Introduction to Economic and Financial Simulation

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Chapter 1

Economic Simulation

Today's economic models are typically models of the financial system embodying equations that are believed to predict the behaviour of the economy from observational data such as GDP, Employment, Credit levels, etc. Notoriously they fail to do this over any significant period of time, and in particular they fail to predict financial crises which often seem to originate in the banking system.

Threadneedle originated as a double entry book keeping based simulation of the fractional reserve banking system and was designed to explore the banking system's behaviour under different forms of regulatory control and financial instrument. economies, where banking is central to all activities both as the system that creates, stores and transfers money between economically active agents, and as one of the major sources of credit (debt) for economic activity. This means that the banking system and its behaviour is integral to all simulations reflecting its role in the modern economies.

Economic simulation is in principle a different approach to studying economic systems than the current approaches of mathematically influenced economic and financial models. Both simulation and modelling though are terms that are in haphazard use throughout the scientific disciplines. Generally, and especially in economics, 'model' is used to refer to a purely mathematical representation of a system, which is believed to accurately capture the behaviour of the system under study. For example, $T = 2\pi\sqrt{L/g}$ is the mathematical model for the period of oscillation of a pendulum, and a highly accurate one. Similarly, heliocentralism - the medieval european idea that the Sun and the Planets revolved around the earth - was based on epicycles, a complex mathematical model of the solar system which accurately fit the observable data of that time, even though it was based on wildly incorrect assumptions. Mathematical models can sucessfully predict a system's behaviour, especially over short periods, while still being completely incorrect in their underlying assumptions.

English however has a tendency to overload the meaning of its nouns, and science also uses real models which are copies or scaled replicas of systems under study. Model airplanes that can fly for example, or can't fly, but are aerodynamically equivalent enough for their flight properties to be studied in wind tunnels.

A simulation conversely, is strictly an attempt to imitate the operation of a real-world system over time, by building a replica that in some way captures the actual behaviour of the system under study. This can also be quite loosely defined. For example, the Boids[**?**] artificial life simulation was an early computer simulation that reproduced the flocking behaviour seen in some species of birds by creating an artificial environment where a simple set of rules, applied individually by each computer agent, was able to generate collective behaviour without any form of centralised co-ordination.

To add to the confusion some simulations, the Minsky 'economic simulator'[**?**] is one, while described as "simulating economic models", essentially incorporates mathematical models and is based on a simulation of believed banking balance sheet behaviour. It would be more accurate to describe this as a model following the economic tradition. Eurace on the other hand, is an Agent Based Model also based on a balance sheet approach, which while incorporating some mathematical models of agent behaviour is closer to a simulation than a model in the Economic sense. Neither of these can be described as realistic in the premises they are based on, primarily due to their reliance on balance sheet operations, rather than something more fundamental.

Why does this matter? Any mathematical model is only as reliable as the accuracy of its underlying formula and the circumstances it is used in. However, any simulation is only as accurate as its ability to accurately and completely capture the elements of the system under examination their interactions and behaviour. Long period systems such as the economy, which incorporate memory, and are sensitive to their conditions, can be particularly challenging to approaches with either toolbox.

Chapter 2

Fractional Reserve Banking

Since banking is central to all Threadneedle simulations, it is important to understand the basics of how it works - which is not, at time of writing, well presented in Economic texts. Figure 2.1 shows the ledger view

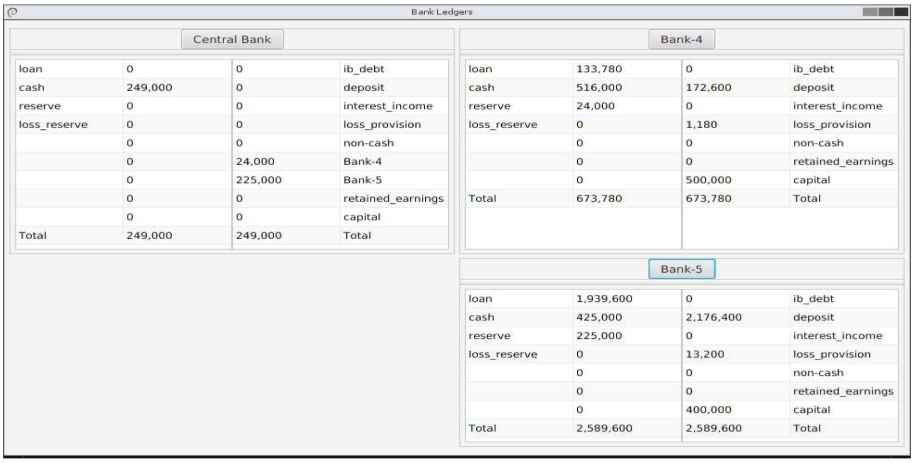

Figure 2.1: Bank Ledger View within Threadneedle

of a 2 Bank simulation (Button: Show Banks) running in Threadneedle. It uses the accounting balance sheet presentation of bank ledgers, which places bank assets on the right, and bank liabilities shown on the left. While assets and liabilities are accounting definitions, and ledger classification usually follows intuitively, they are also influenced by the requirements of the double entry book keeping rules within which they are embedded. For example, interest income accounts where a bank puts interest income received on its loans to customers are classified as liabilities. The accounting veil for this is that it is money 'owed to the owners of the bank' - the alternative explanation is simply that the double entry book keeping structure requires it to be.

Setting up a bank in Threadneedle is relatively straightforward. All agents receive an account when they are created, and can also receive a deposit at that time. This deposit is performed as a cash deposit, and provides part of the liquidity for the bank.[1] The *Saver* agent can also be used to provide a cash deposit with no other side effects. The *Investor* agent is used to specifically create capital, and receives a Share ownership as specified.

The Central Bank Reserve and Basel Capital perecentages can be changed for the entire banking system under the Central Bank's menu, which also controls the base interest rate. This can be changed at any time during the simulation with immediate effect.

The long term behaviour of a bank with respect to lending and money creation then depends quite critically on how it is setup, in particular with respect to its cash holdings (which regulate lending through the central bank), and its capital holdings, which under Basel also regulate lending.

[1]When banks are founded in modern economies, the initial liquidity is provided by the investors, typically in return for preferential shares.

Bank Operations

In practice there are four key operational transactions that embody banking operations which it is important to know, in order to sucessfully design bank based simulations. [2].

Deposit Cash

Individually, banks operate by statistically multiplexing physical (asset) cash, against bank liability deposits, as shown on the ledger. When physical cash is deposited at a bank, the double entry book keeping operation is: The physical cash deposited into the bank is now the property of the bank, whilst a liability deposit

debit cash	credit deposit

account has been created which is the property of the person who deposited the cash. That person now has a claim on physical cash owned by the bank, but not on the actual physical notes that they deposited.

Transfer money to account at the same Bank

If A, the owner of the account now wants to transfer money to B who also has an account on the same ledger - say by writing a cheque, or as transfer request on their bank account's website, then the bank uses the book keeping operation: Notice that since no physical cash was involved in this transfer, and yet a monetary

debit deposit account (A)	credit deposit account (B)

payment took place, this is the operation that gives liability deposit accounts their own status as a form of money.

Transfer money to account at another Bank

Taking the previous example a little further. If B's account is at another bank, then physical cash is at least nominally involved, since physical cash[3] is used to transfer money *between banks*. Consequently a bank must

credit cash Bank 1	debit deposit account (A)
debit cash Bank 2	credit deposit account (B)

always have some asset cash (or electronic equivalent) available to perform any required transfers between banks, as well as to meet requests to physically withdraw cash, otherwise it is insolvent. The general term for this in banking is *liquidity*, and sucessful banks monitor and attempt to control their liquidity status extremely carefully, which can have surprisingly far reaching economic consequences.

Lending

When a loan is made, the bank does the following:

debit loan Borrower A	credit deposit account (A)

and when it is repaid, the money is removed as the principal is repaid, and transferred from the depositor, to the bank when interest is paid:

(1) credit loan Borrower A	debit deposit account (A)	(Repay Principal)
(2)	debit deposit account (A)	Pay Interest
	credit interest income	Pay Interest

[2] A complete list of the double entry book keeping operations used in Threadneedle, accompanied by worked examples, can be found in Description of the Operational Mechanics of a Basel Regulated Banking System [**?**]

[3] Or its modern electronic equivalent. There is believed to still be an element of physical transfers in some parts of the system.

The result of banks making loans over time is to create a much larger quantity of money represented in liability deposit accounts, than exists as physical cash. Initially this will occur very quickly, and then assuming regulatory controls are to some degree effective, stabilise, as loan repayment begins to remove the money being created. The long term behaviour of the system essentially rests on the difference between the rate of new lending, versus loan repayment and loan default. This is the core of the statistical multiplexing relationship that banks have to manage in their day to day operations, the economic ramifications of which are to this date, extremely poorly understood.

Liquidity

Liquidity - the availability of asset cash to meet demands for withdrawals, and in particular transfers to other banks, is a significant issues both in simulations, and for the real economy. Simulations that are not designed to avoid liquidity problems will invariably enounter them very quickly, as imbalances between banks arise due to loan repayment. While Threadneedle does implement interbank lending and banks will automatically attempt to borrow from other banks to correct short term imbalances, in practice this will only accentuate any long term imbalances in liquidity flows.

This is where a high level view of loans as simply flows of money between sectors, conflicts more than a little with what actually occurs within the banking mechanisms. We should also note here that this is an area where Threadneedle is known to not accurately simulate the behaviour of economies with small numbers of large banks - since the precise mechanisms used within the banks to manage their branch banking ledgers are at this time unknown. Threadneedle uses a single ledger for each bank.

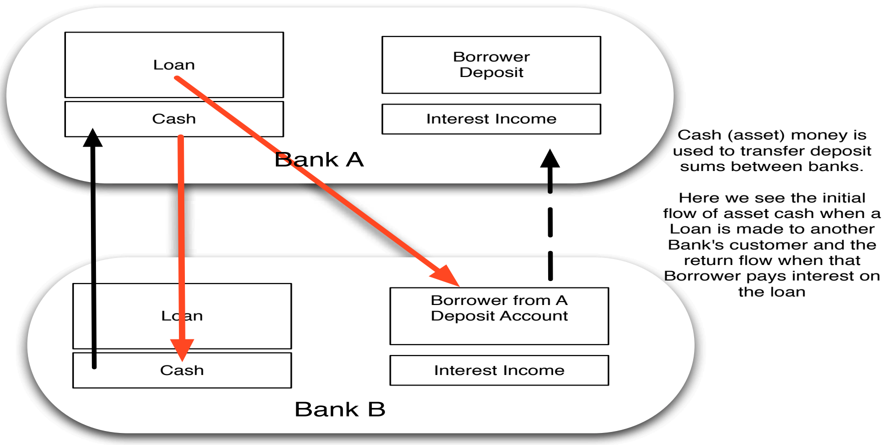

Figure 2.2: Bank Ledger View within Threadneedle

Figure 2.2 shows the asset cash transfers that accompany a customer loan, when a bank makes a loan to a deposit holder at another bank. For example although the interest payment is made from the customer's liability deposit account to Bank A's liability interest income account, in order to perform the payment a matching flow of cash has to flow between the banks to register the transfer. Since loans are necessarily unbalanced - more asset cash flows back to the bank making the loan, due to interest payments, than Bank B receives as loan capital, over the long term Bank B progressively loses asset money to Bank A, creating a liquidity issue for Bank B.

This is not an issue solely confined to Bank loans. Any loan made between two parties at different banks, will inevitably create an unbalanced liquidity flow over the long term - and the activities of lending companies that simply use banks for deposit funds are not under the Bank's direct control. Similarly although lending banks strongly prefer customers to receive their salaries at their bank, nothing prevents subsequent moving of accounts. Loan securitization - where loans are packaged and sold for example - carries no guarantees about where in the banking system these loans will end up, or what the influence of their long term flows will be on the system.

These issues are important economically, because if sufficient stress is placed on inter-bank liquidity, banks will stop making new loans, and a credit crisis may be triggered. The key simulation issue is that simulations must be designed to respect the liquidity eneds of the banks, given that even when their terms are identical, loans are not necessarily equivalent to each other, with respect to the long term monetary flows they create within the banking system, and this goes beyond the simple issue of money creation accompanying bank loans, but not other forms of lending. It casts light on banking not as a monolithic entity, but rather as a subtle geographically based network process that over time manipulates a monetary field that in many respects is locally and regionally generated, rather than centrally controlled.

In simulations, the simplest way to test for unwanted liquidity issues is to use a single bank for the entire simulation. Companies can also restrict their hiring to workers using the same bank as they do, and Regions can be used to further restrict worker availability. Knowing that Banks are geographically organised, and make lending decisions based on liquidity, we believe that we are seeing issues under simulation that are also arising within modern economies, and so should consequently be explored.

Insolvency

Insolvency on the other hand is the long term inability for a bank to cover its obligations due to loan default, or outright theft (it can happen). The definition of 'long term' in this context depends to some extent on national accounting rules and practices around loss handling.

Fundamentally, insolvency arises from defaults by customers on their loans. Once a customer stops paying a loan, special treament and handling by the bank of that loan/customer is typically triggered, both by its internal processes and as regulatory requirements. In theory, after some number of missed or delayed payments, the loan will be closed by the bank, any collateral associated with the bank seized, and sold to repay the loan. If the collateral of the loan is insufficient to cover the outstanding capital, then that amount is treated as an expense and must be written off by the bank. Loan write off follows a three step process:

1. Deduct from loss provisions (if any)
2. Deduct from profits (if any)
3. Deduct from capital

If the bank cannot cover the write off from 1 or 2, then it is effectively insolvent and ceases to be a going concern. Typically at this point some form of government intervention occurs in order to protect the money represented as customer deposits, since any significant loss of liability deposit money within a banking system potentially causes fiscal deflation.[4]

Threadneedle currently performs steps 1 and 2 automatically, but places the bank in runoff mode (where existing loans are repaid, but no new ones are made) in step 3. Anything more sophisticated is left as an exercise to the user, since there are so many forms intervention can take. Loss provisions are made automatically from interest payments, and adjusted as loan capital varies over time. This may not be strictly accurate, since we strongly suspect that in many banking systems toda todayy, loan fees charged by the bank at the beginning of the loan to borrowers are providing loss provisions. If loan payments are skipped for three (configurable) consecutive steps, the loan is placed in write-off, any collateral is sold, and any outstanding amount is written off according to the order above.

Loss handling interacts directly with the definition of 'long term' - in particular how long a bank can remain technically insolvent, but still continue as a business. Strictly, all a bank needs to do to continue as a business is receive enough money in interest on its loan book to cover its expenses. Since write-offs are also an expense, in the limit banks are faced with the choice between writing off a loan and going under, and keeping the non-performing loan on their books and continuing in business. This is better known as the Zombie Bank phenomena from the aftermath of the 1980's Japanese Bubble.

Loss handling is consequently subject to a variety of nationally varying regulatory requirements, primarily in order to prevent exactly this situation. That said, in practice banks have a fair amount of leeway in their

[4] 1929 Great Depression style.

internal processes, with respect to changing loan terms, re-financing, etc. in order to prevent a loan from being placed in default. This may result in counter-intuitive behaviour such as a bad customer receiving a favourable rate on a new loan in order to prevent a loan default on an old one.

Viewed as a system we can make the observation that banks are extremely vulnerable to loan losses. A back of the envelope analysis on loan losses suggests that a bank can afford to absorb at most 1% of its total loan book in losses every year, before it runs into difficulties, and this doesn't (in engineering terms) offer a lot of fault tolerance. The partial dependency of the write-off operation on the price of the collateral provided with the loan also implies a direct interaction with market based pricing mechanisms, which may in turn be influenced directly by the banking system in a number of ways, for example bank lending being used as source for market trading, and if bank losses and write-offs are sufficiently high that fiscal deflation occurs risking a potential cascade failure as lower prices trigger more loan defaults, and more loss of money from the system. From a macro-economic perspective perhaps the question we should be asking, is why the system doesn't crash more often?

Chapter 3

Creating Simulations

All agents in Threadneedle must have a bank account to participate in monetary exchange, and so the bank or banks that will be used for the simulation must always be defined first. These will then provide the banking system within the economy. A central bank will be created automatically for each country. By default, each bank will also have a reserve (deposit) account at the central bank, and this account will be used for transfers of money between banks.

In the real world, while this particular arrangement is not untypical of small countries pre-21st century, there are many variations. In countries such as the USA, with large numbers of small banks, tertiary arrangements can occur, where small banks have accounts at larger banks to provide access to inter-bank transfer facilities. The USA is also distinguished by having 12 Federal Reserve banks, linked together into a central banking system, rather than a single central bank.

In other countries with small numbers of large banks, the UK for example, clearing has been a separate facility, arranged between banks - originating in manual processes where clerks would meet in order to balance transfers between banks, and only exchange the remainder. Campbell-Kelly[?] provides a nice comparison between the 19th century practices adopted in the US and the UK.

In the 21st century most countries are now using, or adopting, Real Time Gross Settlement systems, which allow transfers between banks to be performed electronically in near to real time. It is an open research question as to what extent these mechanisms are systemically affecting.

Fractional Reserve or 'Full' Reserve

While all banks in Threadneedle operate using double entry book keeping, there is no requirement that they make loans. It is possible to create a constant money economy, simply by ensuring that banks only take deposits and do not lend any money. Other lending agents can be used to provide loans if desired. Liability deposit accounts are still created, and transfers between these accounts at different banks are still mediated through asset cash transfers between the banks involved.

Note, it depends on the author, whether or not this in fact corresponds with the form of banking generically referred to in the Economics literature as 'Full Reserve'. The unpublished 1939 paper A Program for Monetary Reform[?] Most proponents of full reserve in fact argued for a partial reserve - since the full reserve would only apply to demand deposits which would still have allowed bank lending (and the associated money creation) to occur.

In Threadneedle unless banks are restricted to not offer loans, they will participate in a fractional reserve based system and make loans subject to their individual lending decisions. By default these are simply based on their configurable reserve requirements.

Market Price Deterimination

Several forms of market are available in Threadneedle, and these are a source of ongoing experimentation. Currently a market maker market will be automatically created for any widget maker that is added to the simulation - this market will buy and sell from agents with its own trading funds and attempt to adjust price based on supply, demand and its own monetary holdings. Market makers are restricted to not offer a price higher than the amount of money they currently have on hand, and by default do not borrow. Nothing prevents users adding borrowing to their behaviour though.

A very simple list market is also available where items are simply listed in ascending order of price. No funds are attached to this form of market.

A stock market implementation is also provided which implements a full bid/sell market where bids and sells are listed on the market market and automatically matched when possible.