# Banking Simulation MAS

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## Abstract

In this paper, we present a design for a multiagent system model of the United States banking system, in which many bank and borrower agents interact under the operational constraints imposed by a single Federal Reserve agent. Using this model, we investigate the affect of agent behaviors over a period of time under various environmental conditions and for various agent parameterizations. In particular, we address the general issue of system longevity by performing an in-depth investigation of a number of specific hypotheses. In this investigation, we find that results that differ from our expectations, so we provide an analysis and discussion of these differences and offer how the system of hypotheses may be adjusted to perform experiments that can provide more insight into the general problem that our hypotheses address.

## Introduction

The subprime mortgage crisis is an ongoing real estate and financial crisis due to a rise in mortgage failures caused in-part by the aggressive competition among financial institutions for borrowers, without sufficient consideration to risk factors associated with those borrowers, such as their ability to make monthly payments (Bernanke, 2009).

In this paper we first present our design for a multiagent system model of the United States banking system, in which a number of bank agents, many borrower agents, and a single Federal Reserve agent interact in ways that resemble their real-world counterparts. Each agent supports a number of parameters that determine its characteristics (e.g., amount of money), and influence its behavior (e.g., ability to make a monthly loan payment). A particular parameterization of an agent can lead to conditions that are different from those of another parameterization. Since there are many such parameterizations for each of the many agents in our system, it is not feasible to run simulations for all parameter combinations. Although we are generally interested in studying the consequences of agent interactions in the simulated environment, in this paper we address hypotheses that allow us to narrow our focus to the relative performances of simulations parameterized to provide insight into specific problems. These hypotheses are:

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.

The parameter combinations that we use to address each of these hypotheses as well as data analysis procedures are described in the corresponding section of this paper.

# Model Design

## Description and Discussion

In the following sections, we describe a multiagent system model of the United States banking system. We address the simulated environment, each of the agent types that can exist within that environment, and implementation-specific details. Throughout these sections, information related to a topic of discussion may be included, even if it does not relate directly to subject of the section itself—this is done out of convenience for both the author and the reader in order to highlight the relationship between components of the system.

## Environment

In our model, the simulated environment is a two-dimensional $L \times L$ grid that serves to simulate spatial separation between bank and borrower agents. While not necessarily true, it can be useful to equate each of the grid's cells with a square mile or another similar physical area that is convenient. In this environment, $B$ bank agents and $N$ borrower agents are distributed randomly in both the horizontal and vertical axes, such that no two agents occupy the same space. Once an agent is assigned a location, it does not move for the duration of the simulation. This corresponds to real-world banking establishments and households or businesses, which are infrequently relocated. The Federal Reserve agent does not occupy space within the simulation environment.

The passage of time is simulated in our model by a sequence of time steps. Each of these steps is the simulation equivalent of a real-world month. To the extent that these steps exist, time passes in discrete intervals. However, to more accurately represent the asynchronous behavior of the agents' real-world counterparts, at the beginning of each time step, the execution order of agents is randomly reassigned. Therefore, the interval between discrete time steps are the simulation equivalent of the span of time between new months, and the random execution order of agents serves as a basic model of the asynchronous behavior of the bank and borrower agents' real-world counterparts. Although the execution order of individual agents is randomized, the order of agent types is static—in particular, all borrower agents act before bank agents, and all bank agents act before the Federal Reserve agent. This execution order was chosen so each borrower has the opportunity to request and select its initial loan, and make the first payment on the selected loan (if any), so banks can have a source of income before they are asked to pay their operating cost. This serves as a simple means to help stabilize the simulation in its initial stages.

This model does not incorporate a mechanism to regenerate borrowers or banks, and all borrowers have a non-zero probability of defaulting on their loan payments, and since borrowers continue requesting and repaying loans until they default, all borrowers will eventually default. The simulation will end when there are no surviving banks with eligible borrowers or after a specified number of steps.

## Agents

### Banks

*Borrowing Neighborhood*

When the simulation begins, each bank is randomly assigned an amount of money $M$ from a global money pool $P$. Each bank has an associated borrowing neighborhood, which is the area contained by a circle of radius g, centered at the bank's location $(X, Y)$ in the environment. A bank's neighborhood radius g varies with its amount of money $M$. This scenario is shown in Figure 1.

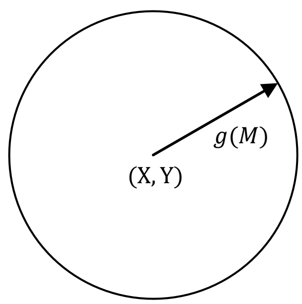



Figure 1: A bank's neighborhood is the area contained by a circle of radius g, centered at the bank's location (X,Y) in the environment.

Specifically, a bank's borrowing neighborhood radius is given by the relationship $g = \frac{M_0}{P_0}L + M^{1/3}\left(\frac{M}{P}L\right)$, where $L$ is the width of the environment and serves as a basis on which radii can be measured, $M$ is the bank's current amount of money, and $P$ is the current sum of all operational banks' money. The value $M^{1/3}$ serves as a growth factor for the second term, which increases the range of the bank's original neighborhood based on its current money in relation to the sum of all banks' money.

A bank's per-round operating cost $O$ is a function of its initial amount of money $M_0$ and current wealth $M$, given by $O = 0.005(M_0 + M)$.

A bank's neighborhood can extend beyond the environment's boundaries, where no borrowers exist. This can be problematic since the number of borrowers available to take out loans from bank is likely less than it would be if no portion of its neighborhood extended beyond the environment. This reduces the likelihood that the bank will receive sufficient income to pay its operating costs without losing money, thereby increasing the likelihood of its bankruptcy. This effect is most prominent when a bank is very wealthy relative to other banks, and is located very near the boundary of the environment. The operating cost definition can be adapted to charge banks only for their neighborhood area within the environment's boundaries. The new operating cost is $O = N(0.005(M_0 + M_t))$, where N is the fraction of the bank's neighborhood within the environment.

The maximum area contained in a bank's neighborhood is the area contained by a circle of radius $g$. This area is $\pi g^2$. However, a portion of a bank's area may extend beyond the boundaries of the simulated environment. The neighborhood are within the environment can be approximated numerically by dividing the area within the environment into rectangles of varying width $\mathcal{L}$ and unit height, then adding the areas contained by these rectangles. This area is equal to $\sum_{y=0}^{g} \mathcal{L}(y)$. This is more precisely expressed as $\sum_{y=y_2}^{y_1} x_2(y) - x_1(y)$, where $y_1$ and $y_2$ are the lower-most and upper-most coordinates in the vertical axis, respectively, and where $x_1$ and $x_2$ are the left-most and right-most coordinates in the horizontal axis for a given value of $y$, respectively. These values are $y_1 = min(Y + g, L_H)$, $x_1 = max(X - \ell(y), 0)$, $x_2 = min(X + \ell(y), L_W)$, and $y_2 = max(Y - g(M), 0)$, where $X$, $Y$, $L_W$, and $L_H$ are the coordinates of the bank in the horizontal and vertical axes, and the width and height of the environment, respectively. **Error! Reference source not found.** shows the geometric interpretation used to derive these area approximations.

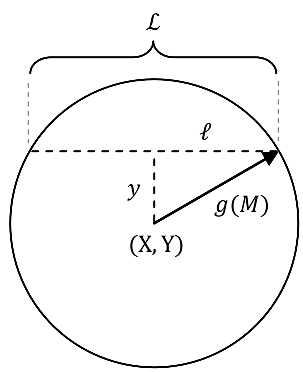



Figure 2: The geometric relationships used to derive the numerical approximations for neighborhood area within the environment.

Banks generate income by granting loans to borrowers within their borrowing neighborhoods. A bank's borrowing neighborhood is the area surrounding the bank in which a borrower can request a loan from that bank. Borrowers located outside of a bank's borrowing neighborhood cannot request loans from the corresponding bank. Banks do not offer loans to borrowers unless borrowers request them. Therefore, in order to make a profit, banks should design loans that are sufficiently appealing to borrowers but include an amount of interest that allows them to meet their operating cost.

*Loans*

When a bank receives a loan request, it first evaluates the requesting borrower's per-round probability of defaulting on a loan payment, and the requested loan amount. If the borrower's per-round probability of defaulting $C$ 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 amount requested exceeds the bank's maximum allowed loan size, a counter offer is produced for a smaller and allowable amount. If the borrower's default probability is within the bank's bounds on tolerance, the bank produces an offer with up to four different options for the borrowers can choose from. Options that may be included in a bank's offer are 15-year fixed-rate, 30-year fixed-rate, 15-year adjustable-rate, and 30-year adjustable-rate loans. In designing each option, a bank sets the base repayment amount based the loan amount requested in relation to the requesting borrower's risk and the number of months over which the loan must be repaid. The bank then applies its current loan processing rate, and ensures that the annual percentage rate (APR) of the resultant loan is within the legal limits, as specified by the Federal Reserve agent. If a loan's APR is outside of the legal limits, that loan option is not included in the bank's offer.

Specifically, for a given borrower with per-payment default risk of C, the probability of a bank receiving all payments on a loan to be repaid over p months is $C_t = (1 - C)^p$, where $p = 180$ or $p = 360$. Thus, to break even, a bank should recuperate no less than the amount $A_r = \frac{A}{C_t}$. Banks apply their processing rate, $F$, to this amount such that $A_t = F \times A_r$ becomes the total amount to be repaid. A borrower's monthly payment $A_m = \frac{A_t}{p}$ is the total amount to be repaid divided into equal payments. The resulting loan's APR is $I_{APR} = \left(\frac{At}{A}\right)^{12/p}$. If the APR is below the lower-bound $I_L$ or above the upper-bound $I_U$ as specified by the Federal Reserve agent, then the loan is excluded from the offer.

If the borrower's monthly payment, $A_m$, is greater than its maximum monthly payment R for some loan option, then the borrower cannot afford that option, so the bank offers the largest loan within that category that the borrower can afford, for the amount $A_t = \frac{R \times p}{F} C_t$.

A bank's maximum allowable loan size $X$ is a function of its upper-bound on risk tolerance, initial amount of money $M_0$ and its current amount of money $M$, given by the relation $X = 75C_U(M_0 + M)$. If a borrower requests a loan for an amount $A > X$, then the bank proposes a counter offer to the borrower for a loan.

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. Therefore, in order to meet its operating costs, a bank must adjust its loan processing rate F as well as its bounds on risk tolerance $C_L$ and $C_U$ in such a way that it can sustain itself by at least meeting its operating costs given its relative amount of money in comparison to other banks.

Once a bank grants a borrower a loan, the borrower continues to pay on that loan, even if it falls out of the bank's borrowing neighborhood. 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.

*Processing Rate Adjustment*

Banks that frequently win loans or cannot meet their operating costs with loan payment revenue alone will increase their processing rates while those that find themselves losing a significant number of loans will decrease processing rates. During each time step, banks adjust their profit margins by an amount $\Delta F$ such that their new profit margins are $F' = F + \Delta F$, where

$$\Delta F = \text{Aggression} \times \left(\left(\frac{\text{Income}}{\text{Expense}} - \text{Target Revenue Ratio}\right) + \left(\frac{\text{Loans Accepted}}{\text{Loans Rejected}} - \text{Target Loan Acceptance Ratio}\right)\right).$$

Here, the second factor serves as a measure of closeness to a bank's desired performance. The aggression factor determines how aggressive a bank will be in adjusting the profit margin in order to become closer to the desired performance. The bank's revised profit margin will be $F' = F + \Delta F$.

*Risk Tolerance Adjustment*

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. During each time step, banks adjust their default tolerance upper-bound by an amount $\Delta C_u$ such that their new profit margins are $C_u' = C_u + \Delta C_u$, where

$$\Delta C_u = \text{Aggression} \times \left(1 - (1 - (\text{Target Loan Default Percent} - \text{Default Percent}))^{1/180}\right).$$

*Liquidation*

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.

*Bank Failure*

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.

## Borrowers

When the simulation begins, borrowers are assigned a desired loan amount $A$, a per-step probability of defaulting on loan payments $C$, and a maximum monthly payment amount $R$. Each of these parameters is assigned a value selected uniformly at random from an interval that has been specified as simulation parameter. This allows us to investigate the behaviors of a sample of borrowers in a certain class.

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. A borrower who has repaid its loan in full will attempt to negotiate yet another loan.

When a borrower defaults on a loan payment, it is effectively removed from the simulation environment and the remaining balance on the loan is not repaid to the bank that granted the loan. A borrower will be considered orphaned when it is not within any bank's competition radius.

*Loans*

When seeking a loan, borrowers identify the banks with borrowing neighborhoods that include its location in the environment. Each borrower produces a desired loan amount based on its initial parameterization, then requests a loan of that amount from each of the identified banks, and selects the loan with the lowest repayment value to loan value ratio.

When a borrower is actively repaying a loan, it will attempt to take out replacement loan for the amount equal to the sum of the unpaid principal on the current loan and any prepayment penalty. A borrower will not accept any counter-offered loans for less than this amount. 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 $0.8A \times I^{1/2}$.

A borrower may receive a counter offer to its loan request when a bank cannot afford to offer the request amount or the amount exceeds its maximum allowable loan amount. When a counter offer is received, it is accepted with probability $\left(\frac{\mathrm{A_c}}{\mathrm{A}}\right)^2$, where $\mathrm{A_c}$ is the counter-offered amount and $\mathrm{A}$ is the initially-requested amount. The likelihood of decreases as the counter-offer decreases from the requested amount.

Borrowers reject all loans in an offer with monthly payments $A_m$ that exceed their maximum monthly payment amount R.

## Federal Reserve

A single Federal Reserve (Fed) agent exists to set the global upper bound $I_L$ and lower bound $I_L$ on the annual percentage rate of interest (APR) that banks can legally offer to borrowers, such that $I_L < I_U$. The Federal Reserve agent reacts to changes in the environment with sensitivity $S$.

*Annual Percentage Rate of Interest (APR) Adjustments*

High rates of defaults result in the Federal Reserve agent lowering the global interest rate upper bound $I_U$ while very low rates of defaults will cause the Fed to raise the interest rate upper bound. During each time step, the Federal Reserve agent adjusts the global interest rate upper bound by an amount $\Delta I_U$ such that the new rate is $I_U' = I_U + \Delta I_U$, where

$$\Delta I_U = 0.005S \times \big((1 - S) - \ (1 - \text{Loan Default Percentage})\big),$$

and

$$\text{Loan Default Percentage} = 1 - \left(1 - \frac{\text{Number of Defaulted Loans}}{\text{Number of Loans}}\right)^{180}.$$

The Fed raises the global interest rate lower bound $I_L$ when a large number of banks are unable to meet their operating costs and lowers the interest rate lower bound when banks are very easily able to meet their operating costs. The revised lower bound will be $I_L' = I_L + \Delta I_L$, where

$$\Delta I_L = 0.005S \times \left(\frac{\text{Number of Banks with Negative Average Revenue}}{\text{Number of Banks}}\right).$$

## Implementation

Our multiagent system model was written in the Java programming language using the Repast 3.1 agent modeling toolkit. Our code is well-documented using Javadoc comments, which were used to generate an HTML-based reference for our code.

## Graphical Interface Components

The graphical user interface to our simulation consists of a visualization of the environment and the agents within it, and plots of several different variables as they change over time.

The visualization represents the environment, the agents within the environment, and useful information about each of the agents. The environment itself is represented by the black $L \times L$ grid that occupies the entirety of the containing window's viewport. Agents are occupy one cell within the environment grid, and therefore appear as $1 \times 1$ squares of some color at the location assigned during the simulation's initialization. This visualization for an execution of the simulation is shown in Figure 3. This figure may be helpful as a reference in the following discussion of its components.

Each bank agent's borrowing neighborhood is represented as a circle centered at the bank's location, and varies in size according to that of the corresponding banks' neighborhood at the time the visualization is produced. Each operational bank agent and the corresponding neighborhood are assigned a unique color that is easily distinguishable from that assigned to other banks (for up to at least ten banks, for the first ten bank colors were selected manually in order to provide a maximal level of visual disparity between banks, but those thereafter are be assigned a color by Repast which likely but not necessarily produces a color easily distinguishable from the other selected colors). Bankrupted bank agents are shown in a dark gray color, and liquidated agents are shown in light gray.

Like bank agents, borrower agents are shown differently according to their state. Each borrower that does not currently have but is seeking a loan is shown in green. Each borrower who is currently paying on a loan is shown in the color of the bank that granted the loan. Borrowers in each of these states are surrounded by a circle of the same color as the agent. For borrowers currently paying on loans, this circle appears in one of two sizes, indicative of the length of time over which the loan will be repaid (either 180 or 360 steps/months), where the larger circle represents borrowers with loans to e repaid over the longer period. Contained in this circle is another circle which decreases in size as the loan is repaid; when the loan is completely paid off, this circle collapses onto the point where the borrower is located. For seeking loans, a single circle is shown, which serves only to provide an obvious visual distinction between seeking borrowers located within a bank's borrowing neighborhood and those located outside of all banks' neighborhoods. Those orphaned borrowers are shown with no surrounding circle and are gray in color (they appear star-like on the black environment grid). If a bank's borrowing neighborhood grows to include an orphaned borrower, the borrower becomes a seeking borrower and is represented accordingly.

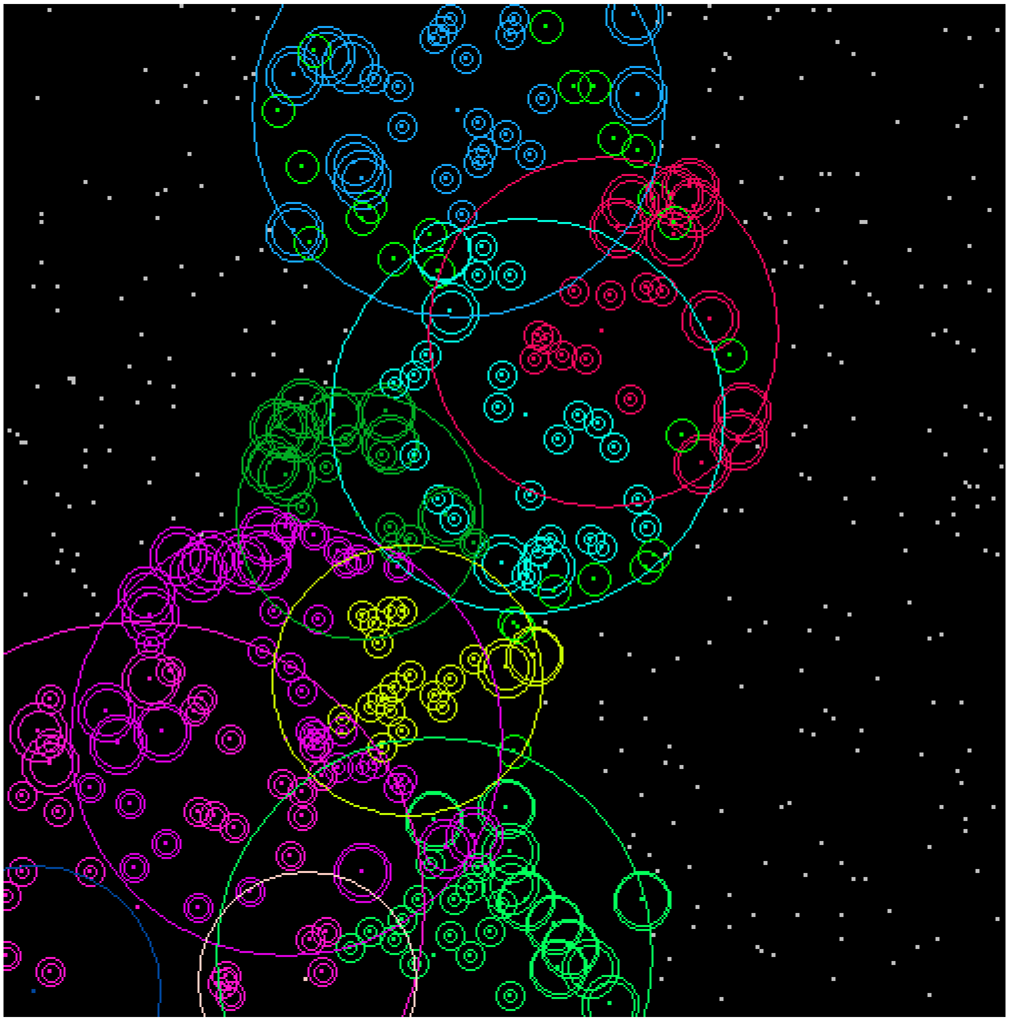


Figure 3: An example visualization showing the simulated environment and the agents within it.

The plots shown during a simulation indicate each bank's amount of money, revenue, loan processing rate, risk tolerances, and profit margin, as well as the number of loans each bank has granted, and the ratio of loan offers accepted to rejected (by borrowers). Also shown are plots that summarize borrower status, and the interest rates of banks in relation to the limits imposed by the Federal Reserve agent. By default, the simulation updates all displays every six time steps, which is the equivalent of a simulated six month period.

In addition to this, a log file was maintained with sufficient information to retrace the behaviors that occurred during the execution of the simulation. This logged information was used to perform a detailed analysis of experiments and draw conclusions for each of our hypotheses.

# Experiments

As we have a high degree of agent interactivity and no clear "win" condition, it was difficult to ascertain precise numerical values for simulation parameters. However, based on our selected hypotheses, we were able to select parameters believed to be appropriate for drawing conclusions for each of those hypotheses. These parameters are shown in Table 1.

*Parameters*

| | | |
|---|---|---|
| B | Number of banks | 10 |
| N | Number of borrowers | 500 |
| L | Environment horizontal and vertical length | 250 |
| P | Environment's initial cash allotment | 1,000,000 |
| $C_L$ | Individual bank's acceptable default risk lower bound | 0.0 |
| F | Individual bank's loan processing rate | Randomized<br>1.045 ± 0.015 |
| A | Individual borrower's loan amount | Randomized<br>16,000 ± 14,000 |
| R | Individual borrower's maximum repayment rate | Randomized<br>350 ± 250 |

Table 1.1: Default parameters that do not vary between tests.

| | | |
|---|---|---|
| | Permit banks to offer 180-month loans | True<br>False |
| $C_U$ | Individual bank's acceptable default risk upper bound | 0.01<br>0.003 |
| $I_L$ | Fed-controlled interest rate lower bound | 1.0 |
| $I_U$ | Fed-controlled interest rate upper bound | 1.1<br>1.3<br>3.0 |
| S | Fed's sensitivity to adjusting the interest rate bounds | 0.0<br>0.4<br>0.8 |
| C | Individual borrower's probability of defaulting on any given payment | 0.007 ± 0.002 |

Table 1.2: Parameters for M1 test set, consisting of 72 tests.

| | | |
|---|---|---|
| | Permit banks to offer 180-month loans | True<br>False |
| $C_U$ | Individual bank's acceptable default risk upper bound | 0.01<br>0.003 |

| | | |
|---|---|---|
| $I_L$ | Fed-controlled interest rate lower bound | 1.0 |
| $I_U$ | Fed-controlled interest rate upper bound | 1.1<br>1.3<br>3.0 |
| S | Fed's sensitivity to adjusting the interest rate bounds | 0.0<br>0.4<br>0.8 |
| C | Individual borrower's probability of defaulting on any given payment | 0.007 ± 0.002 |

Table 1.3: Parameters for M2 test set, consisting of 72 tests.

| | | |
|---|---|---|
| | Permit banks to offer 180-month loans | True<br>False |
| $C_U$ | Individual bank's acceptable default risk upper bound | 0.01<br>0.003 |
| $I_L$ | Fed-controlled interest rate lower bound | 1.0 |
| $I_U$ | Fed-controlled interest rate upper bound | 1.1<br>1.3<br>3.0 |
| S | Fed's sensitivity to adjusting the interest rate bounds | 0.0<br>0.4<br>0.8 |
| C | Individual borrower's probability of defaulting on any given payment | 0.007 ± 0.002 |

Table 1.4: Parameters for M2 test set, consisting of 72 tests.

| | | |
|---|---|---|
| | Permit banks to offer 180-month loans | True<br>False |
| $C_U$ | Individual bank's acceptable default risk upper bound | 0.01<br>0.003 |
| $I_L$ | Fed-controlled interest rate lower bound | 1.0 |
| $I_U$ | Fed-controlled interest rate upper bound | 1.1<br>1.3<br>3.0 |
| S | Fed's sensitivity to adjusting the interest rate bounds | 0.0<br>0.4<br>0.8 |
| C | Individual borrower's probability of defaulting on any given payment | 0.007 ± 0.002 |

Table 1.5: Parameters for C1 test set, consisting of 108 tests.

| | | |
|---|---|---|
| | Permit banks to offer 180-month loans | True<br>False |
| $C_U$ | Individual bank's acceptable default risk upper bound | 0.01<br>0.003 |
| $I_L$ | Fed-controlled interest rate lower bound | 1.03 |
| $I_U$ | Fed-controlled interest rate upper bound | 1.1<br>1.3<br>3.0 |
| S | Fed's sensitivity to adjusting the interest rate bounds | 0.0<br>0.4<br>0.8 |
| C | Individual borrower's probability of defaulting on any given payment | 0.007 ± 0.002 |

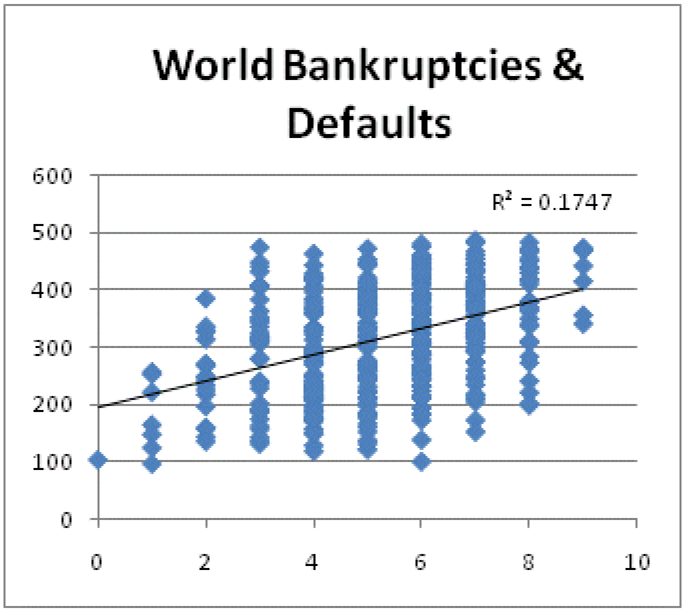
Table 1.6: Parameters for C2 test set, consisting of 108 tests.

The results obtained using these parameter combinations are described in the following section.

# Results

*Hypothesis 1: High bank risk tolerances and high borrower probabilities of defaulting result in more bank failures*

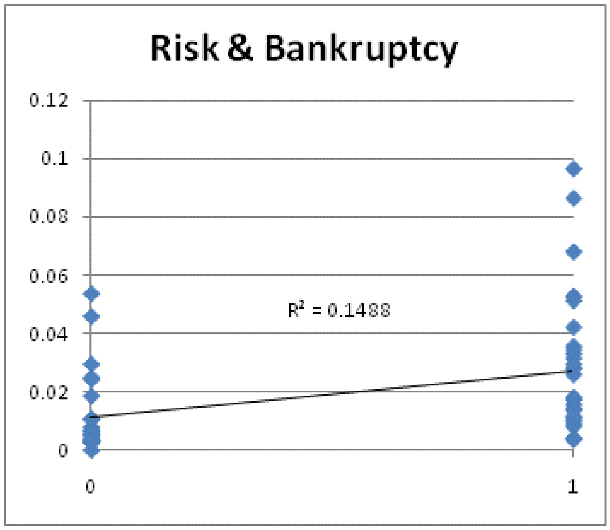
It was assumed that banks most likely to fail would be those that experienced high default rates and since default rates are directly tied to borrower default probabilities and banks' proclivity to make loans to those borrowers, it seemed reasonable to speculate that borrower risk would be a significant contributing factor to bankruptcy. The relationship between individual bank loan defaults and bankruptcy was meager ($R^2$=0.0207), but interestingly, the relationship between world defaults and world bankruptcies was somewhat stronger ($R^2$=0.1747). This implies that there may have been some secondary effects caused by defaulting, such as loss of income from other banks not later being able to make new loans to the defaulted borrowers.




Similarly, while there was not much correlation between individual bank's risk values and rates of bankruptcy ($R^2$ = 0.019), there was a minor relationship between the world-level risk assigned each bank and total bankruptcies ($R^2$=0.1161).

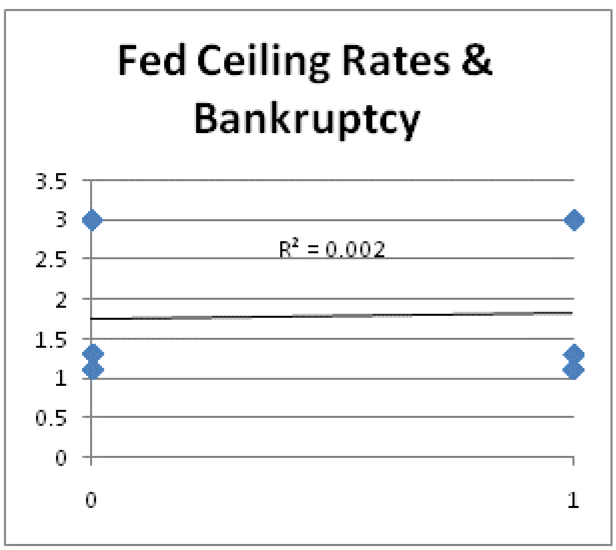
A better indicator than actual observation of risk values was each bank's risk intent. Banks that intended to be risk-oriented and adjusted their borrower default probability tolerances in response to feedback were more likely to experience bankruptcy ($R^2$ = 0.062). There was not a correlation with the borrower's probability of default and the probability of bankruptcy ($R^2$=0.0003). Despite world-level observations, there does not appear to be a strong relationship between individual borrower risk, bank risk tolerance, and bankruptcies so we conclude that our first hypothesis is false.

However, when we examine the subpopulation, we find that there are particular configurations that better correlate bank risk and bankruptcy. Specifically, environmental factors taken together that increase the odds of bankruptcy are low risk borrowers, the availability of only 30-year loans, a low Fed-imposed interest rate ceiling (10%), a moderately involved Fed (Sensitivity = 0.4), and the absence of a Fed-imposed interest rate floor.



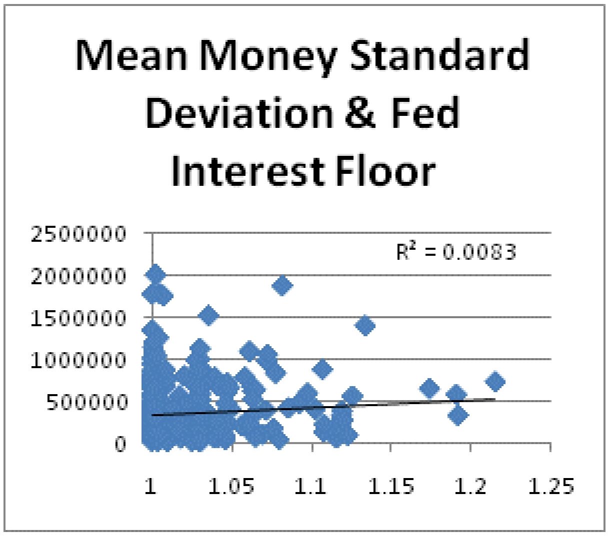

*Hypothesis 2: Reducing upper limits on interest rates will reduce rates of bank failures*

As in our first hypothesis, we believed risk to be correlated with bankruptcy and that an interest rate ceiling would contain that risk due to the impossibility of making a profit over time on loans to risky borrowers. We found no individual relationship ($R^2 = 0.002$) or world relationship ($R^2 = 0.0096$) between the Fed ceiling interest rate and frequencies of bankruptcy, even under different values for Fed reactivity (Sensitivity = 0.0, 0.4, 0.8). Our second hypothesis is also false.



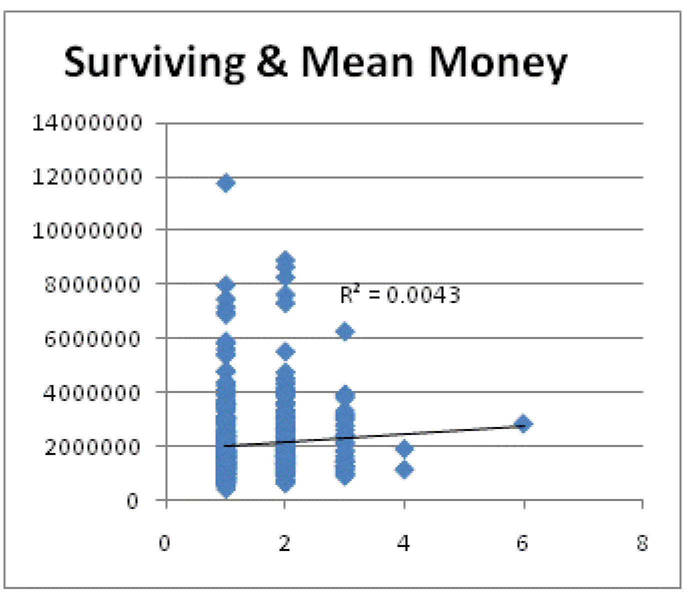

*Hypothesis 3: Reducing lower limits on interest rates will increase competition at the expense of banks with high operating costs*

We expected to see that as the Fed interest rate floor increased, banks' tendency to deviate from the mean of their wealth would decrease due to the diminished capacity for banks to undercut their competition; however, we found no correlation ($R^2 = 0.0083$). While Banks nearly always had competition, they also tended to have unique, non-competitive domains that allowed them to maximize their profits without having to compete excessively in shared domains until much later in the simulation when radii became much larger.  Our third hypothesis is false.



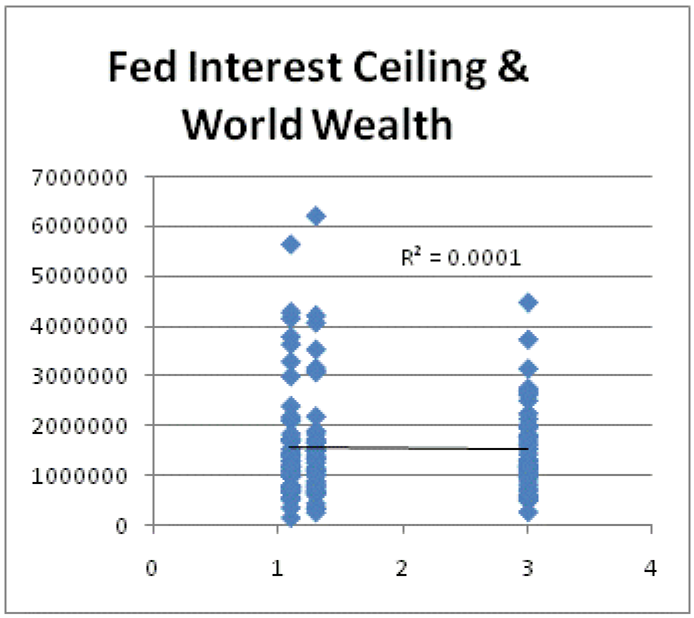

*Hypothesis 4: Configurations with banks outliving borrowers will be systems that have more money for longer periods of time with less amounts of variance*

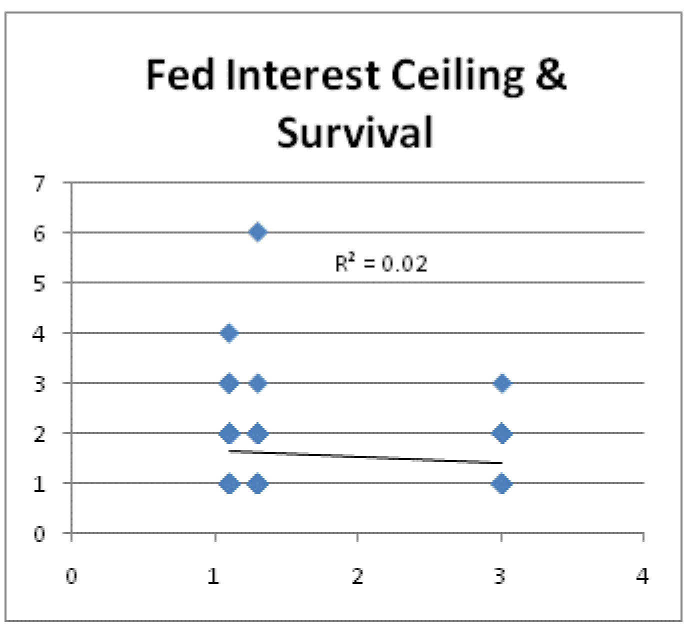
For this hypothesis, we considered the number of surviving banks – those that neither bankrupted nor liquidated – as well as world wealth and deviation from the wealth mean.  It was assumed that long-lived banks would necessarily have stable and consistent incomes due to their courting stable borrowers.  This is due to both the previously mentioned diminished influence of risk on survivability and the 1200 step limitation that prevented successful banks to continue accumulating wealth indefinitely.  Thus, we are unable to report a relationship between survival and mean wealth ($R^2$ = 0.0043) and between survival and deviation from mean wealth ($R^2$ = 0.013).



*Hypothesis 5: If every bank is risk averse, each bank will grow stably and uniformly with its peers*

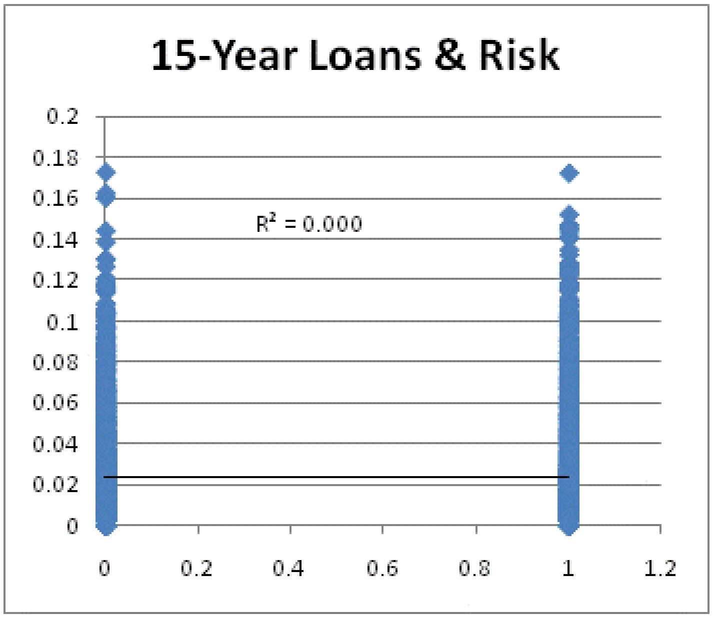
In our fifth hypothesis, we examined world environments that are risk-constrained (Fed Sensitivity = 0.0) and how banks accumulate wealth in those environments. We expected that the prohibiting of banks from taking on borrowers likely to default and the diminished range for which to competitively set interest rates would cause banks to avoid bankruptcy and adapt smoothly to each other, but we found no correlation to world money ($R^2$ = 0.0001) or to bank survival rates ($R^2$ = 0.02). Again, this is likely due to the diminished link between risk and bankruptcy, allowing banks to earn incomes regardless of their tolerances, and the ability of banks to maximize profits within their unique domains.



*Hypothesis 6: If every borrower prefers 30-year loans, banks will increase their risk tolerances*

It was reasoned that a borrower repaying a loan over 360 payments has more opportunity to default than the same borrower repaying out a loan for only 180 payments, and thus, banks would need to increase their tolerance for risk in order to compete for loan; however, we observe absolutely no correlation between risk tolerance and borrower loan preference.




<u>What We Found</u>

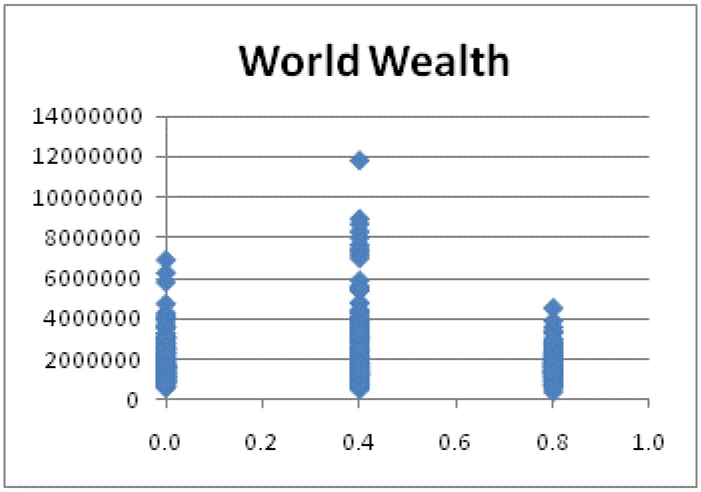
*Personality*

Each bank had four randomized personality variables that described its goal behaviors. The first of which was target neighborhood dominance; it described the preference of winning loans from competition in its adjustments of profit margin. The second was the bank's target revenue ratio which also impacted the adjustment of profit margin. The third was target default ratio and described the bank's preference for risk. Lastly, there was a reactivity trait that described the degree of single step corrections banks would make in order to achieve their targets.

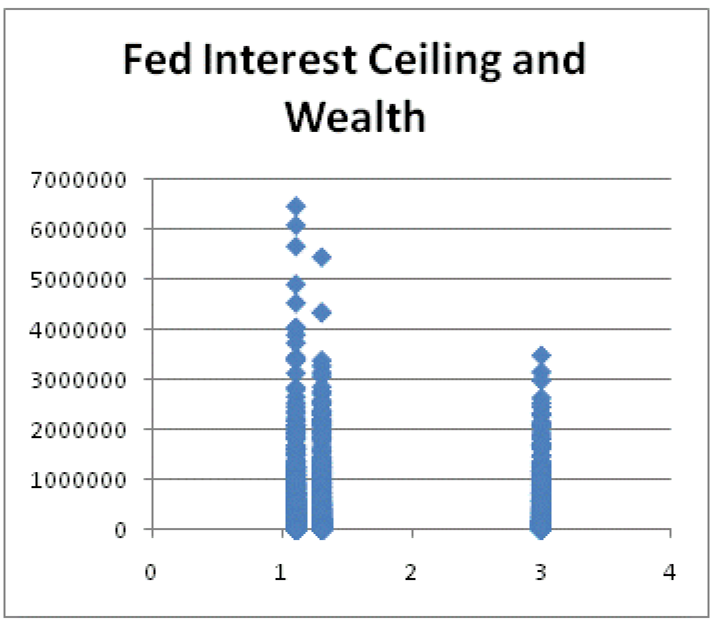
The impact of personality for the ranges we tested was slight, but generally observable. We found that banks with lower target default and neighborhood dominance ratios and high reactivity levels were more likely to survive. The significance of target revenue was negligibly in favor of higher ratios.

*Federal Reserve*

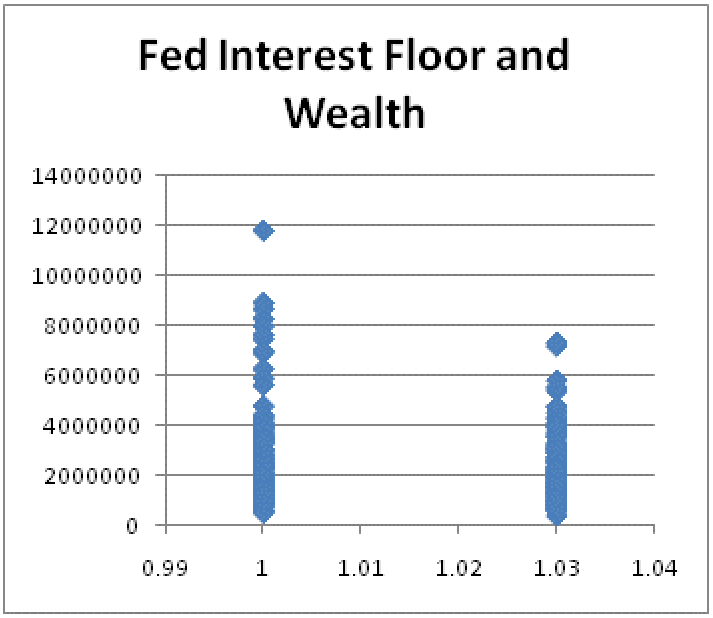
Generally, the effect of the Fed agent was not very pronounced, but we can see a few effects of the presence and absence of the Fed on the environment. A moderately reactive Fed (Sensitivity = 0.4) was best able to maximize world wealth, but no particular setting had much of an impact on bankruptcies.




Lower Fed interest ceiling rates tended to allow banks to accumulate more wealth, but had no bearing on bankruptcies.




Similarly, lower Fed interest floors increased wealth, but had no relevance to bankruptcies.




Hindsight

The quality of our analysis was impacted by sacrificing some real-world modeling due to system constraints. The bank to borrower ratio should have been at least ten-fold higher, which would have drastically increased competition and eliminated or greatly reduce the ability of banks to find their own niche domain within which to maximize profits at the expense of borrowers in competitive regions. Unfortunately, attempting to do so rendered the simulation tediously slow and eventually produced output errors within RepastJ.

In order to accomplish all of our testing, approximately 33 machine-hours, in a reasonable amount of time, we limited our steps to 1200 reasoning that 100 years would be enough time to observe any behavior for which we were looking. If not for the reduced bank to borrower ratio, it may well have been, but we feel that in our configuration 1200 steps was too short.

We expected more pronounced results from our analysis or bank-borrower risk. Some hints of a relationship exist, but not enough for us to satisfy our hypotheses. We should have tried higher bank and borrower risk levels.

Lastly, in an effort to achieve rationality and optimality, we gave banks the option to liquidate and retain their wealth rather than adjust their risk behaviors. Much of the premise of our work was based upon “adapt or die”, to which liquidation added “take your marbles and go home”. To the extent that we wished to see how banks would handle uncomfortable choices, the liquidation option undermined our analysis.

Implications

That said, it is telling that banks performed as well as they did given the environments we put them in – we found the system to be more robust than we had expected. In light of that, it may not be worthwhile to levy heavy restrictions as a general rule, but instead to detect periods that warrant more global policy involvement – in effect, reactivity variable that is itself dynamic. On the other hand, moderate and measured Fed involvement actually increased wealth for all banks in the environment. We also found that banks themselves would do well to remain sensitive and adaptive to market conditions and more able to survive when they can establish non-competitive domains.

# Future Work

*Strategy Selection*

Our model can be improved by including bank and borrower specific strategy selection that depend on their configuration with respect to other agents in the environment insofar as they can model those agents based on their interactions with them.

*Q-learning of Based on Learned Utility of Actions*

Our model could be further improved by allowing banks to learn which behaviors are most beneficial based on learned utilities. Behaviors include, adjusting the size of radius, adjusting processing rates, risk tolerances. The utility for each behavior could be based on the gain that performing a particular behavior produced. Over time, based on the bank's configuration in the world with respect to borrowers and other banks (and those banks' borrowers), certain behaviors are likely to be better than others for a particular bank, that help it make a profit given its circumstances. These behaviors are those that increase the profit margin the most in a given situation. So, this involves identifying the situation a bank is currently in, and identifying the most useful behaviors for that situation.

This could be done in a purely reactive, probabilistic way, or in a rational way that computes expected gain based on past experience as well as current conditions.

*Borrower Agent Modeling*

Banks could model their local neighborhood by observing the characteristics and properties of borrowers as well as their requests. Borrower profiles could even be constructed, so when certain characteristics are seen in a new borrower, they could be matched with a profile which likely describes how they will behave.

*Borrower Population Regeneration and Fluctuation*

Borrowers currently do not regenerate once they have defaulted on a loan payment. Regeneration could be implemented according to some mechanism. For example, perhaps when a borrower defaults, one or more borrowers could be spawned, based on some probability. The borrower density and distribution of borrower density could vary over time. This would allow insight into how banks can adjust to a changing environment.

# Bibliography

Bernanke, B. S. (2009, April 14). *Four Questions about the Financial Crisis*. Retrieved December 13, 2009, from Board of Governors of the Federal Reserve System: http://www.federalreserve.gov/newsevents/speech/bernanke20090414a.htm