Problem Statement

We intend to design a model of a bank-borrower-Federal Reserve ("Fed") relationship that maximizes social welfare and minimizes involvement of the Fed all the while avoiding a catastrophe similar to the real-world 2007 subprime mortgage crisis that resulted in the to-date failure of over 130 banks.

B banks and N borrowers will be spread over an L x L square mile area. Banks will be assigned a random amount of money M from a global pool P, an operating cost o(M), a loan processing rate F, a maximum loan size x(M), and will compete against other banks for borrowers within some radius g(M) of its random map location by adjusting and fine-turning its various parameters based on the parameters of surrounding banks and its own fitness in terms of income, number of loans, number of loans that could not be repaid, and number of lost borrowers. Banks will also represent their risk tolerances by randomly assigned lower and upper bounds, $C_L < C_U$, of borrower default probabilities at which they are willing to loan. A single Fed will exist to reactively set global floor and ceiling interest rate lending limits, $I_L < I_U$ respectively, at some variable sensitivity S. Borrowers are randomly assigned a desired loan amount A, maximum repayment rate R, and a per-round probability C of defaulting on their payments, which is variable by function $h(B_{0,}B_i)$. Banks will seek to make fixed rate and adjustable rate loans to borrowers at some interest rate $I_L < I < I_U$ to be made over either p = 180 or p = 360 payments, i.e. monthly payments for fifteen or thirty years. Interest on adjustable rate loans will vary according to each bank's variable loan processing rate. At any time, a borrower is free to attempt to renegotiate for a better loan with another bank that, upon acceptance, assumes control of the originating loan and pays the balance due to the originating bank. A fee will be assessed by the originating bank if the loan is closed within five years of its granting as a function of the principal loan amount and interest rate, j(A,I). A borrower who has repaid its loan in full will attempt to negotiate yet another loan. Borrowers "die" when they default and cannot repay their loans. In reality, when banks fail, borrowers' payments go to the Federal Deposit Insurance Corporation (FDIC) acting on the bank's behalf then back out to the bank's creditors. For our purposes, this is money removed from the system and we will consider both banks and borrowers "dead" when banks cannot pay their operating costs. A borrower will be considered orphaned when it is not within any bank's competition radius. The simulation will end when there are no surviving banks with eligible borrowers.

In order to provide a meaningful graphical representation, we plan to color code bank agents according to their risk tolerances and borrower agents according to their risks of defaulting. Orphaned agents will be assigned a unique color, independent of their default risks. Bank agents' visual sizes will be based upon the sum of their cash reserves and loan values and borrower agents' visual sizes will represent the amounts of their loans.

At the beginning of every discrete time step of the simulation, the bank, borrower, and fed agents are randomly shuffled to more accurately simulate the behavior of their real-world counterparts.

Agent Design Strategy

Our model utilizes three types of agents: borrowers, banks, and the Federal Reserve. While borrowers and banks engage in negotiations, banks and the Fed engage in behavior monitoring and regulation. Whether or not to make behavior adjustments will be based upon changes in the moving averages of relevant variables.

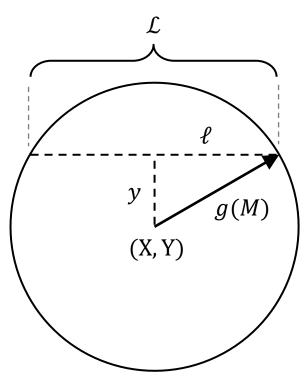
Banks

Purpose

Banks offset their operating costs by granting loans to nearby borrowers according to how well their own risk-taking and profit-seeking objectives match the borrowers' characteristics. A bank that is too risk-averse chances not making enough loans to offset its operating costs. A bank that is too risk-tolerant chances making loans to borrowers who cannot repay them.

Parameters & Behaviors

Each bank will assess *borrower risk* and its *desired profit margin* to attempt to generate four possible loan offers for each borrower request: a fixed rate 15-year loan, an adjustable rate 15-year loan, a fixed rate 30-year loan, and an adjustable rate 30-year loan.



Each bank is randomly assigned an amount of money M from a global money pool P. A bank's radius g is a function of its amount of money M. Since a bank's radius can extend beyond the visible area displayed on the screen and no borrower agents are located outside of the visible area, a bank with a radius that extends beyond the visible area have an operating cost that may not be affordable. This is due to the lack of income from borrowers that would be in the area that is not visible. This effect is most prominent when a bank's radius is very large and most of the area within the radius is located outside of the visible area. For this reason, a bank's operating cost O is a function of the visible area a'(g) for radius g(M), the total area a(g) for radius g(M), and the amount of money M. The operating cost is defined as

$$O_t = \frac{a'}{a}(0.005(M_0 + M_t))$$

where

$$a = \pi \cdot g(M)^2$$

and

$$a' = \sum_{y=y_T}^{y_B} x_R(y) - x_L(y)$$

where

$$x_L = \max(X - \ell(r), 0)$$

$$x_R = \min(X + \ell(r), W)$$

$$y_T = \max(Y - g(M), 0)$$

$$y_B = \min(Y + g(M), H)$$

A bank's radius g_t varies in time with the time-dependent parameters M_0, M_t, P_0, and P_t.

$$g_t = (\text{base radius}) + (\text{current money radius})$$

$$g_t = \frac{M_0}{P_0} g_{max} + \max\left(\frac{M_t}{P_t} g_{t-1}, 0\right)$$

where g_{max} is a scaling radius constant, M_t is the amount of money a bank has at time t and P_t is the sum of the operational banks' money at time t. M_t is defined as

$$M_t = \begin{cases} M(t), & \text{if bank is operational at time } t \\ 0, & \text{otherwise} \end{cases}$$

and P_t is defined as

$$P_t = \begin{cases} P(t), & \text{if bank is operational at time } t \\ 0, & \text{otherwise} \end{cases}$$

$M(t)$ and $P(t)$ return the amount of money a bank in operation a bank has at time t, and the total money possessed by banks in operation at time t, respectively.

Each bank's per-round operating cost O will be a function of its initially allocated money M_0 and current wealth M_i, such that $O = 0.005(M_0 + M_i)$.

Similarly, each bank's maximum allowable loan size X will be a function of its risk tolerance, initially allocated money M_0 and current wealth M_i, such that $X = 75C_U(M_0 + M_i)$.

A bank that has exhausted its access to eligible borrowers "liquidates", retaining its cash reserves and no longer incurring operating expenses; this solution does not punish banks for effectively managing loans by forcing them to adjust their eligibility parameters to accommodate undesirable borrowers.

For a given borrower with per-payment default risk of C, the probability of a bank receiving all payments is $C_t=(1-C)^p$, where p = 180 or p = 360. Thus, to break even, a bank should recuperate $A_r=A/C_t$. However, the bank will desire its own profit margin and apply its processing rate to the total such that $A_t = F \times A_r$. The resultant APR will then be $I = (A_t/A)^{(12/p)}$.

Caveats:

If the APR is below I_L or above I_U, then the loan violates Fed policy and is not offered.

If the borrower's monthly payment, A_t/p, is greater than its maximum monthly payment R, then the borrower cannot afford the loan and the bank will counter with the largest loan within that category that the borrower can afford: $((R \times p)/F) \times C_t$, which the borrower is free to accept or reject.

If the borrower's per-round probability of defaulting is not within the bank's desired risk parameters, i.e. less than C_L or greater than C_U, the loan request is rejected.

If the loan request is larger than the bank's cash reserves or maximum allowable loan size, a smaller loan is proposed to the borrower.

Once a bank grants a borrower a loan, the borrower can continue to pay on that loan, even if it falls out of the bank's radius. However, the borrower will not be able to consider this bank when asking for another loan if it pays its current loan off, and the bank's radius has not expanded to include the borrower.

Profit Margin Adjustments

Banks that frequently win loans or cannot meet their operating costs with loan payment revenue alone will increase their profit margins while those that find themselves losing a significant number of loans will decrease their profit margins. This will require that banks track their loan win/loss and revenue made/missed ratios.

Profit margins are adjusted according a “performance” score, which is calculated according to the following formula:

$$\text{Performance} = \begin{cases} \dfrac{\text{gain}}{\text{total}}, & \text{gain} > \text{loss} \\ \dfrac{\text{loss}}{\text{total}}, & \text{loss} < \text{gain} \\ 0, & \text{loss} = \text{gain} \end{cases}$$

<u>Risk Tolerance Adjustments</u>

Banks will respectively increase or decrease their risk tolerances as they infrequently or frequently experience borrower defaults. To accomplish this, banks will track the ratio of loan defaults to total loans.

Borrowers

Purpose

Borrowers search for a bank who will grant their loan request, while seeking to minimize their interest rates.

Parameters & Behaviors

When seeking a loan, borrowers locate all banks whose availability radii (g(M)) overlap the borrowers' map positions. Each borrower will make the same loan request from each bank and choose the loan with the lowest ratio of repayment value to loan value.

Even after loan approval, borrowers will continually attempt to renegotiate their loans for a better deal with other banks, but can only accept bank offers for the amount equal to the sum of the unpaid principal balance on the current loan and any prepayment penalty. Borrowers must pay a penalty if the loan being replaced is closed within five years of its granting. The penalty assessed will be six months worth of interest on 80% of the principal balance, or 0.8A x $I^{(1/2)}$.

When a borrower receives a loan counter-offer (offered when a bank cannot afford to offer the loan amount originally requested at the time the borrower accepts the loan), it accepts the counter-offer with probability $P = \left(1 - \frac{A - A'}{A}\right)^2 = \left(\frac{A'}{A}\right)^2$, where A' is the new loan amount offered and A is the amount originally requested. By using this probability, loan amounts closer to the original amount are more likely to be accepted.

Federal Reserve

Purpose

The Fed exists to set parameters that banks must follow, ideally to optimize the market, but at least to prevent a massive failure of banks.

Parameters & Behaviors

The Fed will make periodic observations according to its sensitivity S, and act accordingly.

As a bank's sensitivity S increases, it will assess the behavior of banks and borrowers more frequently with respect to the number of time steps that have passed. This frequency is equal to $\mathrm{f_s} = S \cdot 12$ (assessments per 12-month period).

Interest Rate Adjustments

High rates of defaults will result in the Fed globally lowering the interest rate upper bound (I_U) while very low rates of defaults will cause the Fed to raise the interest rate upper bound. The Fed will track loan default ratios in the same manner as banks, but do so globally.

The Fed will globally raise the interest rate lower bound (I_L) when a large number of banks are unable to meet their operating costs and lower the interest rate lower bound when banks are very easily able to meet their operating costs. Revenue made/missed ratios will be monitored globally by the Fed in the same manner as observed individually by banks.

Desired Emergent Behavior

We hope to see banks effectively manage risk amidst competition to avoid failure. The Fed should manage policy just enough to ensure a stable system.

Because our model does not incorporate a mechanism to regenerate borrowers or banks, and all borrowers have some greater than zero risk of defaulting on their loans, and borrowers will continue requesting and repaying loans until they default, our model should not perpetuate indefinitely.

We expect the most successful configurations to have banks outliving borrowers, suggesting that banks successfully navigated dynamic market conditions.

Hypotheses

1. High bank risk tolerances and high borrower probabilities of defaulting result in more bank failures.

2. Reducing upper limits on interest rates will reduce rates of bank failures.
3. Reducing lower limits on interest rates will increase competition at the expense of banks with high operating costs.
4. Configurations with banks outliving borrowers will be systems that have more money for longer periods of time with less amounts of variance.
5. If every bank is risk averse, each bank will grow stably and uniformly with its peers.
6. If every borrower prefers 30-year loans, banks will increase their risk tolerances.

Experiments

As we have a high degree of agent interactivity and no clear "win" condition, it is difficult to ascertain at this point what the precise numerical values of interest will be—determining these values is what we hope to accomplish.

In order to test the crisis sensitivity of the system, we will attempt to recreate the steps causing calamity. Borrower risk levels C and bank risk tolerance C_U will be set relatively high in order to simulate the existence of a bubble market. The Fed sensitivity S will be set to zero, and interest rate limits, I_L and I_U, unspecified so that the Fed is completely uninvolved in market regulation. Risk levels will be regularly increased between simulations in anticipation that a tipping point will be found.

Once a crisis tipping point is discovered, the role of the Fed will then be increased through S, allowing the Fed to regulate I_U in hopes of intercepting runaway risk.

In separate tests, the effect of decreasing I_L on each bank's ability to compete and pay its costs will be examined. Rates of failures and unique loan offers will be measured as I_L is reduced.

At the conclusion of each simulation, the number of surviving banks as well as each individual bank's starting cash, remaining cash, number of loans, and risk parameters will be recorded.

<u>Proposed Experimentation Values</u>

B	Number of banks	100
N	Number of borrowers	10,000 50,000 100,000
L	Land size	60
P	Environment's initial cash allotment	2×10^9 1×10^{10} 2×10^{10}
M	Individual bank's initial cash allotment	Randomized

		(P/B)± 0.75(P/B)
C_L	Individual bank's acceptable default risk lower bound	Randomized 0.00030 ± 0.00030
C_U	Individual bank's acceptable default risk upper bound	Randomized 0.00090 ± 0.00030
F	Individual bank's loan processing rate	Randomized 1.020 ± 0.010
I_L	Fed-controlled interest rate lower bound	0.0 2.0 4.0
I_U	Fed-controlled interest rate upper bound	∞ 12.0 8.0
S	Fed's sensitivity to adjusting the interest rate bounds	0.00 0.15 0.30
A	Individual borrower's loan amount	Randomized 200,000 ± 150,000
R	Individual borrower's maximum repayment rate	Randomized 1250 ± 750
C	Individual borrower's probability of defaulting on any given payment	Randomized 0.00065 ± 0.00055