Replacing Diamond-Dybvig

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Abstract Diamond and Dybvig 1983 is a now classic model of banking failure. This model and the considerable ancilliary literature studies two equilibria: the "good" equilibrium of bank stability and the "bad" equilibrium of bank failure. A major limitation of these models is that while they acknowledge the fact of these two equilibria, they are silent on how a system in the desired equilibrium suddenly moves into the run equilibrium. Agentization refers to the process of taking usually classic models, economic or otherwise, and representing them in agent-based simulations that hopefully reproduce those model's central features. I consider an agentized Diamond-Dybvig model that reveals some major conceptual limitations in Diamond-Dybvig that limits its utility as the foundation of agent-based studies of bank runs. Then I present an alternative bank run model that may provide such a basis not only for the study of bank runs but also for broader models of financial contagion.

1 Introduction

Diamond and Dybvig [2] is a classic model of bank runs and often cited as a justification for government deposit insurance. Bank runs are an obvious example of the economic problem of self-fulfilling prophecies and present major external costs. Further, the Diamond-Dybvig model is often used as an argument for "inherent bank fragility". One challenge in the study of bank runs is that it has often been suggested they have a psychological elements; that is, so long as depositors believe they can get their money, the don't want it. This fits uncomfortably with traditional economic conceptions of agents. On the other hand, this can be taken as a simple fact of agent behavior and so modeled. We will see that perhaps techniques based on Von-Neumann- Morgenstern expected utility are not the best modeling tool for this purpose.

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2 A Brief Description of the Diamond-Dybvig Model

It is challenging to fit the concept of a bank run into a traditional economic framework. Diamond-Dybvig represents an important attempt to do this. Simplified presentations of the Diamond-Dybvig model can be found in [1] or [3]. My brief exposition will be based on [3]. The model has two periods of time. Agents initially have a certain endowment that they wish to invest in some production technology with a known return at $t = 2$. Agents come in two types, 1 and 2 according to whether they will live until $t = 2$. Neither the agents nor the bank know their type. Thus, the "bank" in this model also serves as an insurance agency in the sense that the agents that will not live until $t = 2$ may withdraw their deposit plus some agreed upon premium. However, this comes at the expense of the return the agents receive at $t = 2$. Since the agents do not know how long they will live, they accept this lower return as an insurance premium. The difficulty comes when too many agents withdraw in at $t = 1$. If agents believe that there will be nothing left at $t = 2$, they will also withdraw early. Thus, the model contains two equilibria. If all other agents are withdrawing, it is always rational for the agent to also withdraw and gamble on a favorable place in line. On the other hand, if only the short-lived agents withdraw, all other agents stay the course.

3 Price Theoretic Criticisms of the Model

White criticizes this model in [3] from a price theoretic point of view. Firstly, the investment is an odd hybrid of debt and equity. I will return to this. The DD bank has no separate class of equity holders which can insulate depositors from losses. Its total debts always exceed its equity. This is relevant as there are actual historical examples of bank failures where all depositors were paid in full. Further, real world banks can suspend note redemption. In Diamond-Dybvig this interferes with consumption. In the real world it may or may not. Note though that these are criticisms of the model's *policy implications*. They do not address the aptness of Diamond-Dybvig as a description of bank-run dynamics.

4 Limitations of Price Theoretic Banking Models

In the real world, assuming the bank run is a self-fulfling prophecy, the bank is sound until it ceases to be and this is a sudden phase change. Price theoretic models can describe multiple equilibria but the relevant modeling question is *how banks move from one equilibrium to the other*. Within an equilibrium setting, one can distinguish between an illiquid bank and an insolvent one. In a broader financial crisis, the bank's assets no longer have a well-defined value. To study banking and financial crises, it is necessary to move beyond equilibrium models. Agentization is a way to proceed.

5 The Agentized Diamond-Dybvig Model

Since the agentized Diamong-Dybvig model is not the core topic of this short piece, it is sufficient to discuss what the agentization revealed. The Diamong-Dybvig ABM shows that the insurance aspects of the model are what actual drive the behavior. This extends the previously-mentioned debt-equity hybrid. While it is true that agents prefer to wait for the investment to mature, once some agents have withdrawn, agents often prefer to gamble on their place in line rather than the investment return. In real life banking, interest acrues and there is no bonus for withdrawing. Thus, this model artifact is driving the behavior. More fundamentally, agents are not buying debt or an equity; rather they are buying an *option*.

6 A Replacement Bank Run Model

In economics, it takes a model to beat a model. I have argued both the necessity of bank run ABM's and that the classical Diamond-Dybvig Model is not a good basis for the same. Thus, it is necessary to provide another model, ideally similar to the Diamond-Dybvig model but without the artifact driving the behavior. Before launching into the model description, it is useful to reconsider the process of banking.

Depositors want to borrow long-term and lend short-term. This is only possible where another entity is willing to take the other side of that deal. The result is an entity with short-term liabilities and long term assets. Let us attempt to adhere as closely as possible for the Diamond-Dybvig framework; accepting the investment aspect as well as endowing agents with a Von-Neumann-Morgenstern utility function. On the other hand, for the sake of simplicity, it is useful to ignore cash flow around the economy. Thus, agents will save for retirement and earn interest but will not borrow.

6.1 Brief Model Description

The replacement model has two types of agents. Both agents have a target endowment. Some agents are savers aiming to retire at 70 ticks. While their spending behavior displays some randomness, they have a target endowment calculated on the basis of the ability to consume from age 70–100. There is no uncertainty in agent life-spans. Other agents are spenders who do not save for retirement and have a target endowment that is constant over their lifetime. They earn their income their entire life. In both cases, agents earn interest on deposits. The savers build weath over time. The spenders do not. This is intended to capture a realistic aspect of depositors. Not all depositors have the same time horizon.

In each tick, agents run simulations to decide whether they are better off, in expectation, staying in the bank or withdrawing. There is no initial period where they decide how much to deposit as there is no distinction between deposits and endowments. Whenever an agent withdraws, all other agents reconsider their position. The tick ends either with a bank failure or with the remaining agents acruing and interest payment. At the next tick, all agents resume banking. Thus, the cost for those who withdrew is one tick worth of interest payment.

6.2 Model Pseudo-Code

```
Initialize Agents
For 1 to Agent Count
      initialize Agent with endowment, risk preference, and
      probability parameter

Initialize Model
continue = TRUE
while continue
      Random Sort Agents
      continue = FALSE
      agents withdraw exogenously
      for agent in remaining agents
            agent decides whether or not to withdraw
            if withdraw continue=TRUE
for agent in remaining agents
      pay interest
for agent in all agents
      if agent is spender then pay income
      if agent is saver and age <=70 then pay income
      spend money
      age agent one year
      if agent age is 100, remove agent and generate new agent
```

6.3 Model Behavior and Lessons

In this particular model, there is almost always a bank run within a few ticks. The spending agents in particular face a very consequential ruin probability. This raises an interesting question: to the extent agents do not use banks to build wealth, there must be a greater downside to banking. This is consistent with the fact that poorer people are much more likely to not use banks. It also suggests that a follow up model should be even simpler than this model. Such a model would not involve incomes or interest payments but simply model the marginal decision of each agent to withdraw or not. Then, the background parameters associated with various equilibria can be studied as part of nesting this model in a richer model.

7 Conclusion

These models both feature a single isolated bank but the techniques developed could be extended to networks of banks. The main requirement to extending this to a broader financial system is to explicitly model cash flow and lending behavior; perhaps borrowing tools from percolation theory. However, keeping such rich models in a kind of equilirbium is a challenge. The way forward is to associate desireable equilbria with a set of initial parameters and then make use of machine learning methods to calibrate the richer model toward a model realization consistent with the initial parameter space of the simpler model.

References

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