The Macroeconomic Impact of Adding Liquidity Regulations to Bank Capital Regulations*

Francisco B. Covas John C. Driscoll†

PRELIMINARY AND INCOMPLETE
October 14, 2011

Abstract

We study the macroeconomic impact of introducing a minimum liquidity standard for banks on top of existing capital adequacy requirements in a dynamic general equilibrium model. 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. We calibrate that imposing a liquidity requirement that assumes a 5 percent run-off rate on deposits and a need to fund committed lines of credit up to 10 percent would lead to a steady-state decrease of 5 percent in the amount of loans made, about a 20 basis point increase in lending rates, and an increase in securities holdings of about 20 percent. Output would fall about 0.7 percent. The welfare cost of imposing such requirements is about one-sixth of that associated with a gradual increase in capital requirements from 6 to 10 percent.

*We thank Luca Guerrieri, Michael Kiley, Jae Sim, Nellie Liang, and Matteo Iacoviello for helpful remarks. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of anyone else associated with the Federal Reserve System.

†Division of Monetary Affairs, Federal Reserve Board. E-mails: `Francisco.B.Covas@frb.gov`; and `John.C.Driscoll@frb.gov`.

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 on the intermediary.

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.

In this paper, we study the macroeconomic impact of introducing a minimum liquidity standard for banks on top of existing capital adequacy requirements in a dynamic general equilibrium model. 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.[1]

Under a liquidity standard based on a scenario that assumes a 5 percent run-off rate on deposits and a need to fund committed lines up to 10 percent of loans we find that loans would decline by about 5 percent and securities would increase by about 20 percent in the new steady state. On the liability side, deposits are little changed and equity falls as banks' portfolios become safer. The introduction of a liquidity standard prevents the most productive banks from fully exploiting their profitable opportunities, which reduces the supply of bank loans and increases the cost of funds and as a result aggregate output

[1] In general equilibrium, market prices–loan, deposit, rental and wage rates– are allowed to adjust to their new equilibrium values.

drops by about 0.7 percent in the new steady state. After the introduction of a liquidity standard banker's equity falls because their portfolio becomes safer, which in turn reduces their demand for a precautionary buffer of equity above the minimum level.

We also analyze the responses in our economy to an increase in capital requirements from 6 to 10 percent. On the asset side, the increase in capital requirements acts as a tax on assets with non-zero risk-weights, so the portfolio of bankers becomes more concentrated in securities, which carry a zero risk-weight. These results are similar to the ones obtained with the introduction of a liquidity standard. On the liability side, equity increases and deposits fall in response to the increase in capital requirements, so the deposit rate declines to clear the deposit market. The reason for the decrease in deposits is that, the increase in capital requirements reduces the borrowing capacity of banks. Because risk is not perfectly insured, bankers respond by reducing the size of their balance sheet and choose a safer portfolio. The reduction of the borrowing limit has a permanent effect on the aggregate variables of our model. Interestingly, an increase in capital requirements triggers a more accentuated increase in the liquidity coverage ratio than the introduction of a liquidity standard, which suggests that if the objective is to have banks holding more liquid assets this objective could be accomplished simply with higher capital requirements.

The welfare loss amounts to about 0.12 percent of consumption each year in response to a sudden introduction of a liquidity standard. A more gradual introduction of liquidity requirements would reduce the welfare loss by 25 percent. The welfare cost is about one-sixth of the loss associated with a gradual increase in capital requirements from 6 to 10 percent. Overall, the amount of consumption that has to be given to each agent so that he is indifferent between remaining in the baseline economy and moving to an economy with higher capital and liquidity requirements amounts to about 0.6 percent each year along the transition path.

The model developed in this paper is closely related to the papers by Angeletos (2007) and Covas (2006). These two papers augment the standard model with uninsurable labor income risk, as in Bewley (1986), İmrohoroğlu (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).

This paper is also closely related to the literature on the macroeconomic impact of banking frictions in otherwise standard macroeconomic models. Van den Heuvel (2008b) 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 use a different set of model assumptions.

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 concludes and the last section discusses some possible extensions to the current model.

2 The Model

We construct a general equilibrium model with agents that face uninsurable risks.[2] 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 securities. Loans and securities are subject to uncorrelated investment risk shocks that determine the potential profitability of bankers. An important feature of the banker's problem is the presence of occasionally binding capital and liquidity constraints.

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

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

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

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. The wage and the deposit rates are determined in general equilibrium such that the labor market, the market for deposits and the market for corporate capital clears in the steady state. Finally, we assume workers are subject to a borrowing constraint; that is $a_{t+1}^w \geqslant \underline{a}$, where $\underline{a} \leqslant 0$. Also, that we have introduced a demand for deposits by assuming that its holdings bring utility to the worker.

Let $v^w(z, x_w)$ be the optimal value function for a worker with earnings ability ϵ and cash on hand x_w.[3] The entrepreneur's optimization problem can be specified in terms of the following dynamic programming problem:

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

A list of the parameters of the worker's model 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 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 the corporate sector. 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

[3] Because the worker'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.

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} 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:

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

where κ represents the fraction of capital that can be pledged at the bank as collateral. Under this set of assumptions, the entrepreneur's budget constraint is as follows:

$$\begin{aligned} c_t^e + k_{t+1} + a_{t+1}^e + b_{t+1} &= x_t^e, \\ x_{t+1}^e &= z_{t+1} f(k_{t+1}, l_{t+1}) + (1 - l_{t+1})w + (1-\delta)k_{t+1} + R^L b_{t+1} + R a_{t+1}^e, \end{aligned}$$

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.[4] The entrepreneur's optimization problem can be specified in terms of the following dynamic programming problem:

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

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

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' and asset holdings a_e'. A list of the parameters of the entrepreneurial model is shown in the

[4] 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.

middle panel of Table 1.

Bankers. Bankers are also heterogeneous with respect to wealth holdings 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. Bank hold two types of risky assets—loans (b) and securities (s)—and fund the assets with deposits (d) and equity (e). Each period, the banker chooses loans it makes to the entrepreneurs, denoted by b_{t+1}. Loans are assumed to mature at a rate $\bar{\delta}$ and the cost of operating the loan technology is given by ϕ_b.[5] The revenue to the bank is represented by

$$y_t^b = R^L \theta_t g(b_t),$$

where θ_t denotes the idiosyncratic productivity of the bank, and the function $g(b_t)$ exhibits decreasing returns to scale.[6] Differences in productivity across banks may be thought of as, in part, reflecting differences in the ability of banks to screen applicants or monitor borrowers, or differences in market power.

In addition, the bank can also invest its net worth in an alternative bank-specific technology. The key distinction of this alternative investment is that it is less risky than bank loans. We also assume that the shocks of the alternative investment are uncorrelated with the loan technology, which provides some diversification to the banker. The technology available to the banker is represented by

$$y_t^s = \varepsilon_t h(s_t)$$

where ε_t denotes the bank-specific productivity, s_t is the stock of assets invested in this technology, and $h(s_t)$ is a decreasing returns to scale function. As in the case of loans we also allow for expense costs, denoted by ϕ_s, to capture costs of operating this bank-specific technology.

[5] In this version we allow for investment reversibility, so the value of $\bar{\delta}$ is not relevant in order to obtain the solution of the model. It is possible to extend the model to allow for adjustment costs beyond $\bar{\delta}$ to capture partial or full irreversibility of loans, as in Van den Heuvel (2008a). Adding adjustments costs to the model would require one additional state variable. In practice, investment irreversibility increases the risk of operating the technology; in this setup we try to motivate the illiquidity of loans by assuming two technologies with very different degrees of risk.

[6] Note that we do not assume that the loan is paid in full at the end of each period, so bank revenues are equal to the return on the loan, $(R^L - 1)\theta_t g(b_t)$, plus a fixed revenue stream that does not depend on the loan rate, $\theta_t g(b_t)$. An alternative interpretation is for R^L to be the price for loan services instead of a gross spread.

The banker's budget constraint is written as follows:

$$
\begin{aligned}
c_t^b + b_{t+1} + s_{t+1} + d_{t+1} = x_t^b, \\
x_{t+1}^b = R_L\theta_{t+1}g(b_{t+1}) + \bar{\delta}b_{t+1} + (1-\bar{\delta})b_{t+1} - \phi_b b_{t+1} + \\
\varepsilon_{t+1}h(s_{t+1}) + (1-\phi_s)s_{t+1} + R_D d_{t+1}.
\end{aligned}
$$

where x_t^b denotes the banker's period t wealth.

The banker borrows through deposits that it receives from the workers and the entrepreneurs. We assume that bank borrowing is constrained due to the existence of capital requirements which are not explicitly modeled. In particular, the banker's equity, e_{t+1}, must be greater than a fraction of bank loans[7],

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

where $e_{t+1} \equiv x_t^b - c_t^b$, and χ denotes the capital requirement parameter. In addition, the banker also faces a liquidity constraint, in which it must hold at least a fraction ξ_0 of its deposits and a fraction ξ_1 of its loans in the less risky asset

$$
s_{t+1} \geqslant -\xi_0 d_{t+1} + \xi_1 b_{t+1}.
$$

The parameters (ξ_0, ξ_1) are a simplified way of capturing banks liquidity needs as envisioned with the introduction of the liquidity coverage ratio. In particular, ξ_0 would be calibrated to capture run-offs of deposits and ξ_1 draws on committed lines of credit, both under stressed conditions.

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

$$
v^b(\theta, \varepsilon, x_b) = \max_{c_b, b', s', d'} u(c^b) + \beta_b E[v^b(\theta', \varepsilon', x_b')|\theta, \varepsilon], \tag{3}
$$

$$
\begin{aligned}
\text{s.t.} \quad & c_b + b' + s' + d' = x_b \\
& x_b' = R_L\theta' g(b') + (1-\phi_b)b' + \varepsilon' h(s') + (1-\phi_s)s' + R_D d' \\
& e' \geqslant \chi b', \\
& s' \geqslant -\xi_0 d' + \xi_1 b', \\
& b' \geqslant 0.
\end{aligned}
$$

From the properties of the utility function, $g(\cdot)$ and $h(\cdot)$, the optimal level of consumption,

[7] We are imposing a risk-based capital ratio and assuming that securities carry a zero risk weight.

and the two risky investments are always strictly positive. The constraints that may be occasionally binding are the capital and liquidity constraints. A complete list of parameters for the banker's problem is shown at the bottom of Table 1.

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, $v^b(\theta, \varepsilon, x_b, b)$; 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 $\{c^b(\theta, \varepsilon, x_b)$, $b^b(\theta, \varepsilon, x_b), s(\theta, \varepsilon, x_b), d(\theta, \varepsilon, x_b)\}$; 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, $\Gamma_b(\theta, \varepsilon, x_b)$, 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, the banker's policy functions solve the banker's decision problem (3).*

4. *The loan and deposit markets clear:*

$$\nu \int b^e \, d\Gamma_e = (1 - \eta - \nu) \int b^b \, d\Gamma_b, \quad \textit{(Loan market)}$$
$$\eta \int d^w \, d\Gamma_w = (1 - \eta - \nu) \int d^b \, d\Gamma_b, \quad \textit{(Deposit market).}$$

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

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

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 1.5, a number often used in representative-agent macroeconomic models. We set ω equal to 0.915 to match the deposit rate in the steady state at 46 bps. 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:

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

We set γ_e to 1.5 as in 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 0.23. We lack direct information to calibrate the stochastic process for entrepreneurs, however it seems reasonable to assume a process at least as persistent as the one of workers, and 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 0.30.

Table 1: Parameter Values Under Baseline Calibration

Parameter	Description	Value
	Worker's	
β_w	Discount factor	0.960
γ_w	Coefficient of relative risk aversion	1.500
ω	Weight on consumption	0.915
ρ_ϵ	Persistence of earnings risk	0.700
σ_ϵ	Unconditional s.d. of earnings risk	0.230
$\underline{a}$	Borrowing constraint	0.000
η	Mass of workers	0.698
	Entrepreneur's	
β_e	Discount factor	0.930
γ_e	Coefficient of relative risk aversion	1.500
ρ_z	Persistence of productivity risk	0.700
σ_z	Unconditional s.d. of productivity risk	0.300
κ	Borrowing constraint	0.872
α	Capital share	0.480
ν	Labor share	0.350
δ	Depreciation rate	0.080
ν	Mass of entrepreneurs	0.302
	Banker's	
β_b	Discount factor	0.927
γ_b	Coefficient of Relative Risk Aversion	1.000
χ	Capital requirements	0.060
α_b	Curvature of loan revenues	0.750
ρ_θ	Persistence of shock to loan revenues	0.900
σ_θ	Unconditional s.d. of shock to loan revenues	0.300
ϕ_b	Intermediation cost	0.050
α_s	Curvature of securities revenues	0.701
σ_ε	Unconditional s.d. of shock to securities revenues	0.020
ϕ_s	Securities expense rate	0.036
	Corporate sector	
β_b	Capital share	0.330
γ_b	Depreciation rate	0.080

As is standard in the business cycle literature, we choose a depreciation rate δ of 8 percent for the entrepreneurial as well the corporate sector. The degree of decreasing returns to scale for entrepreneurs is equal to 0.83—slightly less than Cagetti and De Nardi (2006)—with a capital and labor shares of 0.48 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 about 0.85 percent, which corresponds to κ set to 0.872.[8]

The discount factor of entrepreneurs is chosen to match the average loan rate between 1997 and 2007. Based on bank holding company and call report data the weighted average real interest rate charged on loans of all types was 6.51 percent. By setting β_e to 0.93 we obtain this calibration. As explained above we fixed the discount factor of workers at 0.96 and picked the weight on consumption to yield a deposit rate of 0.46 bps.

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 intermediation cost, ϕ_b, the capital constraint parameter, χ, and the expense cost and standard deviation of the less risky technology, ϕ_s and σ_ε, respectively. The remaining parameters of the banker's problem are determined so that a selected set of moments in the model are close to a set of moments available in the bank holding company and commercial bank call reports. The banker has log utility to minimize the amount of precautionary savings induced by occasionally binding capital and liquidity constraints. 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 intermediation cost, ϕ_b, is set to 5 percent, which includes both net charge-offs and non-interest expenses. The ratio of non-interest expense to total assets is equal to 3.6 percent, and that is the value that we assume for the expense cost of the safer technology, that is we set ϕ equal to 0.036. As for the standard deviation of the safer technology, we set it to be equal to 2 percent, which is roughly the average annualized volatility of U.S. Treasury securities.

As for the parameters set internally, namely the banker's discount factor, the three parameters of the banker's loan technology, and the curvature of the safer technology are chosen to match a set of five moments calculated from the call report data. The moments selected are: (i) tier 1 capital ratio, (ii) leverage ratio, (iii) return-on-assets, (iv) the cross-

[8] Leverage is defined as debt to assets, that is $-b/k$. At the constraint $b = -\kappa k$, hence maximum leverage in the model is equal to $\kappa = 0.872$.

Table 2: Selected Moments

Moment	Data	Model
Tier 1 capital ratio	9.31	9.50
Leverage ratio	6.92	7.78
Return-on-assets	1.35	2.31
Cross-sectional volatility of ROA	1.17	0.51
% Eligible liquid assets	18.17	18.19
Loan rate	6.51	6.49
Deposit rate	0.46	0.47
Consumption to Output	0.69	0.67
Banking Assets to Output	1.00	1.01
% Labor in entrepreneurial sector	—	50.52
% Labor in corporate sector	—	49.48
% Output of entrepreneurial sector	—	61.17
% Output of corporate sector	—	31.30
% Output of banking sector	—	7.54

Note: Data is annual between 1997 and 2006, with the exception of the percentage of eligible liquid assets that starts in 2001. This percentage includes all assets with a zero risk weight plus assets with a 20 percent risk weight up to the 40 percent limit of the total stock of liquid assets. We included 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.

sectional volatility of return on assets, and (v) the ratio of assets with a zero Basel I risk-weight to total assets. The upper panel of Table 2 presents a comparison between the data and the model for this selected set of moments. Figure 1 shows the steady state invariant densities of wealth for workers, entrepreneurs and bankers.

4 Analysis of Baseline Economy

Partial Equilibrium. We first examine the banker's policy rules, and the distribution of capital and/or liquidity constrained bankers as a function of bankers' wealth and productivity. Throughout this section we solve the banker's problem also subject to a liquidity constraint by assuming a run-off factor of 5% for deposits and a need to fund committed lines that amount up to 10% of loans, that is we let $\xi \equiv (\xi_0, \xi_1) = (0.05, 0.10)$. The remaining parameters are kept at their steady state level.

Figure 2 plots the policy rules for bank loans, securities, deposits and consumption as a function of wealth and productivity. The solid blue lines represent the decision rules of

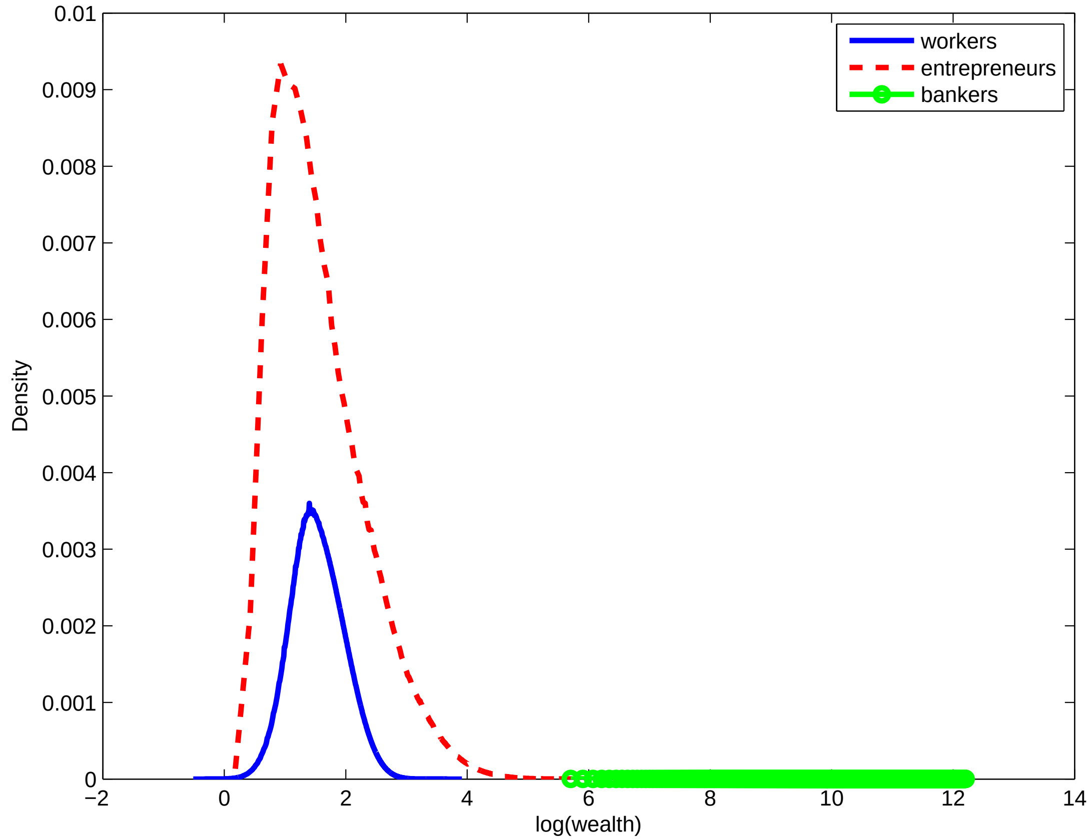
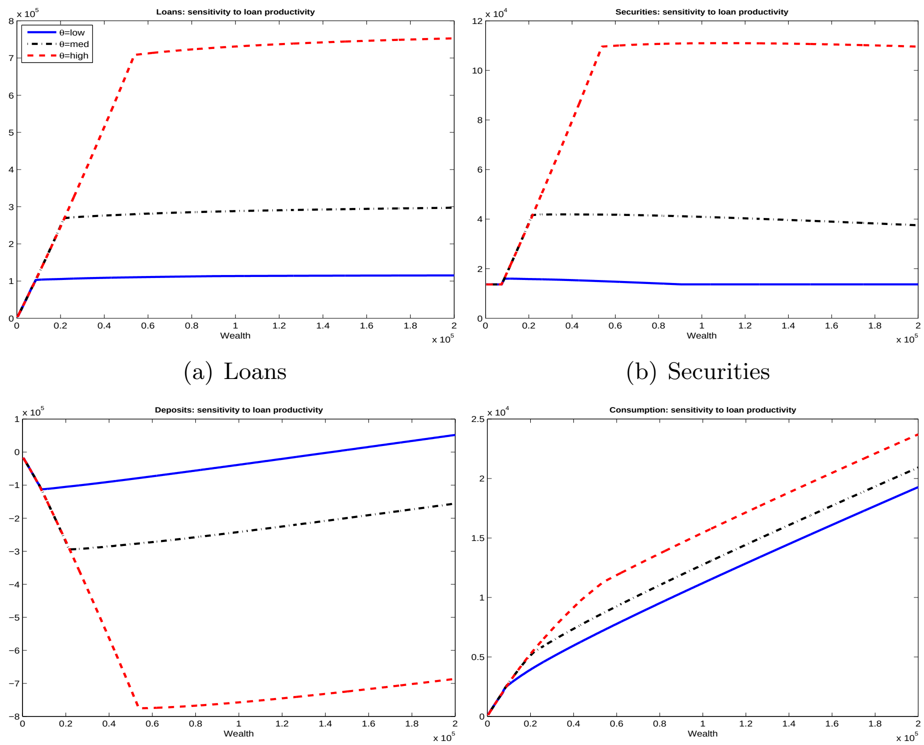


Figure 1: Invariant density function of wealth

bankers endowed with $\theta = \bar{\theta}_5$, the dotted black lines corresponds to $\theta = \bar{\theta}_6$ and the red dashed line corresponds to $\theta = \bar{\theta}_7$ (highest productivity level). The optimal level of loans depends on the level of θ because the shock to loan revenue is persistent. Referring to the plot in the top left panel, bankers are capital constrained if their wealth is located to the left of the kink in the policy rule for loans.

The stochastic process for securities (i.e., ε) is i.i.d., hence the optimal level of the investment in the banker's portfolio does not change with the level of the stochastic process. As shown in the top right panel, a level of securities above the blue line to the right of the kink implies that the liquidity constraint is binding. This includes all of the most productive banks, and a significant fraction of the banks with the average productivity level.

The lower left panel shows the policy rule for deposits which is more or less a mirror image of the policy rule for bank loans. To the left of the kink bankers' rely on deposits up to the point where their capital constraint is binding. To the right of the kink, the capital constraint is no longer binding and bankers finance a larger share of their assets



(a) Loans

(b) Securities

(c) Deposits

(d) Consumption

Figure 2: The Bankers' Policy Rules

Notes: Policy rules for the bankers.

with equity. Typically, bankers' are always borrowing, which is indicated by a negative value of deposits.[9]

Table 3 shows the percentage of wealth held at each quintile and the level of loan productivity. As shown in the Table, low productivity bankers in the first quintile of the wealth distribution hold about 0.8 percent of the entire wealth of the banking sector. Conversely, the most productive bankers in the top quintile hold roughly 35 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.[10]

Table 4 shows the share of capital constrained (Panel A) and liquidity constrained (Panel B) bankers in equilibrium. Within each productivity level smaller banks are more likely to be capital constrained than larger banks. For the liquidity constraint we observe the

[9]In the steady state 99.8 percent of banker's are taking deposits from households and entrepreneurs.

[10]In our calibration the share of wealth held by the top quintile is slightly more than 60 percent. In the data, the average between 1997-2006 was more than 90 percent.

Table 3: Bankers' Wealth Distribution

	% wealth held by				
	0 – 20%	20 – 40%	40 – 60%	60 – 80%	80 – 100%
Low revenue	0.8	0.3	0.2	0.2	0.2
Medium revenue	1.9	5.5	9.9	17.9	27.6
High revenue	0.0	0.0	0.0	0.9	34.6

NOTE: All figures are in percent. The stochastic process for the loan technology is discretized into a markov-chain with 7 states. The low revenue state corresponds to the first two states of the markov chain, the medium revenue state to the next three states and the high revenue state to the last two states. 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 6.49% and a deposit rate of 0.47%.

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	23.1	0.0	0.0	0.0	0.0
Medium revenue	80.1	57.4	49.6	54.3	0.0
High revenue	100.0	100.0	100.0	96.2	57.7
	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	0.0	25.1	70.2
High revenue	0.0	0.0	0.0	54.0	100.0

NOTE: Each cell in panel A reports the share of bankers with a binding capital constraint in each wealth/loan revenue bucket. Each cell 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 6.49% and a deposit rate of 0.47%.

Table 5: Partial Equilibrium Analysis of the Banking Sector

	Baseline	Δ's relative to Baseline		
Capital requirements	6%	6%	10%	10%
Liquidity requirements	—	5%,10%	—	5%,10%
1. Securities	13.6	19.5%	0.0%	11.8%
2. Loans	61.4	-6.1%	-19.7%	-23.4%
3. Assets (=1+2)	75.0	-1.4%	-16.1%	-17.0%
4. Deposits	69.2	-0.9%	-18.5%	-18.8%
5. Equity	5.8	-7.7%	11.6%	4.7%
6. Securities-to-Assets (%)	18.2	22.1	21.7	24.5
7. Liquidity coverage ratio (%)	142.2	177.4	176.2	203.2
8. Liquidity constraint binds (%)	0.0	21.8	0.0	15.3
9. Capital ratio (%)	9.5	9.3	13.2	13.0
10. Capital constraint binds (%)	47.4	48.3	59.3	60.2
11. Leverage ratio (%)	7.8	7.3	10.3	9.8
12. Return-on-assets (%)	2.3	2.3	2.6	2.6

NOTE: Results are based on the invariant distribution of bankers. The baseline economy is one in which capital requirements are equal to 6 percent (χ = 0.06) and there are no liquidity requirements. The rate on loans and the rate on deposits are fixed at 6.49 and 0.47 percent, respectively. In column 1, rows 1-5 the values are in thousands.

opposite. Larger banks are more likely to be liquidity constrained than smaller banks. Banks that are more productive in terms of loan revenue, choose to allocate the minimum amount of their assets to securities. If the concentration of assets were higher in the model, the share of banks with a binding liquidity constraint would be even higher.

The first column of Table 5 reports the solution of the partial equilibrium version of the banker's model. 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 increasing the capital and liquidity requirements simultaneously. The size of the changes in regulatory requirements are just an approximation to he announced changes in regulatory requirements by the BIS. For example, the run-off rate of deposits in BCBS (2010b) is 5 percent for stable deposits and 10 percent or higher for less stable deposits. We are assuming a run-off rate of 5 percent for all types of liabilities. We also assume a 10 percent increase in the stock of loans, and although the model does not explicitly allow for entrepreneurs to drawn on committed loans, the scenario underlying the liquidity standard allows for a potential increase in the stock of loans due to drawdowns on loan commitments. Below we analyze results which consider higher run-off rates for deposits and higher drawdown rates for loans.

The introduction of a liquidity requirement leads to an increase in the stock of securities and a decrease in the stock of loans. This substitution does not lead to a significant decline in total assets. Since the share of securities-to-assets increases, the banker's portfolio becomes less risky and demands a lower precautionary capital buffer (buffer drops 20 bps from 9.5 to 9.3). As shown in line 5 of Table 5 equity falls by about 8 percent. The leverage ratio also decreases in response to an increase in the liquidity requirement, as the denominator includes assets with a zero risk weight. Hence, an increase in liquidity requirements will likely make the leverage ratio more likely to bind relative to the risk-based capital ratio.[11]

An increase in capital requirements from 6 to 10 percent would, in partial equilibrium, increase the stock of equity at banks by about 12 percent, decrease deposits and loans by about 20 percent, and leave securities holdings roughly unchanged. There is no change in securities because it receives a zero risk weight, hence are not directly impacted by the increase in the capital requirement. An interesting result is that the liquidity coverage ratio (and the ratio of securities-to-assets) increases significantly in response to an increase in the capital requirement. Also, deposits decline significantly as a larger share of assets are now being financed with equity.

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 shrinks by more than 15 percent and it is accompanied by declines in loans and deposits of about 20 percent. These declines will lead to adjustments in the loan and deposits rates which is the topic of the next section.

General Equilibrium. The first column of Table 6 reports the general equilibrium solution of the full model without a liquidity requirement. As shown in the previous section, an increase of the capital requirement leads to a decline in the supply of loans and deposits. In general equilibrium the prices (R_L, R_D, R, w) have to adjust to clear the loan, the deposit, the asset and the labor markets.

The second column of Table 6 reports the general equilibrium results in response to the introduction of a liquidity standard. The loan rate increases by 18 bps, the deposit

[11] In the model the leverage ratio never binds, but one exercise could consider replacing the risk-based capital constraint with a leverage ratio constraint, to investigate if the impact of an increase in liquidity ratio is different in this context.

Table 6: General Equilibrium Analysis

	Baseline	Δ's relative to Baseline		
Capital requirements	6%	6%	10%	10%
Liquidity requirements	—	5%,10%	—	5%,10%
1. Securities	13.6	20.2%	19.0%	32.1%
2. Loans	61.4	-5.1%	-8.2%	-11.6%
3. Assets (=1+2)	75.0	-0.5%	-3.2%	-3.6%
4. Deposits	69.2	0.1%	-5.6%	-5.5%
5. Equity	5.8	-6.7%	24.8%	18.2%
6. Securities-to-Assets (%)	18.2	22.0	22.4	24.9
7. Liquidity coverage ratio (%)	142.2	176.7	182.4	207.4
8. Liquidity constraint binds (%)	0.0	21.9	0.0	14.5
9. Capital ratio (%)	9.5	9.3	12.9	12.7
10. Capital constraint binds (%)	47.4	47.3	61.0	61.2
11. Leverage ratio (%)	7.8	7.3	10.0	9.5
12. Return-on-assets (%)	2.3	2.3	2.5	2.5
12. Loan rate (%)	6.49	6.67	6.79	6.92
13. Deposit rate (%)	0.47	0.46	0.26	0.26
14. Output	2.6	-0.7%	-1.2%	-1.7%
15. Excl. banking sector	2.4	-0.6%	-1.0%	-1.4%
16. Entrepreneurial sector	1.6	-1.8%	-3.0%	-4.3%
17. Corporate sector	0.8	1.8%	3.0%	4.2%
18. Consumption	1.8	-0.3%	-0.6%	-0.8%

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. In column 1, rows 1-5 the values are in thousands.

decreases by 1 bps. The differences between partial and general equilibrium results are not very significant, as the liquidity standard causes relatively smaller changes in equilibrium prices. The impact on the new steady state level of output is non-negligible—about 0.7 percent decline in output.

The third column of Table 6 reports the general equilibrium results when capital requirements increase from 6 to 10 percent. The loan rate increases by 29 bps, and the deposit rate declines by 21 bps in order to clear the loan and deposit markets. The differences between partial and general equilibrium results are significant as shown in lines 1-5 of the table. The increase in the loan rate leads to a smaller decline in loans in general equilibrium. Because the decline in loans is less dramatic in general equilibrium, banks increase their holdings of securities to alleviate their capital constraint. In partial equilibrium holdings of securities were unchanged in response to an increase in capital requirements. Thus, the adjustment of prices in general equilibrium pushes the share of securities to assets even further. The increase in the share of securities lowers the capital buffer from 3.5 to 2.9 percentage points as securities are less risky than loans. Moreover, the liquidity coverage ratio increases even further to about 185%.

With respect to the impact on output and consumption, we find that aggregate output declines by about 1.2 percent after the increase in the capital requirement from 6 to 10 percent. The entrepreneurial sector (representing the bank dependent borrowers) reports a decline of 3 percent in output. In contrast, the corporate sector expands production by about 3 percent.

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 to decline by about 1.7 percent.

5 Transitional Dynamics

Introduction of a liquidity requirement. Figure 3 shows the transitional dynamics of our economy in response to the introduction of a liquidity standard. The increase in liquidity requirements occurs in period 1, which under our assumptions of the liquidity scenario implies the parameters (ξ_0, ξ_1) increase from zero to 5 and 10 percent, respectively. Bankers react to the introduction of a liquidity standard by decreasing the supply of loans and increasing holdings of securities. This triggers an immediate increase in the loan rate from 6.50 to 6.67 percent. Deposits drop slightly in response to the shock as workers shift their portfolio allocation towards assets in the corporate sector (nonbank dependent), and the deposit rate initially increases by about 2 basis points, but falls by 1 basis point in the long run. Compared to the responses of loans and securities, the change in deposits is very sluggish. Equity falls because the liquidity requirement induces bankers to hold a higher fraction of their portfolio in securities which are less risky, which reduces the demand for a buffer of equity above the minimum capital requirement. The liquidity coverage ratio shown in the last panel to the right increases from 140 to 175 percent as the banks with the strongest loan revenue shift their portfolio allocation from loans into securities.

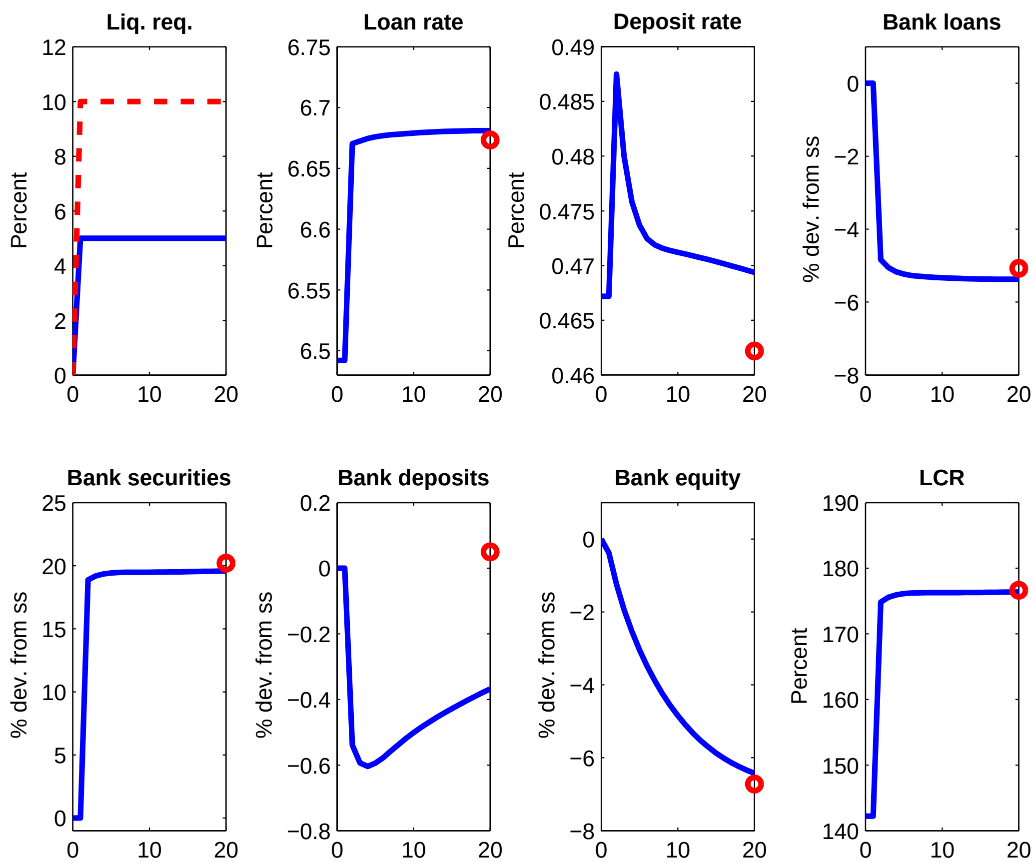


Figure 3: Transitional Dynamics: Introduction of Liquidity Requirements

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 200 periods, but only first 20 periods are shown. The circles in the last period indicate the final steady steady state value. In the top left panel the solid line depicts the change in the run-off factor of deposits (ξ_0), and the dashed line the change in the amount needed to fund committed credit lines (ξ_1).

Figure 4 depicts the responses of consumption and output aggregated across workers, entrepreneurs and bankers and the response of output and capital of entrepreneurs. The chart plots the responses of a sudden and a gradual increase in liquidity requirements. We show both responses to illustrate the effect of a more gradual implementation of the liquidity standard on macroeconomic variables. Naturally, output declines considerably more for the

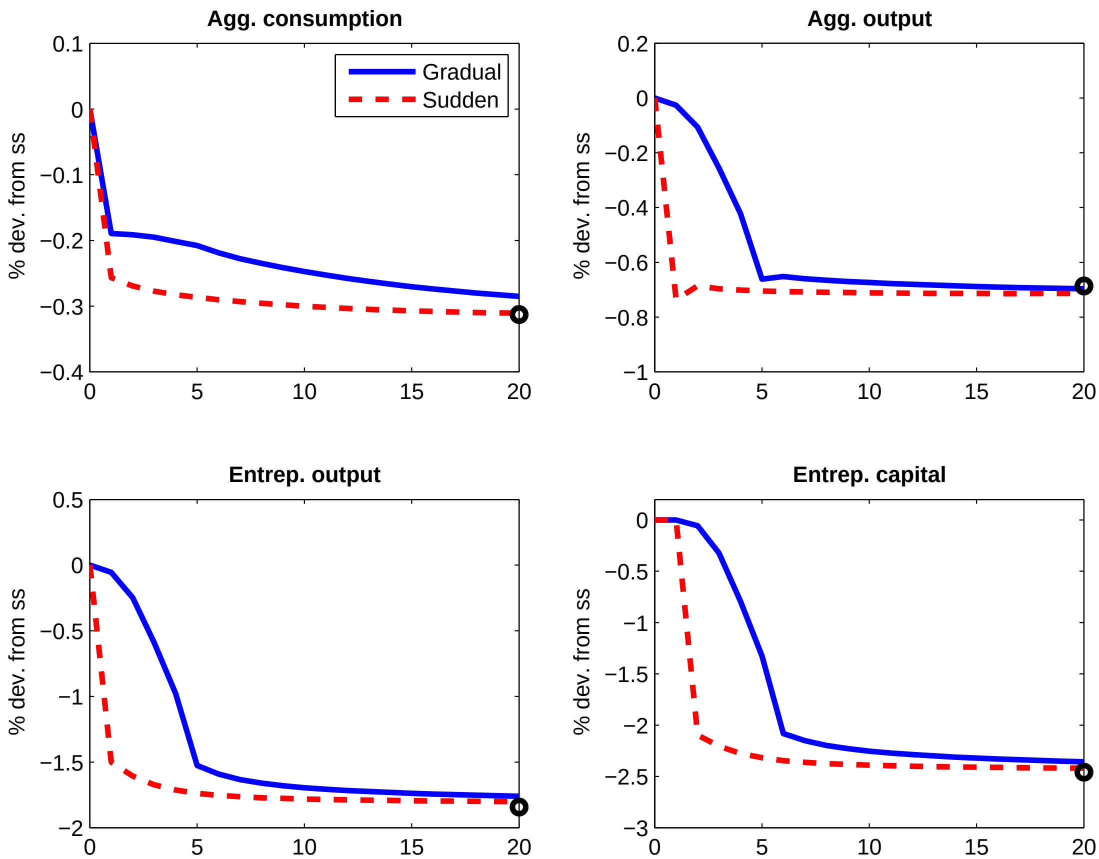


Figure 4: Introduction of Liquidity Requirements: Sudden vs. Gradual

Notes: See notes to Figure 3. The gradual increase in liquidity requirements occurs at a constant rate between period 1 and period 5.

entrepreneurs than at the aggregate level. Because entrepreneurs are the bank dependent borrowers the introduction of a liquidity standard shifts capital and labor input out of the entrepreneurial sector to the corporate sector. Moreover, a more gradual increase in liquidity requirements yields a less abrupt reduction in output and consumption during the transition path.

Sensitivity analysis. As shown in Table 6, before the introduction of a liquidity standard the LCR is about 140 percent. This ratio is calculated under a 5 percent run-off rate for deposits and a 10 percent drawdown rate in loan commitments during a liquidity stress event. However, the 5 percent run-off rate on deposits is a lower bound of the requirement proposed by Basel for bank deposits. Also, we do not accurately model loan commitments since loans by entrepreneurs are fully drawn at origination. According to Santos (2011) the average drawdown rate for non-financial borrowers is 23 percent, and are significantly higher during recessions and financial crisis. In addition, the Results of the comprehensive quantitative impact study (BCBS 2010c), estimate that the liquidity coverage ratio for the set of banks included in their sample were 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.[12]

Figure 5 depicts the responses of a subset of the variables of the model under different parametrizations of the liquidity standard. In particular, the dotted line shows the response corresponding to a liquidity coverage ratio of 85 percent prior to the introduction of the liquidity standard. Relative to solid line, which represents out baseline change in the liquidity standard, the loan rate increases from 17 to 43 basis points. The reduction on bank loans exceeds 12 percent and securities increase by about a 45 percent. The shift in banks' portfolios towards safer assets leads to a decline in bank equity. The decline in the supply of loans and increase of borrowing leads to a decline in output of 1.5 percent. Hence, a LCR of 85 percent leads to much stronger responses of the economy to the introduction of a liquidity standard.

Our analysis assumes that only the risk-based capital ratio is binding, so we may be overstating the decline in bankers' equity in response to the introduction of a liquidity standard In particular, the bottom right panel in Figure 5 shows a decline of the leverage ratio by about 100 basis points in the most stringent liquidity stress scenario. This suggests that the leverage ratio is more likely to bind in this case. If that is the case, the decline in equity would be attenuated to reduce the likelihood of a binding leverage ratio. An interesting extension would be to study the effect of an occasionally binding leverage ratio to our results.

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

[12]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.

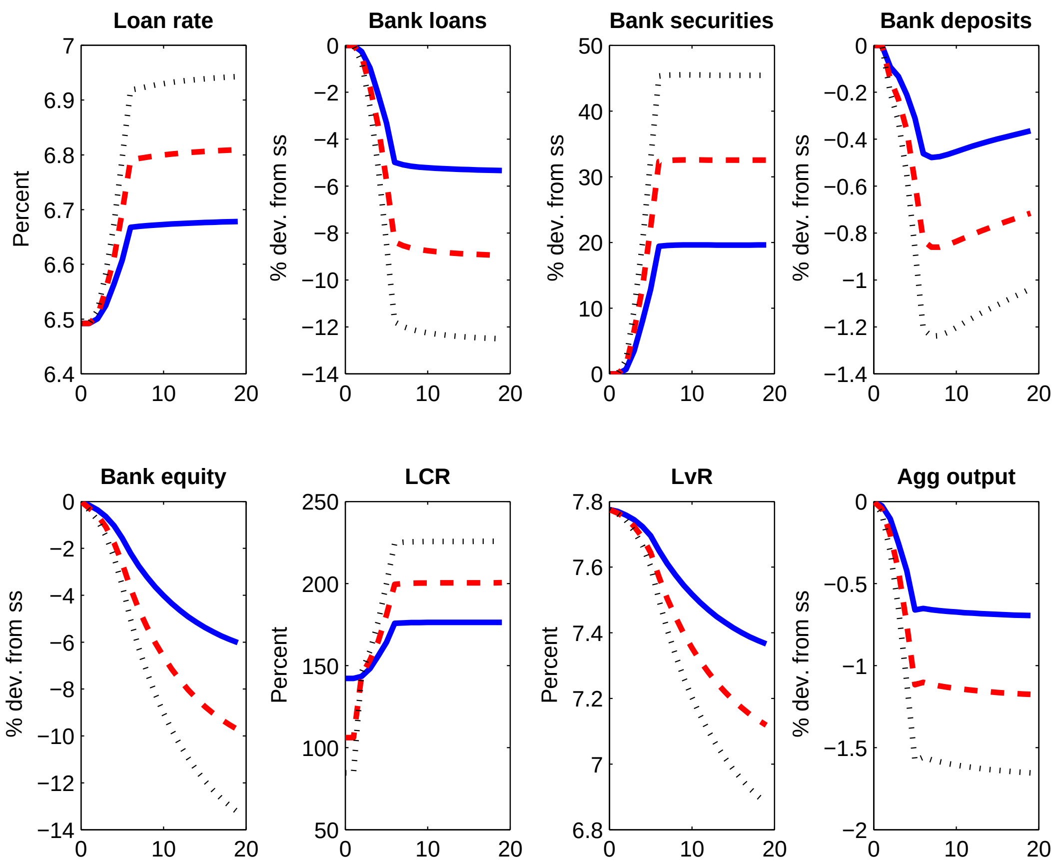


Figure 5: Sensitivity to the Parametrization of the Liquidity Standard

Notes: The solid lines depict the response to a *gradual* introduction of liquidity standard assuming a 5 percent run-off rate of deposits and 10 percent drawdown on loan commitments. The dashed line assumes a 7.5 percent run-off rate on deposits and a 12.5 percent drawdown on loan commitments. Finally, the dotted line assumes a 10 percent run-off rate on deposits and a 15 percent drawdown rate on loan commitments.

to other sources of debt finance with longer maturities and exempted from the liquidity requirement, the impact on loan growth could be mitigated.

Increase in capital requirements. To give a sense of the magnitude of the increase in liquidity requirements, Figure 6 shows the responses of our economy to a gradual increase in capital requirements from 6 to 10 percent. Also shown in this Figure is the response to a gradual introduction of a liquidity standard. Loans and deposits are more responsive to an increase in capital requirements. In particular, the deposit rate decreases markedly after a gradual increase in capital requirements. Bankers demand less deposits because of the need to finance a larger share of their loans with equity. Moreover, to meet the capital requirement bankers allocate a higher share of their assets to securities (the less risky asset which has a zero risk weight), so both the risk-based capital and the liquidity coverage ratios increase to about 13 and 180 percent, respectively. Interestingly, the liquidity coverage ratio responds more sharply to an increase in capital requirements than to the introduction of a liquidity standard.

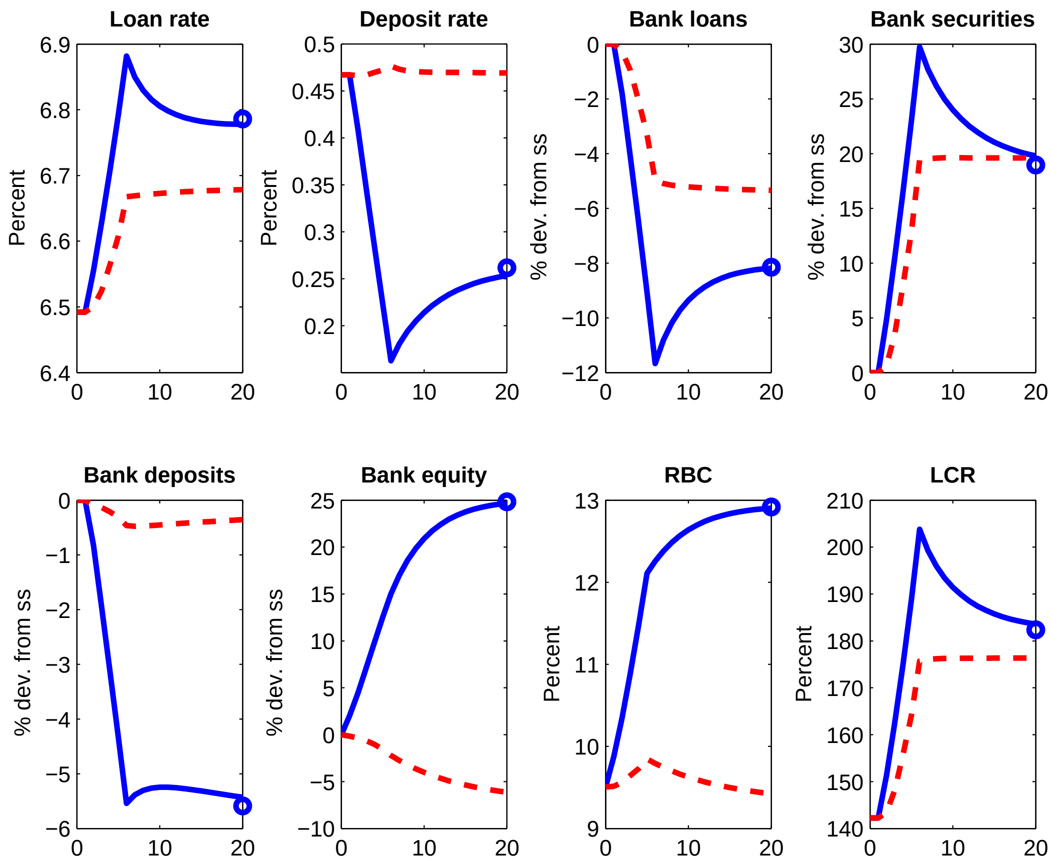


Figure 6: Transitional Dynamics: Increase in Capital Requirements

Notes: The solid lines represent the response to a gradual increase in capital requirements from 6 to 10 percent. The increase occurs at a constant rate during the first five periods. The dashed lines depict the response of the economy to a gradual increase in liquidity requirements as described in the notes to Figure 4. The horizontal axes contain the number of periods after a gradual change in regulatory requirements. The transitional dynamics assume the new steady state is reached after 200 periods, but only first 20 periods are shown. The circles in the last period indicate the final steady steady state value in response to an increase in capital requirements.

Figure 7 shows the path of macroeconomic variables in response to an increase in capital requirements. Both consumption and output fall significantly more in response to an increase in capital requirements than to the introduction of a liquidity standard. The stronger decline of macro variables in response of more stringent capital requirements reflects the

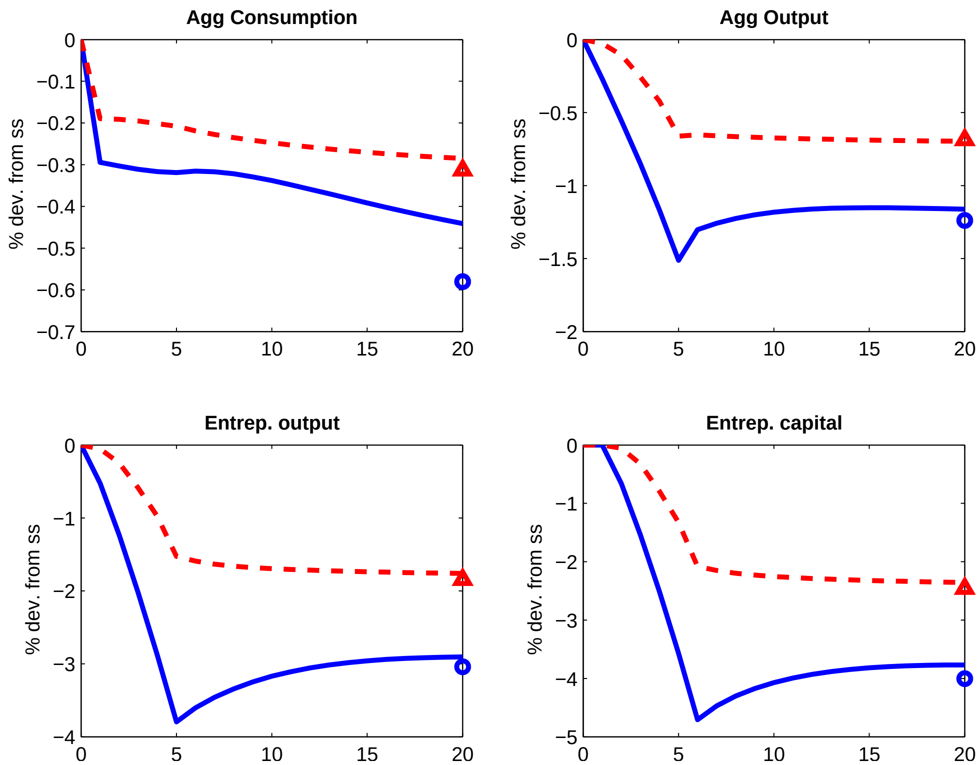


Figure 7: Aggregate Effects of Changes in Regulatory Requirements

Notes: The solid lines represent the response to a gradual increase in capital requirements from 6 to 10 percent. The increase occurs at a constant rate during the first five periods. The dashed lines depict the response of the economy to a gradual increase in liquidity requirements as described in the notes to Figure 4.

more appreciable changes in the composition of the bankers' portfolio as shown in Figure 6.

Welfare costs. Table 7 shows the consumption equivalent variation, that is the constant increment in percentage of consumption that has to be given to each agent so that he is indifferent between the baseline economy and the economy with a liquidity standard. For entrepreneurs, consumption would have to be increased by about 0.40 percent each year in response to a sudden increase in liquidity requirements. The welfare cost would decrease to about 0.30 percent in response to a more gradual increase in liquidity requirements. At the aggregate level the welfare loss is significantly smaller since the welfare cost on workers is close to zero and a more gradual implementation of the introduction of liquidity standards reduces the welfare loss by about 25 percent.

Table 7 summarizes the impact of our regulatory policy experiments in terms of consumption equivalent variation for each type of agent during the transition to the new steady

Table 7: Consumption equivalent variation

	Δ Liq. Req.		Δ Cap. Req.		Both	
	Sudden	Gradual	Sudden	Gradual	Sudden	Gradual
Workers	0.002	-0.008	0.563	0.492	0.582	0.510
Entrepreneurs	0.386	0.314	0.741	0.589	0.978	0.794
Bankers	0.126	0.026	-2.760	-1.930	-2.502	-1.822
Aggregate	0.118	0.089	0.616	0.522	0.701	0.596

NOTE: All figures are in percent. Each number on the table measures the constant increment in percentage of consumption across all states that has to be given to each agent so that he is indifferent between remaining in the baseline economy and moving to another economy that makes a transition to the new steady steady caused by the introduction of a liquidity standard, increase in capital requirements, and both policy changes occuring simultaneously.

states. Entrepreneurs are the most affected by the policy change, as in the model they represent the bank dependent borrowers. On average entrepreneurs require an additional 0.80 percent increase in consumption each each year to be indifferent between the baseline and the economy with both higher capital and liquidity requirements. It should be noted that the welfare loss depends on the wealth of entrepreneurs, with poorer entrepreneurs being relatively more affected by the more stringent regulatory requirements than richer entrepreneurs. Also to note, the welfare of workers (bankers) declines (increases) after an increase in capital requirements due to accentuated drop in the interest rate on deposits. For the aggregate economy the welfare loss is about 0.60 percent under a gradual increase in regulatory requirements during the first five periods of the model.

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 about half the size of the estimate suggested by our model. In particular, our calibration suggests that an increase in capital requirements by four percentage points leads to a decline of 1.5 percent of output after 5 years. Moreover, the decline is permanent in our model since the increase in capital requirements reduces banks' borrowing capacity even in the long-run. 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.

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 1.9 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 Conclusion

Bank liquidity regulations have the highly desirable goals of both reducing the likelihood of bank runs and increasing the likelihood 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. They may also interact with other current regulations, such as capital regulations, in ways not completely intended.

In this paper, we calibrate a dynamic general equilibrium model in which banks are subject to both capital and liquidity regulations. We find that imposing liquidity regulations of the kinds currently envisioned under Basel III would, in the long run, increase lending rates by 20 basis points, reduce loans made by 5 percent, and output by 0.7 percent.

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.

7 Extensions

One potentially useful extension would be to allow for entry and exit into the banking sector, by permitting agents to change identities. Such an extension would provide a beneficial role for capital requirements and liquidity requirements, which both might help reduce exit from the banking sector. Another useful extension would be to introduce adjustment costs for banks (and entrepreneurs). The banker's budget constraint would be written as follows:

$$c_t^b + b_{t+1} + s_{t+1} + d_{t+1} + \Psi(b_{t+1}, \bar{\delta} b_t) = x_t^b$$

where the functional form of Ψ is quadratic and asymmetric:

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

where

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

This extension would make more explicit the illiquidity of loans relative to securities. In particular, bankers would face higher cost in contracting than in expanding their loans. Since, in contrast, deposits can expand or contract costlessly, introducing adjustment costs would also help approximate the maturity transformation that banks do between short-duration liabilities and longer-duration assets.

Either of these two extensions would be very interesting to implement and would make the predictions of the model more realistic. One challenge is that either extension requires solving for equilibrium by iterating on value functions to find the solution of problem of each agent on a discrete grid. In particular, the numerical challenge arises in the solution of the banker's problem which has a relatively large number of choice variables.

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

$$b' + s' = x_b - c_b - d'$$

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, $e_b \equiv x_b - c_b$, 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', s', and d' are as follows:

$$\begin{aligned} u_c(c) &= \beta E\left[\frac{\partial v_b}{\partial x_b}\frac{\partial x_b}{\partial b'}\middle|\theta, \varepsilon\right] + (1-\chi)\lambda - \xi_1\mu \\ u_c(c) &= \beta E\left[\frac{\partial v_b}{\partial x_b}\frac{\partial x_b}{\partial s'}\middle|\theta, \varepsilon\right] + \lambda + \mu \\ u_c(c) &= \beta E\left[\frac{\partial v_b}{\partial x_b}\frac{\partial x_b}{\partial d'}\middle|\theta, \varepsilon\right] + \lambda + \xi_0\mu \end{aligned}$$

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 condition is

$$\frac{\partial v_b}{\partial x_b} = u_c(c).$$

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

$$\begin{aligned} u_c(c) &= \beta E\left[\left(R_L\theta' g_b(b') + 1 - \phi_b\right)u_c(c')\middle|\theta, \varepsilon\right] + (1-\chi)\lambda - \xi_1\mu \\ u_c(c) &= \beta E\left[\left(\varepsilon' h_s(s') + 1 - \phi_s\right)u_c(c')\middle|\theta, \varepsilon\right] + \lambda + \mu \\ u_c(c) &= \beta E\left[R_D u_c(c')\middle|\theta, \varepsilon\right] + \lambda + \xi_0\mu \end{aligned}$$

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 $c_b(\theta, \varepsilon, x_b)$ is approximated using piecewise linear interpolation of the state variable x_b. The variable x_b is discretized in a non-uniformly spaced grid points with 1000 nodes. More grid points are allocated to lower wealth levels. The two idiosyncratic productivity processes, θ and ε, are discretized into seven states 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 600 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 200 periods ($T = 200$). 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^d, 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^d and K/L using a simple linear updating rule. Finally, after convergence of the algorithm, we compare the simulated distribution at $T = 200$, with the steady state distribution of each agent type obtained after the change in the policy parameters.

References

Aiyagari, R. (1994): "Uninsured Idiosyncratic Risk and Aggregate Saving," *Quarterly Journal of Economics*, 109, 659–684.

Angeletos, G.-M. (2007): "Idiosyncratic Investment Risk and Aggregate Savings," *Review of Economic Dynamics*, 10, 1–30.

BCBS (2010a): *An assessment of long-term economic impact of stronger capital and liquidity requirements.*

——— (2010b): *Basel III: International framework for liquidity risk measurement, standards and monitoring.*

——— (2010c): *Results of the comprehensive quantitative impact study.*

Bewley, T. F. (1986): "Stationary monetary equilibrium with a continuum of independently fluctuating consumers," in *Contributions to Mathematical Economics in Honor of Gerald Debreu*, ed. by W. Hildenbrand, and A. Mas-Colell. North-Holland, Amsterdam.

Cagetti, M., and M. De Nardi (2006): "Entrepreneurship, Frictions, and Wealth," *Journal of Political Economy*, 114(5), 835–870.

Coleman, W. J. (1990): "Solving the Stochastic Growth Model by Policy-Function Iteration," *Journal of Business and Economic Statistics*, 8, 27–29.

Covas, F. (2006): "Unisured Idiosyncratic Production Risk with Borrowing Constraints," *Journal of Economic Dynamics and Control*, 30, 2167–2190.

Gertler, M., and P. Karadi (2011): "A model of unconventional monetary policy," *Journal of Monetary Economics*, 58, 17–34.

Gertler, M., and N. Kiyotaki (2011): "Financial Intermediation and Credit Policy in Business Cycle Analysis," in *Handbook of Monetary Economics*, ed. by B. M. Friedman, and M. Woodford, pp. 547–99, Chapter 11. Elsevier Science B.V.

Gertler, M., N. Kiyotaki, and A. Queralto (2011): "Financial Crisis, Bank Risk Exposure and Government Financial Policy," Mimeo.

Hamilton, B. (2000): "Does Entrepreneurship Pay? An Empirical Analysis of the Returns to Self-Employment," *Journal of Political Economy*, 108(3), 604–631.

He, Z., and A. Krishnamurthy (2010): "Intermediary Asset Pricing," Mimeo.

Heer, B., and A. Maussner (2005): *Dynamic General Equilibrium Modelling*. Springer, Berlin, Germany.

Huggett, M. (1993): "The Risk-Free Rate in Heterogeneous-Agent Incomplete-Insurance Economies," *Journal of Economic Dynamics and Control*, 17, 953–969.

IIF (2011): *The Cumulative Impact on the Global Economy of Changes in the Banking Regulatory Framework.*

İmrohoroğlu, A. (1992): "The welfare cost of inflation under imperfect insurance," *Journal of Economic Dynamics and Control*, 16, 79–91.

Kiley, M. T., and J. W. Sim (2011): "Financial Capital and the Macroeconomy," FEDS Working Paper 2011-27.

Kitao, S. (2008): "Entrepreneurship, Taxation and Capital Investment," *Review of Economic Dynamics*, 11(1), 44–69.

Moskowitz, T., and A. Vissing-Jørgensen (2002): "The Returns to Entrepreneurial Investment: A Private Equity Premium Puzzle?," *American Economic Review*, 92, 745–778.

Quadrini, V. (2000): "Entrepreneurship, Saving, and Social Mobility," *Review of Economic Dynamics*, 3, 1–40.

Santos, J. (2011): "Drawdown rates on credit lines: Historical evidence and some implications," Mimeo.

Tauchen, G. (1986): "Finite State Markov-Chain Approximations to Univariate and Vector Autoregressions," *Economics Letters*, 20, 177–181.

Van den Heuvel, S. (2008a): "The Bank Capital Channel of Monetary Policy," mimeo.

——— (2008b): "The Welfare Costs of Bank Capital Requirements," *Journal of Monetary Economics*, 55, 298–320.