Optimal Bank Regulation In the Presence of Credit and Run Risk

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Motivation

- Propose a model with a banking sector that:
  1. Provides liquidity insurance
  2. Enforces loan contracts efficiently which improves risk-sharing
  3. Expands credit extension to the real economy
- Study the externalities emerging from intermediation and examine regulation to mitigate their effect
- We modify the classic Diamond-Dybvig model to address these issues

Our modifications to DD

1. Endogenous determination of runs via a global game
2. Loans are made to fund a risky investment with uncertain liquidation value
3. Bank and borrowers are subject to limited liability
4. Bank has comparative advantage at loan collection
5. Bank can economize on monitoring costs

Basic Diamond-Dybvig

t=1
Riskless loan
funded by deposits

t=2
Idiosyncratic
preference shocks

t=3
Certain investment
outcome

No bank run
Totally random

Investment payoff

Bank run
Totally random

Early investment liquidation

Our Framework

t=1
Risky investment funded by
deposits & equity

t=2
Idiosyncratic
preference shocks
Uncertain liquidation
value

t=3
Uncertain investment
outcome

No bank run
Depends
on fundamentals

Investment payoff
Investment monitoring
Loan and deposits
repayment

Bank run
Depends
on fundamentals

Early investment liquidation

The economy

t = 1

- Entrepreneurs (E) own rights to a project and borrow to implement it
- Savers (R) invest in bank deposits and equity and can also hold a liquid safe asset
- Bankers (B) own initial equity in a bank, can buy more or sell equity to savers, take deposits, make risky loans and invest in liquid safe assets

t = 2

- Depositors learn their type $j = i, p$ and receive a noisy signal about the realization of the liquidation value of loans $\xi \in U\left[\underline{\xi}, \overline{\xi}\right] \rightarrow$ run threshold ξ^*
- In a run, R receive their deposits with probability θ (which is endogenous)
- If B survives, it uses the liquid assets and some loans to serve early withdrawals

t = 3

- E learns productivity shock, A_{3s} ($s \in \{g, m, b\}$) and B decides whether to monitor
- E and B decide whether to default on loans and deposits

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R's Optimization problem

$$\mathbb{U}^R = U(c_1) + \sum_{t=2,3} \left\{ \overbrace{\int_{\underline{\xi}}^{\xi^*} \mathbb{E}_{j,\theta} U_t\left(c_{ts}\left(j, \mathbb{I}_\theta\right); j\right) \frac{1}{\Delta_\xi} d\xi}^{\text{run}} + \overbrace{\int_{\xi^*}^{\overline{\xi}} \mathbb{E}_{j,s} U_t\left(c_{ts}\left(j, \mathbb{I}_w\right); j\right) \frac{1}{\Delta_\xi} d\xi}^{\text{no run}} \right\}$$

- $c_1 = e_1^R - D - P \cdot E^R - LIQ_1^R$
- In a run, a depositor (impatient or patient) receives

  $c_{ts}\left(j, \mathbb{I}_\theta\right) = \mathbb{I}_\theta \cdot D\left(1 + r_2^D\right) + LIQ_1^R + e_2^R,$ where $\mathbb{I}_\theta = 1$ if R is paid
- If a run doesn't occur, impatient withdraw ($\mathbb{I}_w = 1$) and patient wait ($\mathbb{I}_w = 0$):

  $c_2\left(i, \mathbb{I}_w = 1\right) = D\left(1 + r_2^D\right) + LIQ_1^R + P_{sec}E^R + e_2^R$

  $c_{3s}\left(p, \mathbb{I}_w = 0\right) = E_{sec}^R DPS_{3s} + P_{sec}\left(E^R - E_{sec}^R\right) + \left(V_{3s}^D - c_D(D) \cdot \mathbb{I}_d\right) D\left(1 + r_3^D\right) + LIQ_1^R + e_2^R$
- Patient depositors will reveal their type truthfully in equilibrium, i.e.,

  $\mathbb{E}_\omega U_t\left(c_{ts}\left(p, \mathbb{I}_w = 0\right); p\right) \geq \mathbb{E}_\omega U_t\left(c_{ts}\left(p, \mathbb{I}_w = 1\right); p\right)$

R's Optimization problem ctd.

Deposit supply-DS

$$-U'(c_1) + \left(1 + r_2^D\right)\left[\overbrace{\sum_{t=2,3}\left\{\int_{\underline{\xi}}^{\xi^*} \theta \cdot \mathbb{E}_j U_t'(c_{ts}(j,1);j)\frac{1}{\Delta_\xi}d\xi\right\}}^{\text{run}} + \overbrace{\delta\int_{\xi^*}^{\overline{\xi}} U_2'(c_2(i,1);i)\frac{1}{\Delta_\xi}d\xi}^{\text{no run, impatient}}\right]$$

$$\underbrace{+(1-\delta)\int_{\xi^*}^{\overline{\xi}}\sum_s \omega_{3s}U_3'(c_{3s}(p,0);p)\cdot\left(V_{3s}^D - c_D(D)\cdot\mathbb{I}_d\right)(1+r_3^D)\frac{1}{\Delta_\xi}d\xi}_{\text{no run, patient}} = 0$$

- Savers equate the marginal utility of lost consumption today versus the expected marginal utility gain from holding deposits in the future
- In a run, all savers withdraw; their marginal utility depends on their type and the probability that they are repaid, θ
- If a run does not occur, impatient savers are fully repaid at the promised rate, $1 + r_2^D$, while patient savers do not withdraw and receive the uncertain deposit payoff, $V_{3s}^D(1 + r_3^D)$, minus any bankruptcy costs
- Because the individual saver is small, she takes θ, V_{3s}^D, $c_D(D)$ and DPS_{3s}

Equity supply-ES

$$-P \cdot U'(c_1) + \overbrace{\sum_{t=2,3} \left\{ \int_{\xi^*}^{\overline{\xi}} \mathbb{E}_j U'_t\left(c_{ts}\left(j, \mathbb{I}_w\right); j\right) \cdot P_{sec} \frac{1}{\Delta_\xi} d\xi \right\}}^{\text{no run}} = 0$$

- Savers equate the marginal utility loss from buying one bank share at price P to the expected marginal utility gain from selling the share in the secondary market at price P_{sec} (conditional on the bank surviving the run)
- In a run, equity is worthless

Secondary equity market trading

$$P_{sec} = \sum_s \omega_{3s} DPS_{3s}$$

- If a run does not occur, impatient savers sell their bank shares to patient savers
- The secondary equity price is equal the expected value of future dividends because patient savers have linear utility at $t = 3$ and their outside option pays zero interest

B's Optimization problem

$$\mathbb{U}^B = \gamma \cdot U\left(c_1^B\right) + \overbrace{E^B \int_{\xi^*}^{\overline{\xi}} \sum_s \omega_{3s} DPS_{3s}(\xi, \delta) \frac{1}{\Delta_\xi} d\xi}^{\text{no run}}$$

- Banker's consumption at $t = 1$ is:

$$c_1^B = e^B - P \cdot E_1^B$$

- At t=1 the balance sheet constraint is:

$$I + LIQ_1 = D + P \cdot \left(E^R + E_1^B\right) + E_0^B$$

- In a run, deposits are paid according to a sequential service constraint. The probability of repayment is:

$$\theta = \frac{LIQ_1 + \xi \cdot I}{D(1 + r_2^D)}$$

- If the bank survives at t=2 and after learning ξ, it liquidates $y \in (0, 1)$ of its loans to serve early withdrawals:

$$y = \frac{\delta \cdot D(1 + r_2^D) - LIQ_1}{\xi \cdot I}$$

B's Optimization problem ctd.

- The Dividends Per Share at t=3 given survival and after productivity A_{3s} is realized are:

$$DPS_{3s} = \frac{1}{E^B + E^R} \max \left[(1-y)\, V_{3s}^I I \left(1 + r^I\right) - (1-\delta)\, D \left(1 + r_3^D\right), 0 \right]$$

where $V_{3s}^I = \min \left[1, \frac{A_{3s} F\left(I^E + (1-y) I\right)}{(1-y) I (1+r^I)} \right]$ is the percentage repayment on loans

- In bankruptcy depositors are repaid pro-rata and the percentage repayment is

$$V_{3s}^D = \min \left[1, \frac{(1-y)\, V_{3s}^I I \left(1 + r^I\right)}{(1-\delta) D \left(1 + r_3^D\right)} \right]$$

B's Optimization problem ctd.

B will choose risky loans, I, liquid assets, LIQ_1, equity she buys, E_1^B, equity she sells to savers, E^R, the price at which she issues equity, P, the run threshold, ξ^*, and the deposit contract, $\{D, r_2^D, r_3^D\}$ to maximize her utility subject to the balance sheet and the following constraints:

- The banker understands how her actions matter for the probability of a run determined in the global game by equation GG shown below
- The banker understands how her actions affect her incentives to monitor after run uncertainty is resolved

$$IC : E^B \sum_s \omega_{3s} DPS_{3s}(\xi^*) \geq PB \quad \text{where } PB \text{ is a private benefit}$$

- The banker chooses the optimal deposit contract on the deposit supply curve offered by depositors

B's Optimization problem ctd.

Loan supply-LS

$$\frac{d\mathbb{U}^B}{dI} - \psi^{BS} + \psi^{IC}\frac{dIC}{dI} + \psi^{GG}\frac{dGG}{dI} = 0$$

- We parametrize the model such that E default in states m and b for all ξ, while the banker defaults always in state b and $\xi < \hat{\xi}$ in state m
- Due to limited liability, the banker only internalizes states where she is solvent:

$$\frac{d\mathbb{U}^B}{dI} = \frac{E^B}{E^B + E^R}\left[\overbrace{\int_{\xi^*}^{\overline{\xi}} \left\{\omega_{3g}\left(1 + r^I\right)\right\}\frac{1}{\Delta_\xi}d\xi}^{\text{no default, state } g} + \overbrace{\int_{\hat{\xi}}^{\overline{\xi}} \left\{\omega_{3m}A_{3m}F'\left(I^E + (1-y)\,I\right)\right\}\frac{1}{\Delta_\xi}d\xi}^{\text{no default, state } m}\right]$$

- ψ^{BS} is the shadow cost of investment at $t = 0$, i.e., a unit of investment requires a unit of funding
- The banker internalizes how her investment choice affect her incentives to monitor and the probability of a run, dIC/dI and dGG/dI, respectively. ψ^{IC} and ψ^{GG} are the multipliers on these constraints[1]

[1] Let $\Omega = -\psi^{BS} + \psi^{IC}\frac{dIC}{dI} + \psi^{GG}\frac{dGG}{dI}$

B's Optimization problem ctd.

Liquid asset holdings

$$\frac{d\mathbb{U}^B}{dLIQ_1} - \psi^{BS} + \psi^{IC}\frac{dIC}{dLIQ_1} + \psi^{GG}\frac{dGG}{dLIQ_1} = 0 \quad \text{where}$$

$$\frac{d\mathbb{U}^B}{dLIQ_1} = \frac{E^B}{E^B + E^R}\left[\overbrace{\int_{\xi^*}^{\overline{\xi}}\left\{\omega_{3g}\left(1+r^l\right)\frac{1}{\xi}\right\}\frac{1}{\Delta_\xi}d\xi}^{\text{no default, state } g} + \overbrace{\int_{\hat{\xi}}^{\overline{\xi}}\left\{\omega_{3m}A_{3m}F'\left(I^E + (1-y)\,I\right)\frac{1}{\xi}\right\}\frac{1}{\Delta_\xi}d\xi}^{\text{no default, state } m}\right]$$

- The optimal choice of liquid assets is governed by the same considerations determining optimal lending
- But, the marginal returns on the liquid assets are scaled by the liquidation value, ξ, because the bank needs to liquidate $1/\xi$ fewer loans to serve early withdrawals
- Since the liquidity risk from ξ cannot be perfectly hedged, the banker will hold positive liquid assets
- But, the banker will also liquidate some loans to serve early withdrawals, because $\mathbb{E}\left(\xi|\xi > \xi^*\right)$ can be higher than 1 even if unconditionally $\mathbb{E}(\xi) < 1$

B's Optimization problem ctd.

Inside equity

$$-\gamma \cdot P \cdot U'\left(c_1^B\right) + \frac{E^R}{E^B + E^R} \int_{\xi^*}^{\overline{\xi}} \sum_s \omega_{3s} DPS_{3s} \frac{1}{\Delta_\xi} d\xi + \psi^{BS} \cdot P + \psi^{IC} \frac{dIC}{dE_1^B} + \psi^{ES} \frac{dES}{dE_1^B} = 0$$

Buying more equity requires giving up consumption at $t = 1$ in exchange for a higher share of future dividends, in addition to the effects of equity on the rest of balance sheet, on the incentives to monitor, as well as on the savers' equity schedule

Outside equity

$$-\frac{E^B}{E^B + E^R} \int_{\xi^*}^{\overline{\xi}} \sum_s \omega_{3s} DPS_{3s} \frac{1}{\Delta_\xi} d\xi + \psi^{BS} \cdot P + \psi^{IC} \frac{dIC}{dE^R} + \psi^{ES} \frac{dES}{dE^R} = 0$$

Selling equity to the savers reduces the banker's share of future dividends, but still delivers the shadow benefit of more equity, changes the incentives to monitor and changes the point on the savers' equity schedule

Equity price

$$-\gamma \cdot E_1^B \cdot U'\left(e^B - P \cdot E_1^B\right) + \psi^{BS} \cdot \left(E_1^B + E^R\right) + \psi^{ES} \frac{dES}{dP} = 0$$

Choosing a higher equity price requires giving up consumption at $t = 1$, but increases the balance sheet resources and allows the banker to move to a different point in the savers' equity schedule

B's Optimization problem ctd.

Run threshold

- The banker will choose the run threshold, ξ^*, or equivalently the probability of a run given by $q = \left(\xi^* - \underline{\xi}\right) / \Delta_\xi$

$$-E^B \sum_s \omega_{3s} DPS_{3s}(\xi^*, \delta) \frac{1}{\Delta_\xi} + \psi^{IC} \frac{dIC}{d\xi^*} + \psi^{GG} \frac{dGG}{d\xi^*} = 0$$

- The banker balances the reduction in dividends because of a marginally higher ξ^* against the effect from relaxing the *GG* and *IC* constraints

B's Optimization problem ctd.

- The deposit contract specifies the level of deposits, the early and late deposit rate
- The banker chooses a combination (D, r_2^D, r_3^D) to satisfy:

$$\frac{d\mathbb{U}^B}{dD} + \psi^{BS} + \psi^{IC}\frac{dIC}{dD} + \psi^{GG}\frac{dGG}{dD} + \psi^{DS}\frac{dDS}{dD} = 0$$

$$\frac{d\mathbb{U}^B}{dr_2^D} + \psi^{IC}\frac{dIC}{dr_2^D} + \psi^{GG}\frac{dGG}{dr_2^D} + \psi^{DS}\frac{dDS}{dr_2^D} + \nu = 0, \quad \nu \cdot r_2^D = 0, r_2^D \geq 0$$

$$\frac{d\mathbb{U}^B}{dr_3^D} + \psi^{IC}\frac{dIC}{dr_3^D} + \psi^{GG}\frac{dGG}{dr_3^D} + \psi^{DS}\frac{dDS}{dr_3^D} = 0$$

- As before the banker will only internalize the states that the bank is solvent as well as her incentives to monitor and the run probability (the terms in black)
- But, she will also consider how the choice of the deposit contract affects the savers' deposit supply (the terms in blue)
- After the depositors make their decisions, the banker gets to pick investment, liquidity and equity
- The planner internalizes how investment, liquidity and equity affect deposit supply

E's Optimization problem

- E has own equity I^E and will choose the loan contract $\left\{r^l, LTV\right\}$ to maximize her utility subject to the loan supply offered by the bank

$$\mathbb{U}^E = \overbrace{\int_{\xi^*}^{\overline{\xi}} \sum_s \omega_{3s} \left[A_{3s} F\left(\frac{1 - y(\xi,\delta) \cdot LTV}{1 - LTV} I^E \right) - (1 - y(\xi,\delta)) \frac{LTV}{1 - LTV} I^E (1 + r^l) \right]^+ \frac{1}{\Delta_\xi} d\xi}^{\text{no run}}$$
$$+ \underbrace{\int_{\underline{\xi}}^{\xi^*} \sum_s A_{3s} F\left(I^E\right) \frac{1}{\Delta_\xi} d\xi}_{\text{run}} + \mathrm{e}_2^{\mathrm{E}} - \underbrace{\int_{\underline{\xi}}^{\overline{\xi}} c_l \left(y(\xi,\delta) \frac{LTV}{1 - LTV} I^E \right) \frac{1}{\Delta_\xi} d\xi}_{\text{adjustment costs}}$$

- Loans that are recalled disrupt E's remaining projects
- E is protected by limited liability and may default if a run does not occur
- In a run, E continues to produce using her own equity and consumes the proceeds
- The loan supply curve offered by the bank is:

$$\int_{\xi^*}^{\overline{\xi}} \left\{ \omega_{3g} \left(1 + r^l\right) \right\} \frac{1}{\Delta_\xi} d\xi + \int_{\hat{\xi}}^{\overline{\xi}} \left\{ \omega_{3m} A_{3m} F' \left(\frac{1 - y \cdot LTV}{1 - LTV} I^E \right) \right\} \frac{1}{\Delta_\xi} d\xi + \Omega = 0$$

- E takes Ω as given, because she is small
- The planner recognises that Ω depends on the aggregate bank portfolio

E's Optimization problem

The privately optimal choice of the loan contract by E yields the following loan demand equation:

$$\int_{\xi^*}^{\overline{\xi}} \left\{ \omega_{3g} \frac{(1-y(\xi,\delta)) \cdot I^E}{(1-LTV)^2} \left[A_{3g} F' \left((\frac{1-y(\xi,\delta) \cdot LTV}{1-LTV} I^E \right) - (1+r^l) \right. \right.$$
$$\left. \left. + LTV(1-LTV) \frac{\partial LS}{\partial LTV} \left(\frac{\partial LS}{\partial r^l} \right)^{-1} \right] \right\} \frac{1}{\Delta_\xi} d\xi$$
$$- \int_{\underline{\xi}}^{\overline{\xi}} \frac{y(\xi,\delta) \cdot I^E}{(1-LTV)^2} \cdot c_l' \left(y(\xi,\delta) \frac{LTV}{1-LTV} I^E \right) \frac{1}{\Delta_\xi} d\xi = 0$$

- The first line in the loan demand corresponds to E's profit coming from the difference between the marginal product of investment and the gross loan rate
- The second line captures the dependance of the loan rate on the LTV ratio
- The third line shows the effect of the adjustment costs on loan demand
- Although the entrepreneur cares only about the states in which she is solvent, she will partially consider the effect of her loan demand on the states she defaults because the banker prices that in the interest rate

Global Games in Diamond-Dybvig

- Introducing a global game in Diamond-Dybvig is due to Goldstein-Pauzner (2005)
- In GP the bank is funded only with deposits and the liquidation value of investment is fixed
- GP have private signals on the probability of the good productivity shock, ω_{3g}
- ω_{3g} determines the likely value of deposits in the third period
- Lower dominance region is easy to establish $\rightarrow$ low realization of ω_{3g}
- Upper dominance region comes from an external agent who values investment above its liquidation value

Our Global Game

- At t=2 depositors receive private signals regarding the liquidation value of risky investment, $x_i = \xi + \epsilon_i$, where $\epsilon_i \sim U[-\epsilon, \epsilon]$
- The run threshold ξ^*, as $\epsilon \to 0$, is given by:

$$GG = \int_{\delta}^{\theta^*} \left[\sum_s \omega_{3s} \left[c_{3s}(p, \mathbb{I}_w = 0) - c_{3s}(p, \mathbb{I}_w = 1) \right] \right] d\lambda + \int_{\theta^*}^{1} \frac{\theta^*}{m} [c_{3s}(p, \mathbb{I}_\theta = 0) - c_{3s}(p, \mathbb{I}_\theta = 1)] d\lambda = 0$$

- $\theta^* = \frac{LIQ_1 + \xi^* \cdot I}{D(1+r_2^D)}$ is the highest number of depositors running such that the bank is not liquidated
- Upper and lower dominance regions endogenously derived
- Upper dominance threshold, "never run", is easy $\xi^{UD} = \frac{D(1+r_2^D) - LIQ_1}{I}$
- Lower dominance threshold, "always run", is given by $\xi^{LD} = \frac{\delta D(1+r_2^D) - LIQ_1}{I}$, even the impatient cannot be fully paid. This comes because the bank always plans to liquidate some loans to repay depositors – call $\left(\xi^{LD} - \underline{\xi}\right) / \Delta_\xi$ fundamental run risk; recall total run risk is $q = (\xi^* - \underline{\xi}) / \Delta_\xi$

The role of risk-neutrality

- The quasi-linear preferences for savers make the global game easy to solve
  - But, also need to make B risk-neutral so that savers do not insure the banker
- Eliminates some risk sharing:
  - R cares about expected return on equity and deposits, but not volatility of payoffs
  - E cares about expected return on investment, but not volatility of investment outcomes
- We restore the possibility of risk sharing through the adjustment costs and bankruptcy costs

Divergence Between the Planner and the Agents

- Banks are tempted to gamble to exploit limited liability, even though they recognise doing so changes the probability of a run
  - They optimize only over the states in which they are solvent
- Savers and Borrowers are atomistic – take the prices they face as given:
  - All savers and borrowers will make the same choices – collectively this determines the compostition of the banks' balance sheet
  - They would like to write complete contracts regarding the balance sheet but cannot, e.g. the interest rate on deposits should depend on the amount of loans and liquid assets, not just the amount deposited
- The incomplete contracts between the banks and the savers and borrowers mean that the private FOCs and the social planner's FOCs differ

Externalities

- We show that there are at least three distorted margins in banker's private decisions:
  - Distorted asset mix of loans and liquid assets
  - Distorted liabilities mix of equity and deposits
  - Distorted scale of intermediation
- The sources of the distorted margins can been easily seen from comparing the private FOCs to the social planner's FOCs

Constrained Social Planner

- The social planner chooses allocations and prices to maximize a social welfare function:

$$\mathbb{U}^{SP} = w^E \mathbb{U}^E + w^R \mathbb{U}^R + w^B \mathbb{U}^B$$

- But, the planner is constrained by the market structure, i.e., the planner needs to respect:
  1. The balance sheet constraints of *B* and the budget constraints of *E* and *R*
  2. The global game, the incentive compatibility and participation constraints
  3. The loan demand, deposits and equity supply plans by *E* and *R*
- The difference between the bank and the planner comes from limited liability and the bank's incomplete contracts

Private versus Social Banking margins

- To see the asset mix distortion combine the investment and liquid asset optimality conditions
- To see the liabilities mix distortion combine the equity and deposits optimality conditions
- To see the distortion regarding the intermediation scale combine the investment and deposits optimality conditions
  - Alternatively, one could consider other combinations such as investment-outside equity, liquidity-deposits, liquidity-outside equity, etc.
- I will compare the private and social investment-liquidity margins in detail. The other two distortions have similar features

Banker's Investment-Liquidity Margin

$$
\left[\frac{d\mathbb{U}^B}{dI} - \frac{d\mathbb{U}^B}{dLIQ_1}\right]
- \frac{\frac{dGG}{dI} - \frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi^*}} \left[\frac{d\mathbb{U}^B}{d\xi^*}\right]
- \frac{\frac{d\mathbb{U}^B}{dE_1^B} - \frac{d\mathbb{U}^B}{dE^R} + \psi^{ES}\left[\frac{dES}{dE_1^B} - \frac{dES}{dE^R}\right]}{\frac{dIC}{dE_1^B} - \frac{dIC}{dE^R}} \left[\frac{dIC}{dI} - \frac{dIC}{dLIQ_1} - \frac{\frac{dGG}{dI} - \frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi^*}} \frac{dIC}{d\xi^*}\right] = 0
$$

- The privately optimal investment-liquidity margin will weigh the contribution of an additional unit of investment versus an additional unit of liquid assets on bank profits, on the run probability and on the incentives of the bank to monitor
- In the private equilibrium the banker chooses the run threshold and the amount of equity worrying only about their effect on her own profits

Planner's Investment-Liquidity Margin

$$
\begin{aligned}
& w^B \left[\frac{d\mathbb{U}^B}{dI} - \frac{d\mathbb{U}^B}{dLIQ_1} \right] \\
& - \frac{\frac{dGG}{dI} - \frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}} \left[w^B \frac{d\mathbb{U}^B}{d\xi*} \right] \\
& - \frac{w^B \left[\frac{d\mathbb{U}^B}{dE_1^B} - \frac{d\mathbb{U}^B}{dE^R} \right] + \psi^{ES} \left[\frac{dES}{dE_1^B} - \frac{dES}{dE^R} \right]}{\frac{dIC}{dE_1^B} - \frac{dIC}{dE^R}} \left[\frac{dIC}{dI} - \frac{dIC}{dLIQ_1} - \frac{\frac{dGG}{dI} - \frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}} \frac{dIC}{d\xi*} \right] = 0
\end{aligned}
$$

- The planner weighs the banker's utility by w^B
- The planner internalizes the direct effect of I and LIQ on E's and R's welfare
- The planner internalizes how the run matters for E's and R's welfare
- The planner internalizes how relaxing B's IC constraint affects E's and R's welfare
- The planner internalizes how the loan demand, deposit and equity supply choices are affected

Planner's Investment-Liquidity Margin

$$w^B\left[\frac{d\mathbb{U}^B}{dI}-\frac{d\mathbb{U}^B}{dLIQ_1}\right]+w^E\left[\frac{d\mathbb{U}^E}{dI}-\frac{d\mathbb{U}^E}{dLIQ_1}\right]+w^R\left[\frac{d\mathbb{U}^R}{dI}-\frac{d\mathbb{U}^R}{dLIQ_1}\right]$$

$$-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\left[w^B\frac{d\mathbb{U}^B}{d\xi*}\right]$$

$$-\frac{w^B\left[\frac{d\mathbb{U}^B}{dE_1^B}-\frac{d\mathbb{U}^B}{dE^R}\right]+\psi^{ES}\left[\frac{dES}{dE_1^B}-\frac{dES}{dE^R}\right]}{\frac{dIC}{dE_1^B}-\frac{dIC}{dE^R}}\left[\frac{dIC}{dI}-\frac{dIC}{dLIQ_1}-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\frac{dIC}{d\xi*}\right]=0$$

- The planner weighs the banker's utility by w^B
- The planner internalizes the direct effect of I and LIQ on E's and R's welfare
- The planner internalizes how the run matters for E's and R's welfare
- The planner internalizes how relaxing B's IC constraint affects E's and R's welfare
- The planner internalizes how the loan demand, deposit and equity supply choices are affected

Planner's Investment-Liquidity Margin

$$w^B\left[\frac{d\mathbb{U}^B}{dI}-\frac{d\mathbb{U}^B}{dLIQ_1}\right]+w^E\left[\frac{d\mathbb{U}^E}{dI}-\frac{d\mathbb{U}^E}{dLIQ_1}\right]+w^R\left[\frac{d\mathbb{U}^R}{dI}-\frac{d\mathbb{U}^R}{dLIQ_1}\right]$$

$$-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\left[w^B\frac{d\mathbb{U}^B}{d\xi*}+w^E\frac{d\mathbb{U}^E}{d\xi*}+w^R\frac{d\mathbb{U}^R}{d\xi*}\right]$$

$$-\frac{w^B\left[\frac{d\mathbb{U}^B}{dE_1^B}-\frac{d\mathbb{U}^B}{dE^R}\right]+\psi^{ES}\left[\frac{dES}{dE_1^B}-\frac{dES}{dE^R}\right]}{\frac{dIC}{dE_1^B}-\frac{dIC}{dE^R}}\left[\frac{dIC}{dI}-\frac{dIC}{dLIQ_1}-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\frac{dIC}{d\xi*}\right]=0$$

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Planner's Investment-Liquidity Margin

$$w^B\left[\frac{d\mathbb{U}^B}{dI}-\frac{d\mathbb{U}^B}{dLIQ_1}\right]+w^E\left[\frac{d\mathbb{U}^E}{dI}-\frac{d\mathbb{U}^E}{dLIQ_1}\right]+w^R\left[\frac{d\mathbb{U}^R}{dI}-\frac{d\mathbb{U}^R}{dLIQ_1}\right]$$

$$-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\left[w^B\frac{d\mathbb{U}^B}{d\xi*}+w^E\frac{d\mathbb{U}^E}{d\xi*}+w^R\frac{d\mathbb{U}^R}{d\xi*}\right]$$

$$-\frac{w^B\left[\frac{d\mathbb{U}^B}{dE_1^B}-\frac{d\mathbb{U}^B}{dE^R}\right]+\varsigma^{ES}\left[\frac{dES}{dE_1^B}-\frac{dES}{dE^R}\right]}{\frac{dIC}{dE_1^B}-\frac{dIC}{dE^R}}\left[\frac{dIC}{dI}-\frac{dIC}{dLIQ_1}-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\frac{dIC}{d\xi*}\right]$$

$$-\frac{w^E\left[\frac{d\mathbb{U}^E}{dE_1^B}-\frac{d\mathbb{U}^E}{dE^R}\right]+w^R\left[\frac{d\mathbb{U}^R}{dE_1^B}-\frac{d\mathbb{U}^R}{dE^R}\right]}{\frac{dIC}{dE_1^B}-\frac{dIC}{dE^R}}\left[\frac{dIC}{dI}-\frac{dIC}{dLIQ_1}-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\frac{dIC}{d\xi*}\right]=0$$

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Planner's Investment-Liquidity Margin

$$w^B\left[\frac{d\mathbb{U}^B}{dI}-\frac{d\mathbb{U}^B}{dLIQ_1}\right]+w^E\left[\frac{d\mathbb{U}^E}{dI}-\frac{d\mathbb{U}^E}{dLIQ_1}\right]+w^R\left[\frac{d\mathbb{U}^R}{dI}-\frac{d\mathbb{U}^R}{dLIQ_1}\right]$$

$$-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\left[w^B\frac{d\mathbb{U}^B}{d\xi*}+w^E\frac{d\mathbb{U}^E}{d\xi*}+w^R\frac{d\mathbb{U}^R}{d\xi*}+\varsigma^{LD}\frac{dLD}{d\xi*}+\varsigma^{DS}\frac{dDS}{d\xi*}+\varsigma^{ES}\frac{dES}{d\xi*}\right]$$

$$-\frac{w^B\left[\frac{d\mathbb{U}^B}{dE_1^B}-\frac{d\mathbb{U}^B}{dE^R}\right]+\varsigma^{ES}\left[\frac{dES}{dE_1^B}-\frac{dES}{dE^R}\right]}{\frac{dIC}{dE_1^B}-\frac{dIC}{dE^R}}\left[\frac{dIC}{dI}-\frac{dIC}{dLIQ_1}-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\frac{dIC}{d\xi*}\right]$$

$$-\frac{w^E\left[\frac{d\mathbb{U}^E}{dE_1^B}-\frac{d\mathbb{U}^E}{dE^R}\right]+w^R\left[\frac{d\mathbb{U}^R}{dE_1^B}-\frac{d\mathbb{U}^R}{dE^R}\right]}{\frac{dIC}{dE_1^B}-\frac{dIC}{dE^R}}\left[\frac{dIC}{dI}-\frac{dIC}{dLIQ_1}-\frac{\frac{dGG}{dI}-\frac{dGG}{dLIQ_1}}{\frac{dGG}{d\xi*}}\frac{dIC}{d\xi*}\right]$$

$$+\varsigma^{LD}\left[\frac{dLD}{dI}-\frac{dLD}{dLIQ_1}\right]+\varsigma^{DS}\left[\frac{dDS}{dI}-\frac{dDS}{dLIQ_1}\right]+\varsigma^{ES}\left[\frac{dES}{dI}-\frac{dES}{dLIQ_1}\right]=0$$

- The planner weighs the banker's utility by w^B
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Regulatory Ratios

- To describe the equilibrium allocations, it is useful to define the following regulatory ratios:
  1. Capital Ratio $CR = \frac{E_0^B + P\cdot(E_1^B + E^R)}{I}$ (risk-weight on I is 1, risk-weight on LIQ_1 is 0)
  2. Leverage Ratio, $LevR = \frac{D}{I + LIQ_1}$
  3. Liquidity Coverage Ratio $LCR = \frac{LIQ_1 + \mathbb{E}\left[\xi \,|\, \xi < \xi^*\right]\cdot I}{D\left(1 + r_2^D\right)}$
  4. Net Stable Funding Ratio, $NSFR = \frac{E_0^B + P\cdot\left(E_1^B + E^R\right) + w^{NSFR}(1-\delta)\cdot D}{I}$
- $\mathbb{E}\left[\xi|\xi < \xi^*\right]$ is the expected liquidation value of investment in a run and w^{NSFR} measures the stability of deposits

Example	PE	SP for weights $\left(w^E, w^R\right)$		
		(0.3,0.5)	(0.4,0.4)	(0.5,0.3)
I	0.895	0.832	0.839	0.847
LIQ_1	0.085	0.182	0.179	0.175
D	0.789	0.808	0.810	0.812
CEQ	0.191	0.206	0.208	0.209
CR	0.213	0.248	0.248	0.247
$LevR$	0.806	0.797	0.796	0.795
LCR	0.521	0.571	0.569	0.567
$NSFR$	0.279	0.321	0.320	0.319
r^I	1.650	1.671	1.668	1.665
r_3^D	1.161	1.112	1.120	1.127
Run. prob.	0.482	0.429	0.430	0.431
Fund. Run prob.	0.224	0.152	0.154	0.157
Prob. B/ruptcy	0.314	0.281	0.287	0.293
$\%\Delta\mathbb{U}^E$	-	3.41%	3.48%	3.54%
$\%\Delta\mathbb{U}^R$	-	1.87%	1.85%	1.83%
$\%\Delta\mathbb{U}^B$	-	-4.24%	-4.24%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	2.00%	2.10%	2.24%
$\%\Delta\mathbb{T}^{sp}$	-	2.01%	2.01%	2.01%

- Planner corrects the distortion in the asset mix and chooses more liquidity
- Planner corrects the distortion in the liabilities mix and chooses more capital
- Planner chooses a higher scale of intermediation –liquid plus illiquid assets– but reduces risky investment
- The more stable asset and funding choices of the planner are driven by the desire to reduce run and credit risk

Example	PE	SP for weights $\left(w^E, w^R\right)$		
		(0.3,0.5)	(0.4,0.4)	(0.5,0.3)
I	0.895	0.832	0.839	0.847
LIQ_1	0.085	0.182	0.179	0.175
D	0.789	0.808	0.810	0.812
CEQ	0.191	0.206	0.208	0.209
CR	0.213	0.248	0.248	0.247
$LevR$	0.806	0.797	0.796	0.795
LCR	0.521	0.571	0.569	0.567
$NSFR$	0.279	0.321	0.320	0.319
r^I	1.650	1.671	1.668	1.665
r_3^D	1.161	1.112	1.120	1.127
Run. prob	0.482	0.429	0.430	0.431
Fund. Run prob.	0.224	0.152	0.154	0.157
Prob. B/ruptcy	0.314	0.281	0.287	0.293
$\%\Delta\mathbb{U}^E$	-	3.41%	3.48%	3.54%
$\%\Delta\mathbb{U}^R$	-	1.87%	1.85%	1.83%
$\%\Delta\mathbb{U}^B$	-	-4.24%	-4.24%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	2.00%	2.10%	2.24%
$\%\Delta\mathbb{T}^{sp}$	-	2.01%	2.01%	2.01%

- The lower run risk and credit risk are beneficial for *E* and *R*
- *B* loses with regulation: she was already internalizing everything that mattered to her in the *PE*
- But, total welfare is higher
- The mix of capital and liquidity depends on the agent that the planner favors
- If *E* is favored, the planner chooses more capital and less liquidity, resulting in higher investment, but more credit risk and lower liquidity provision (and vice versa)

Regulatory Tools

- We now examine how imposing regulatory restrictions on the aforementioned four regulatory ratios can correct for the distorted margins
- These tools impact more than one margin, but at least three tools are needed to implement planner's solution given that there are three distorted margins
- Although two tools may appear to be substitutes when used individually, they may be complements when optimally implemented

Capital regulation - $w^E = 0.4$, $w^R = 0.4$

	PE	CR	SP
I	0.895	0.904	0.839
LIQ_1	0.085	0.103	0.179
D	0.789	0.797	0.810
CEQ	0.191	0.210	0.208
CR	0.213	0.232	0.248
$LevR$	0.806	0.791	0.796
LCR	0.521	0.531	0.569
$NSFR$	0.279	0.298	0.320
P	0.958	0.919	1.036
r^l	1.650	1.626	1.668
r_3^D	1.161	1.140	1.120
Run prob.	0.482	0.463	0.430
Fund. Run prob.	0.224	0.206	0.154
Prob. B/ruptcy	0.314	0.271	0.287
$\%\Delta\mathbb{U}^E$	-	2.80%	3.48%
$\%\Delta\mathbb{U}^R$	-	0.60%	1.85%
$\%\Delta\mathbb{U}^B$	-	-3.96%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	0.99%	2.10%

- Probability of a run falls
- Prob. of fundamental runs falls
- Probability of bankruptcy falls
- Investment increases (humped-shaped)
- Equity price falls (considerably)
- Loan rate falls
- Deposit rate falls
- E and B are better-off, B is worse-off

Leverage Ratio regulation - $w^E = 0.4$, $w^R = 0.4$

	PE	LevR	SP
I	0.895	0.914	0.839
LIQ_1	0.085	0.105	0.179
D	0.789	0.812	0.810
CEQ	0.191	0.207	0.208
CR	0.213	0.227	0.248
$LevR$	0.806	0.797	0.796
LCR	0.521	0.531	0.569
$NSFR$	0.279	0.293	0.320
P	0.958	0.893	1.036
r^l	1.650	1.634	1.668
r_3^D	1.161	1.179	1.120
Run prob.	0.482	0.467	0.430
Fund. Run prob.	0.224	0.208	0.154
Prob. B/ruptcy	0.314	0.330	0.287
$\%\Delta\mathbb{U}^E$	-	2.11%	3.48%
$\%\Delta\mathbb{U}^R$	-	0.62%	1.85%
$\%\Delta\mathbb{U}^B$	-	-4.16%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	0.86%	2.10%

- Probability of a run falls
- Prob. of fundamental runs falls
- Probability of bankruptcy rises (contrary to CR)
- Investment increases monotonically (contrary to CR)
- Equity price falls (considerably)
- Loan rate falls
- Deposit rate increases
- E and B are better-off, B is worse-off
- (The bank has only on-balance sheet assets)

Liquidity Coverage Ratio regulation - $w^E = 0.4$, $w^R = 0.4$

	PE	LCR	SP
I	0.895	0.861	0.839
LIQ_1	0.085	0.211	0.179
D	0.789	0.892	0.810
CEQ	0.191	0.181	0.208
CR	0.213	0.210	0.248
$LevR$	0.806	0.832	0.796
LCR	0.521	0.574	0.569
$NSFR$	0.279	0.287	0.320
P	0.958	1.003	1.036
r^l	1.650	1.657	1.668
r_3^D	1.161	1.313	1.120
Run prob.	0.482	0.454	0.430
Fund. Run prob.	0.224	0.157	0.154
Prob. B/ruptcy	0.314	0.350	0.287
$\%\Delta\mathbb{U}^E$	-	2.58%	3.48%
$\%\Delta\mathbb{U}^R$	-	1.85%	1.85%
$\%\Delta\mathbb{U}^B$	-	-3.48%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	1.93%	2.10%

- Probability of a run falls
- Prob. of fundamental runs falls
- Probability of bankruptcy rises
- Investment decreases
- Liquidity & deposits rise
- Leverage rises, CR falls
- Loan rate slightly rises
- Deposit rate rises
- Equity price rises
- E and B are better-off, B is worse-off

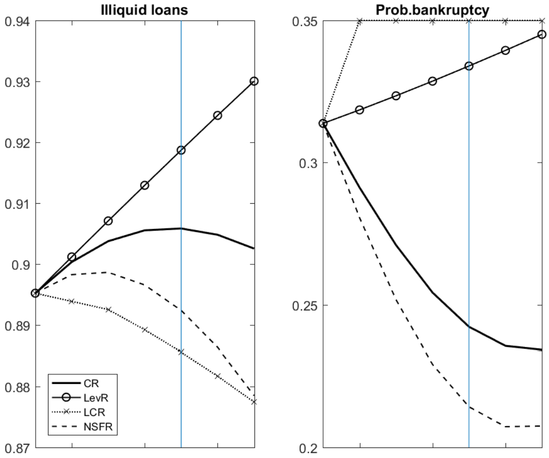
Net Stable Funding Ratio regulation - $w^E = 0.4$, $w^R = 0.4$

	PE	NSFR	SP
I	0.895	0.892	0.839
LIQ_1	0.085	0.128	0.179
D	0.789	0.794	0.810
CEQ	0.191	0.226	0.208
CR	0.213	0.253	0.248
$LevR$	0.806	0.778	0.796
LCR	0.521	0.546	0.569
$NSFR$	0.279	0.320	0.320
P	0.958	0.938	1.036
r^l	1.650	1.612	1.668
r_3^D	1.161	1.098	1.120
Run prob.	0.482	0.441	0.430
Fund. Run prob.	0.224	0.183	0.154
Prob. B/ruptcy	0.314	0.214	0.287
$\%\Delta\mathbb{U}^E$	-	5.44%	3.48%
$\%\Delta\mathbb{U}^R$	-	1.24%	1.85%
$\%\Delta\mathbb{U}^B$	-	-3.92%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	2.02%	2.10%

- Probability of a run falls
- Prob. of fundamental runs falls
- Probability of bankruptcy falls (contrary to LCR)
- Investment decreases
- Liquidity & deposits rise
- Leverage falls, CR rises (contrary to LCR)
- Loan rate falls
- Deposit rate falls
- Equity price falls
- E and B are better-off, B is worse-off

Individual Regulation and Investment

- *CR* and *LevR* result in higher investment, while *LCR* and *NSFR* in lower
- But, the responses can be non-mononotic as regulations tighten



The horizontal axis represents the number of successive times each tool is tightened. The blue line indicates the level of regulatory ratios at the social planner's solution.

Key takeaways from individual regulations

- All regulations reduce the probability of a run resulting in higher welfare for entrepreneurs and savers
- The probability that a run occurs because of bad fundmentals also drops, but does not go to zero
- Bankers are worse-off because regulations do not allow them to take full advantage of limited liability (recall that bankers choose the run probability which maximized their own utility)
- Regulation have a differential effect on investment and credit risk
  - Capital and leverage regulations result in higher investment, but they have a differential effect on the probability of bankruptcy. They appear to be substitutes, but may be jointly used
  - Both liquidity regulations result in lower investment, but they have a differential effect on the probability of bankruptcy. They appear to be substitutes, but may be jointly used

Implementing the planner's solution

- No single regulation can replicate planner's solution:
  - The planner wants more liquidity and lower investment that what capital requirements deliver alone
  - The planner wants more capital that what liquidity regulations deliver alone
- In principle, three independent tools could be used to fix the three wedges, but quantity regulations may not be jointly binding in planner's solution

CR & LCR & NSFR	LevR & LCR & NSFR	CR & LevR & LCR	CR & LevR & NSFR
$\psi^{CR} > 0$	$\psi^{LevR} > 0$	$\psi^{CR} < 0$	$\psi^{CR} < 0$
$\psi^{LCR} > 0$	$\psi^{LCR} > 0$	$\psi^{LevR} > 0$	$\psi^{LevR} > 0$
$\psi^{NSFR} < 0$	$\psi^{NSFR} < 0$	$\psi^{LCR} > 0$	$\psi^{NSFR} > 0$

- Tools that are complements are jointly needed (e.g., CR and NSFR, or CR and LCR)

Combined Regulation - $w^E = 0.4$, $w^R = 0.4$

	PE	CR & LCR	LevR& LCR	SP
I	0.895	0.866	0.866	0.839
LIQ_1	0.085	0.212	0.212	0.179
D	0.789	0.895	0.895	0.810
CEQ	0.191	0.183	0.183	0.208
CR	0.213	0.212	0.212	0.248
$LevR$	0.806	0.830	0.830	0.796
LCR	0.521	0.574	0.574	0.569
$NSFR$	0.279	0.289	0.289	0.320
P	0.958	0.969	0.968	1.036
r^I	1.650	1.652	1.652	1.668
r_3^D	1.161	1.315	1.316	1.120
Run prob.	0.482	0.452	0.452	0.430
Fund. Run prob.	0.224	0.156	0.156	0.154
Prob. B/ruptcy	0.314	0.350	0.350	0.287
$\%\Delta\mathbb{U}^E$	-	2.93%	2.93%	3.48%
$\%\Delta\mathbb{U}^R$	-	1.91%	1.91%	1.85%
$\%\Delta\mathbb{U}^B$	-	-4.31%	-4.31%	-4.24%
$\%\Delta\mathbb{U}^{sp}$	-	2.03%	2.03%	2.10%
$\%\Delta\mathbb{T}^{sp}$	-	1.94%	1.94%	2.01%

- Combining CR or LevR with LCR yields additional gains
- Combining NSFR with CR or LevR is hard because capital is already elevated when NSFR is used alone
- NSFR and LCR are not jointly binding
- CR and LevR are not jointly binding (caveats: only on-balance sheet assets and only one risky asset)

Conclusions

- The effects of regulations in models where banks provide only one service do not generalize
- Capital and liquidity do not need to be substitutes, but can be complements
  - Liquidity regulations are good for dealing with liquidity risk, but not credit risk
  - Capital regulations are good for dealing with credit risk and can help further with run risk
  - Net stable funding regulation is good for dealing with both liquidity and credit risk, but is hard to combine
- At least three distorted margins in private bankings decisions $\rightarrow$ at least three tools to address all the externalities, but need to guarantee that tools are jointly binding