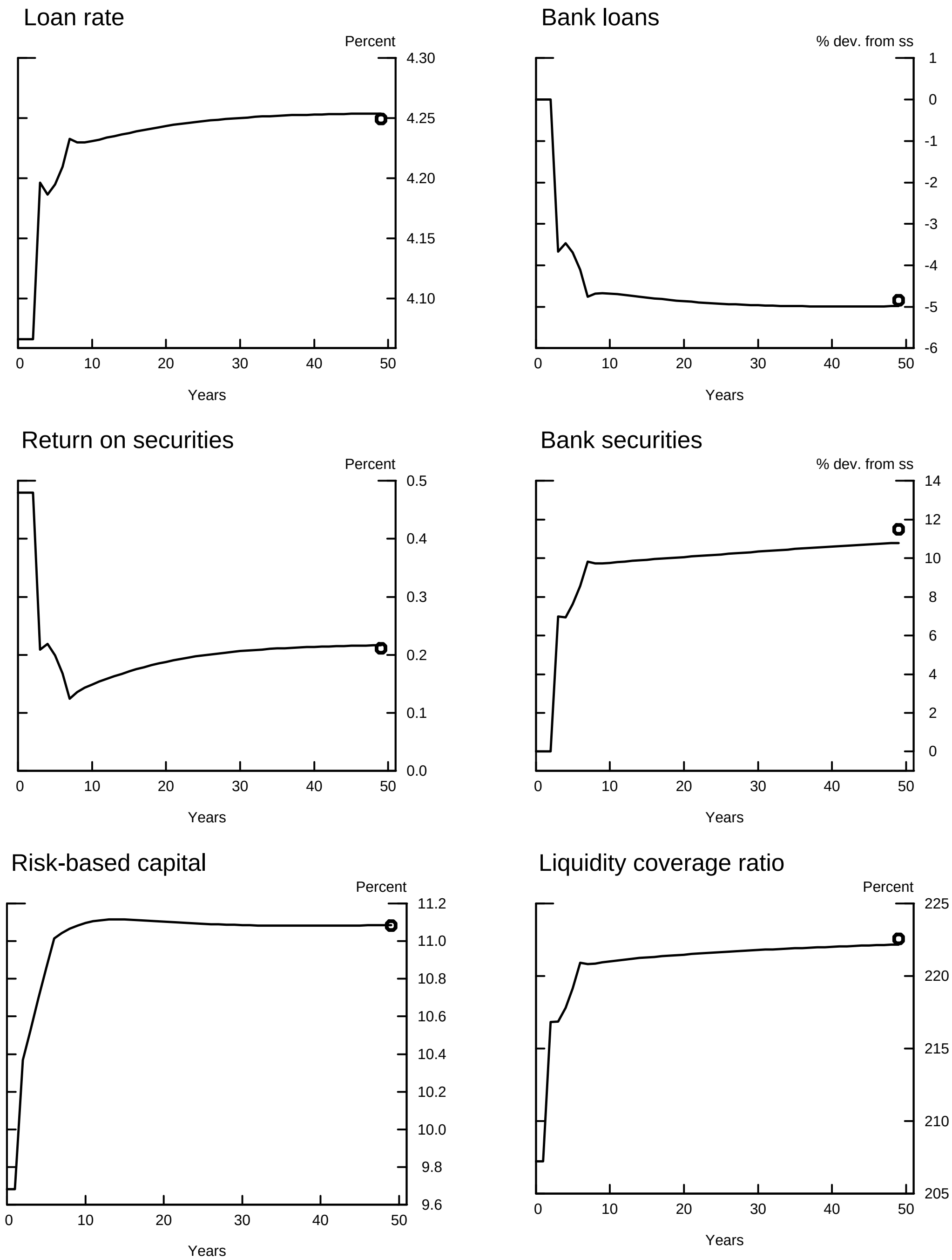


Figure 3: Introduction of Liquidity Requirements

Notes: The horizontal axes contain the number of periods after the change in liquidity requirements. The transitional dynamics assume the new steady state is reached after 60 periods. The dots in the last period indicate the final steady steady state value.

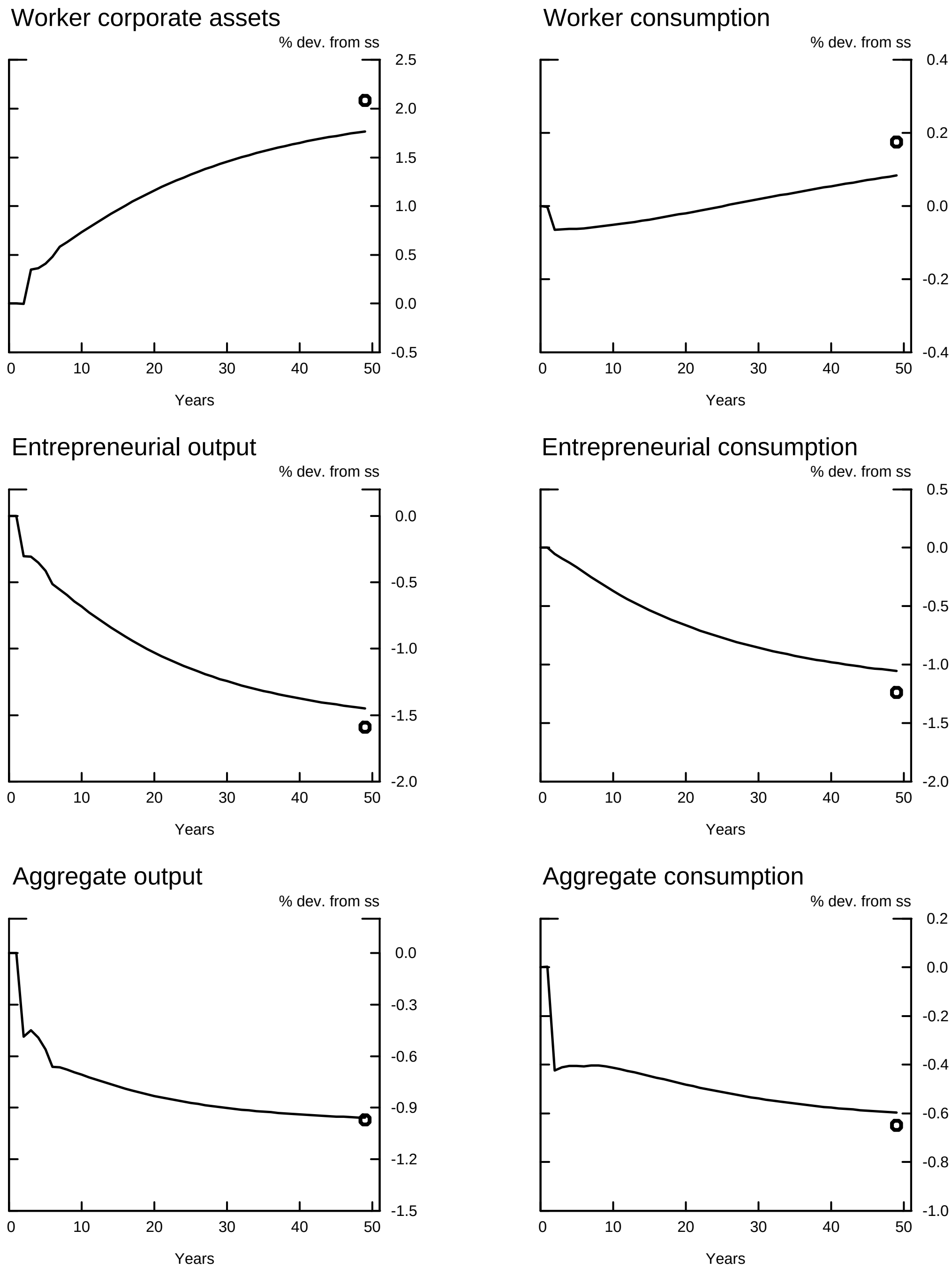


Figure 4: Introduction of Liquidity Requirements

Notes: The horizontal axes contain the number of periods after the change in liquidity requirements. The transitional dynamics assume the new steady state is reached after 60 periods. The dots in the last period indicate the final steady steady state value.

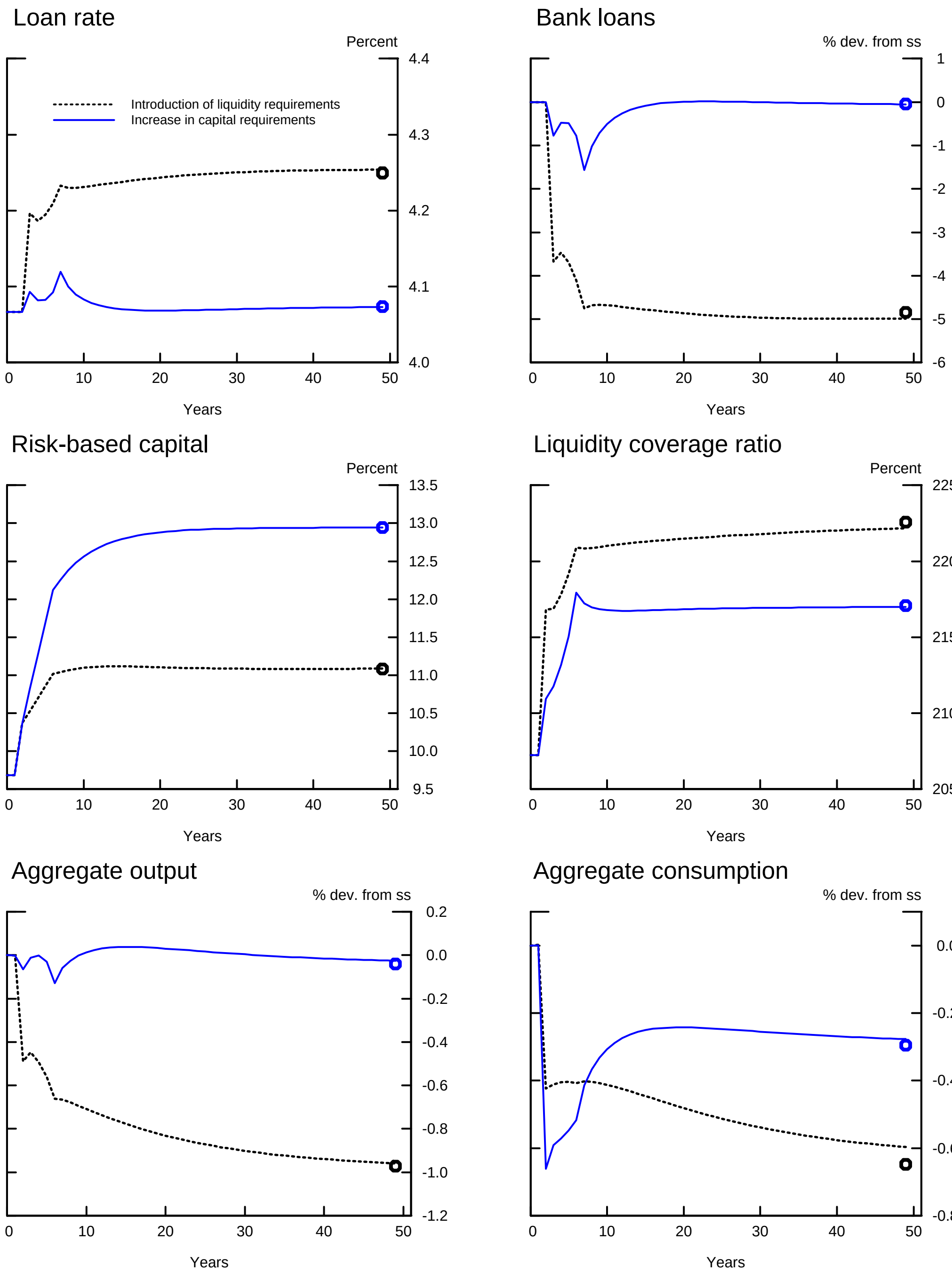


Figure 5: Comparison of Introducing Liquidity Requirements with Increasing Capital Requirements

Notes: The horizontal axes contain the number of periods after the change in liquidity or capital requirements. The transitional dynamics assume the new steady state is reached after 60 periods. The dots in the last period indicate the final steady state value.

Comparing effects of increasing capital requirements with imposing liquidity requirements. In the case of the introduction of liquidity requirements the most affected banks are the larger and more profitable banks, so even though the return on securities also declines considerably because it does not generate a strong precautionary mechanism it does increase the supply of loans by the less profitable and more capital constrained banks. Interestingly, the decline in aggregate consumption in the short-term is considerably more pronounced in the case of more stringent capital requirements as banks accumulate equity by reducing dividend payouts to meet the higher capital requirement (bottom right panel). An important takeaway of this exercise is that the increase in capital requirements also leads to a higher liquidity coverage ratio as securities are more liquid than bank loans.

Sensitivity analysis. As shown in Table 6, before the introduction of a liquidity standard the LCR is a bit over 200 percent. This ratio is calculated under a 30 percent run-off rate for deposits during a liquidity stress event. It is likely that the LCR ratio calibrated in our current calibration is too high, implying that the liquidity requirements are unrealistically low. First, we do not accurately model loan commitments since bank loans by entrepreneurs are fully drawn at origination. According to Santos [2011], the average drawdown rate for non-financial borrowers is 23 percent, and additionally those drawdowns are significantly higher during recessions and financial crisis. Second, the results of the comprehensive quantitative impact study BCBS [2010b], estimate that the liquidity coverage ratio for the set of banks included in their sample was 83 percent for Group 1 banks. In our steady state the liquidity coverage ratio is significantly higher so it is sensible to consider alternative parametrizations corresponding to lower LCRs.[13]

Figure 6 depicts the responses of the variables of the model under different parametrizations of the liquidity standard. In particular, the red line shows the response corresponding to a liquidity coverage ratio of 185 percent prior to the introduction of the liquidity standard. Relative to the dotted line, which represents the baseline change in the liquidity standard, the loan rate increases from 4.05 to close to 4.35 percent (top left panel). The reduction on bank loans exceeds 7 percent (top right panel), and leads to a decline in output of 1.4 percent in the long-run (bottom left panel). Hence, more stringent liquidity requirements lead to much stronger responses of the economy to the introduction of a liquidity standard.

[13]Group 1 banks are those that have Tier 1 capital in excess of 3 billion of euros, are well diversified, and are internationally active. Of the 91 Group 1 banks included in the quantitative impact study, 13 are U.S. banks.

Discussion. In our model there is a positive correlation between loan revenue and bank size. As shown in Table 4, the liquidity requirement is more likely to bind for larger banks than smaller ones. Because there is a significant concentration of assets among the largest banks, they have a large influence on total loans outstanding in our economy. For this reason, we expect to find a stronger impact of changes in liquidity requirements on aggregate variables relative to a setup with a representative bank. In addition, the effect of the introduction of liquidity requirements on aggregate output is permanent.

This occurs because the liquidity requirement prevents the most productive banks from fully exploiting their profitable opportunities, and the introduction of a liquidity requirement does not lead to a material reduction in the cost of funds to the bank. However, our model only allows for one form of debt finance subject to the same liquidity requirement. If banks have access to other sources of debt finance with longer maturities which are exempted from the liquidity requirement, the impact on loan growth could be mitigated.

Discussion of other estimates on the impact of regulatory reform. There are two well-known studies on the macroeconomic impact of the regulatory reform that are helpful to summarize. First, the Macroeconomic Assessment Group (MAG) produced a reported published by the BCBS [2010a] at the end of 2010. Second, the Institute of International Finance IIF [2011]—a global lobby group for the banking industry—publishes a report every year on the macroeconomic impact of regulatory reforms, which was last updated in August of this year. In the MAG report, it is estimated that a one percentage point increase in minimum capital requirements leads to a decline of 0.19 percent of output relative to the baseline in almost five years. Assuming we can scale up the MAG estimate, then a four percentage point increase in capital requirements leads to a 0.80 percent decrease in output over the same period. The contraction in output provided by the MAG analysis is significantly larger than the estimate suggested by our model. In particular, our calibration suggests that an increase in capital requirements by four percentage points leads to a no decline in output after 5 years, only small declines in the short term while loan rates increase temporarily. In the MAG study, the results are based on the assumption that the Modigliani-Miller proposition holds and the way banking assets are financed does not impact aggregate quantities in the long-run. In our model the Modigliani-Miller proposition does not hold because of capital constraints are bankers are not allowed to raise outside equity, however we have even smaller effects on output due to the portfolio reallocation effect and its impact on the return of securities.

The report published by the IIF—a global lobby group for the banking industry—estimates that the combined effect of all regulatory proposals, namely the broad increase in capital requirements, the introduction of a liquidity standard, as well as U.S. specific measures (e.g., Volcker Rule) would lead to a decline of 3.0 percent of GDP after five years. Our combined regulatory changes (4 percentage points increase in capital requirements and the introduction of a liquidity standard) would lead to a decline of 0.9 percent of output after 5 years. In the IIF study, a key driving force of the results in the increase in loan spreads. In our model the loan rate also increases in response to the more stringent regulatory requirements, albeit by much less. Due to the general equilibrium nature of our model, the bulk of the adjustment occurs through the shrinking of banks' balance sheets as bank dependent borrowers curtail their demand for funds in response to higher loan rates. Because the IIF is based on a partial equilibrium analysis, the impact of the regulatory reform on spreads is probably overstated.

6 Capital Shortfalls

As seen during the recent financial crisis, bank capital may erode quickly, and banks' efforts to recapitalize can have large effects on their behavior and on the macroeconomy. In this section, we simulate the effects of a transfer of wealth from the banking to the entrepreneurial and worker sectors both in the case where there is just a capital requirement and in the case where there are both capital and liquidity requirements. Specifically, we want to illustrate the role of the liquidity requirement in the presence of a shock to bank capital and use the bank losses reported in the 2009 Supervisory Capital Assessment Program (SCAP) to calibrate the size of the capital shock.

Our capital shock to bankers is based on a transfer of wealth from bankers to entrepreneurs and workers equivalent to 7.5 percent of steady state output. The size of the shock is based on the 2009 SCAP results, which reported overall banking losses of about $750 billion during 2009 and 2010 under the more adverse macroeconomic scenario. In addition, the bank holding companies that participated in SCAP 2009 accounted for about two-thirds of total assets of the banking sector, which translates into total losses of about $1,125 billion or approximately 7.5 percent of gross domestic product in 2009. Furthermore, we assume that 60 percent of the transfer occurs in the first year, and the remaining 40 percent in the second year. The transfer of wealth between the three sectors is assumed to be unexpected in both years.

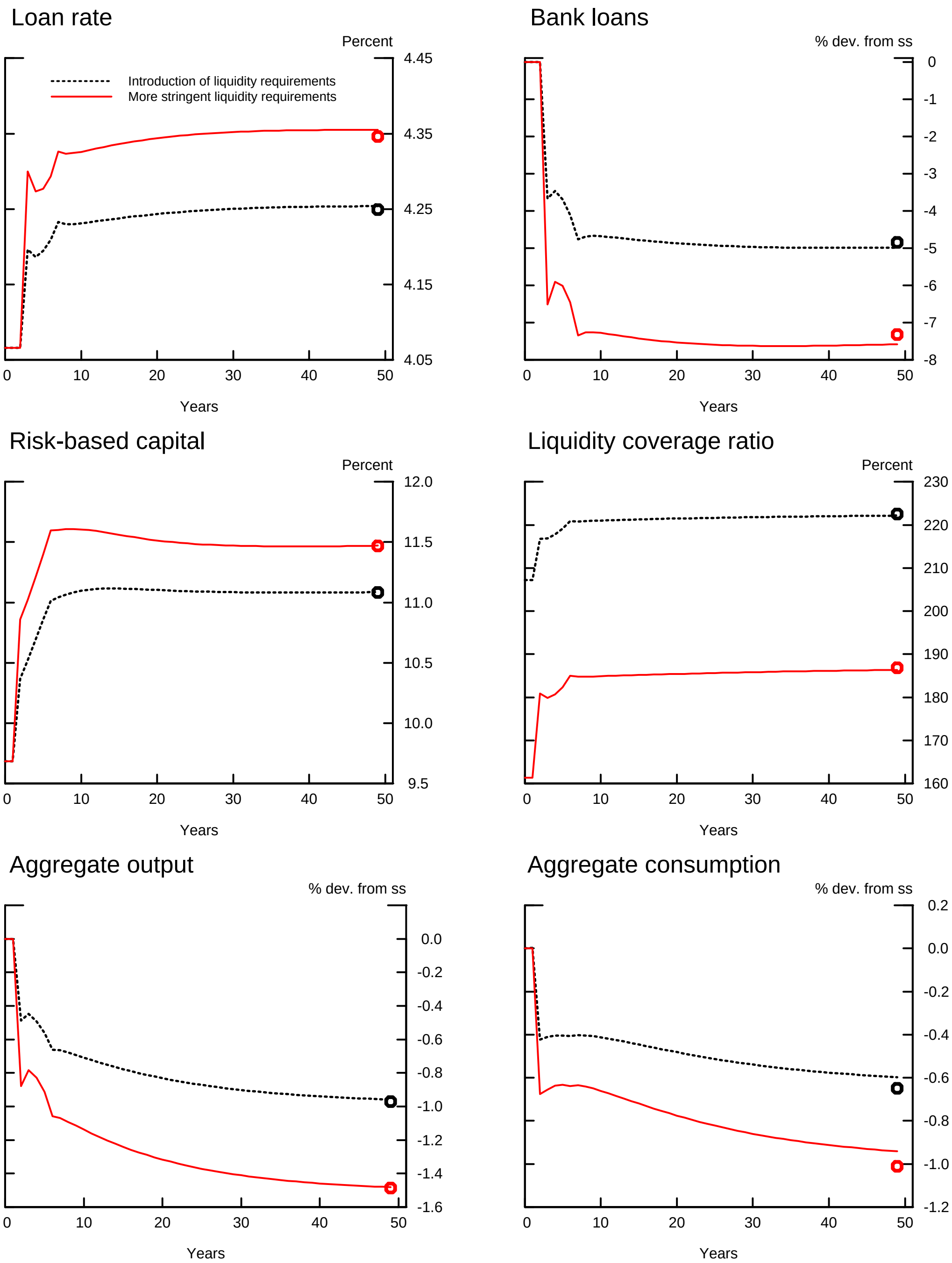


Figure 6: Introducing More Stringent Liquidity Requirements

Notes: The horizontal axes contain the number of periods after the change in liquidity requirements. The transitional dynamics assume the new steady state is reached after 60 periods. The dots in the last period indicate the final steady steady state value. The dashed line represents the liquidity requirements discussed in the previous section, while the solid line represents the introduction of more stringent liquidity requirements.

Figure 7 plots the effects of the wealth transfer shock on bank loan rates and quantities, the risk-based capital ratio, the liquidity ratio, and aggregate output and consumption both with and without a liquidity requirement. Since the size of the capital shock is very large, the impact of the shock on the variables of the model is huge. For example, loans outstanding on banks' books decline by about 8 percent in the first year and 26 percent in the second year in the economy without a liquidity requirement (top right panel). As shown in Figure 7, the responses are qualitatively similar in both the case where there is just a capital requirement and in the case where there are both capital and liquidity requirements. However, the differences in the magnitude of the responses are economically significant. Specifically, loan spreads increase by an additional 20 basis points when the liquidity requirement is absent in the second year (top left panel). In addition, bank loans fall by about 1 and 4 percentage points more in the first year and in the second year, respectively, when the liquidity requirement is absent (top right panel). The differences in the responses arise because in the presence of a liquidity requirement banks choose a higher steady state level of the risk-based capital ratio (middle left panel). This additional capital buffer—obtained under the same capital requirement of 6 percent—allows banks to better withstand the impact of the capital shortfall shock and thus leads to smaller declines in loan growth and loan interest rates. As a result, aggregate output (bottom left panel) and consumption (bottom right panel) fall by nearly half a percentage point less, thus the presence of a liquidity requirement dampens the negative impact of a capital shortfall shock on the macroeconomy.

7 Conclusion

Bank liquidity regulations have the highly desirable goals of both reducing the likelihood of bank runs and increasing the odds that banks will survive runs, should they occur. However, by increasing banks' incentives to hold lower-risk, more liquid assets, such regulations may also reduce the supply of loans and increase their cost to bank dependent borrowers. They may also interact with other current regulations, such as capital regulations, in ways not completely intended.

In this paper, we calibrate a nonlinear dynamic general equilibrium model in which banks are subject to both capital and liquidity requirements that bind only occasionally. We find that imposing liquidity regulations of the kinds currently envisioned under Basel III would, in the long run, reduce loans outstanding on banks' books by nearly 5 percent, and aggregate output and consumption by about 1 percent and 0.6 percent, respectively. In contrast, we also find that an economy with liquidity requirements would be more resilient to shocks to bank capital relative to an economy in which liquidity requirements are absent. We argued that the liquidity requirement has the feature of increasing the size of banks' endogenous capital buffers, and as a result it helps mitigate the effect of bank capital shock on economic activity.

We also report that the effects on lending and other banking variables are substantially larger in partial equilibrium analysis which takes prices as given. This result suggests that attempting to apply partial equilibrium results–i.e. results just on the banking sector–to derive the macroeconomic impact of changes in liquidity or capital regulations are likely to be misleading. But it also indicates that the macroeconomic impacts of changes in liquidity and capital regulation are sensitive to the effects of changes in bank behavior on prices. Our baseline calibration suggests a big impact of bank securities purchases on the returns on such securities–which declines from 48 to 21 basis points after the introduction of a liquidity requirement. A smaller impact on securities rates would increase the size of the effects of liquidity regulation on both the banking sector and the broader macroeconomy.

Finally, we do not explicitly attempt to model the reduction in bank runs owing to the new regulations. Thus, our analysis should not be taken as a full evaluation of the costs and benefits associated with liquidity regulation; nor does it suggest what the optimal level of regulation should be. We leave that for future research.

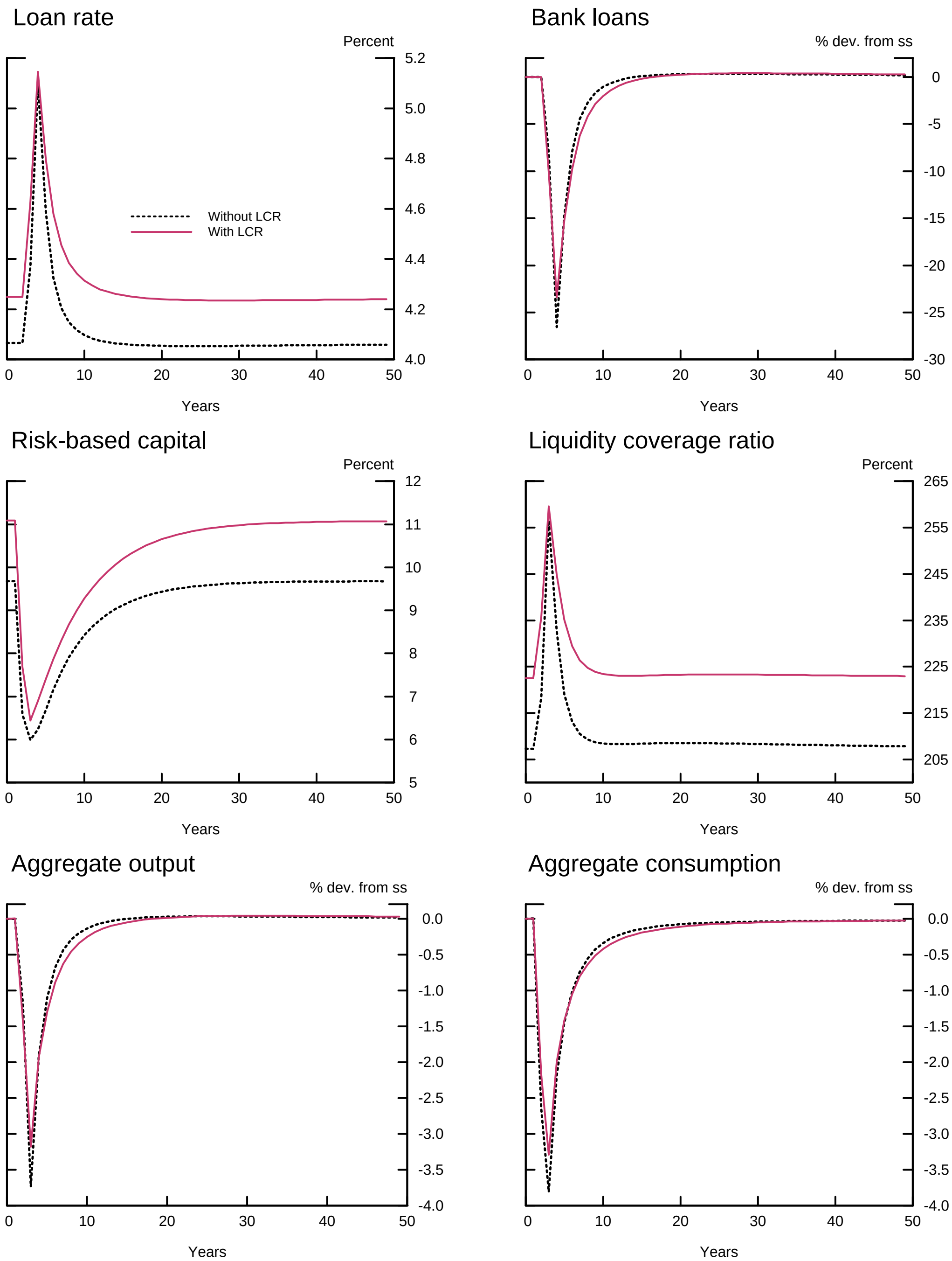


Figure 7: Capital Shortfall

Notes: The horizontal axes contain the number of periods after the transfer of wealth from the banking sector to the household and entrepreneurial sectors. The transitional dynamics assume the steady state is reached after 60 periods. The dashed line represents the economy without liquidity requirements while the solid line represents the responses in the economy with liquidity requirements.

Appendix

In this appendix we derive the banker's capital constraints, the first-order conditions of the banker's problem, and provide an outline of the solution method.

Banker's capital constraint. The balance sheet constraint of the banker is given by

$$b' + s' = x_b - c_b - \Phi(b', \bar{\delta}b) - d'$$

where the left-hand side of this expression is the banker's assets, $b' + s'$, and the right-hand side is the banker's equity, $e_b \equiv x_b - c_b - \Phi(b', \bar{\delta}b)$, and debt, $-d'$. The capital constraint can be written as

$$\begin{aligned} e_b &\geqslant \chi b' \\ b' + s' + d' &\geqslant \chi b' \\ d' &\geqslant (\chi - 1)b' - s'. \end{aligned}$$

Banker's first-order conditions. The first-order conditions for b' and s' are as follows:

$$\begin{aligned} \left[1 + \frac{\partial \Phi(b', b)}{\partial b'}\right] u_c(c) &= \beta_b E\left[\frac{\partial v_b}{\partial x_b}\frac{\partial x_b}{\partial b'} + \frac{\partial v_b}{\partial b'}\middle|\theta, d'\right] + (1-\chi)\lambda + \bar{\delta}\mu \\ u_c(c) &= \beta_b E\left[\frac{\partial v_b}{\partial x_b}\frac{\partial x_b}{\partial s'}\middle|\theta, d'\right] + \lambda + \mu R_S \end{aligned}$$

where λ is the Lagrange multiplier associated with the capital constraint and μ is the Lagrange multiplier associated with the liquidity constraint. Note that the envelope conditions are

$$\begin{aligned} \frac{\partial v_b}{\partial x_b} &= u_c(c) \\ \frac{\partial v_b}{\partial b} &= -u_c(c)\frac{\partial \Phi}{\partial b}. \end{aligned}$$

Using the envelope condition on the set of first-order conditions one obtains:

$$\begin{aligned} \left[1 + \frac{\partial \Phi(b', b)}{\partial b'}\right] u_c(c) &= \beta_b E\left[\left(\theta' g_b(b') + R_L - \phi_b - \frac{\partial \Phi(b'', b')}{\partial b'}\right) u_c(c')\middle|\theta, d'\right] + (1-\chi)\lambda + \bar{\delta}\mu \\ u_c(c) &= \beta_b E\left[R_S u_c(c')\middle|\theta, d'\right] + \lambda + \mu R_S \end{aligned}$$

Numerical solution. The numerical algorithm solves the banker's problem by solving for a fixed point in the consumption function by time iteration as in Coleman [1990]. The policy function $c_b(\theta, x_b, b, d')$ is approximated using piecewise bilinear interpolation of the state variables x_b and b. The variables x_b and b are discretized in a non-uniformly spaced grid points with 100 nodes each. More grid points are allocated to lower levels of each state variable. The two stochastic processes, θ and d', are discretized into five and four states, respectively, using the method proposed by Tauchen [1986]. The policy functions of consumption for workers and entrepreneurs are also solved by time iteration. Because the state space is smaller the variables x_w and x_e are discretized in a non-uniformly spaced grid with 900 nodes. The invariant distributions of bankers, workers and entrepreneurs are derived by computing the inverse decision rules on a finer grid than the one used to compute the optimal decision rules. Finally, the equilibrium prices are determined using a standard quasi-newton method.

Transitional dynamics. The transition to the new stationary equilibrium is calculated assuming the new steady state is reached after 60 periods ($T = 60$). We take as inputs the steady state distribution of agents in period $t = 1$ (prior to the change in policy), guesses for the path of R^L, R^S, and K/L between $t = 1$ and $t = T$, and the optimal decision functions at the new steady state. Using those guesses we solve the problem of each agent backwards in time, for $t = T - 1, \ldots, 1$. With the time-series sequence of decision rules for each agent we simulate the dynamics of the distribution for workers, entrepreneurs and bankers and check if the loan market, the deposit market and goods market clear. If the these markets are not in equilibrium we update the path of R^L, R^S and K/L using a simple linear updating rule. Finally, after convergence of the algorithm, we compare the simulated distribution at $T = 60$, with the steady state distribution of each agent type obtained after the change in the policy parameters.

Markov chains. Both the revenue and deposit shocks of the banker follow a first-order Markov process with 5 and 4 states, respectively. The Markov chain process for the revenue process is as follows.

$$\bar{\theta} = [0.45; 0.67; 1.0; 1.49; 2.22]$$

$$\Pi(\theta', \theta) = \begin{bmatrix} 0.72 & 0.28 & 0.00 & 0.00 & 0.00 \\ 0.03 & 0.81 & 0.16 & 0.00 & 0.00 \\ 0.00 & 0.08 & 0.84 & 0.08 & 0.00 \\ 0.00 & 0.00 & 0.16 & 0.81 & 0.03 \\ 0.00 & 0.00 & 0.00 & 0.28 & 0.72 \end{bmatrix}$$

As for the deposit shock process we assume:

$$\bar{d} = [0.67; 0.88; 1.14; 1.49]$$

$$\Pi(d'|d) = \begin{bmatrix} 0.75 & 0.25 & 0.00 & 0.00 \\ 0.02 & 0.89 & 0.09 & 0.00 \\ 0.00 & 0.09 & 0.89 & 0.02 \\ 0.00 & 0.00 & 0.25 & 0.75 \end{bmatrix}$$

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