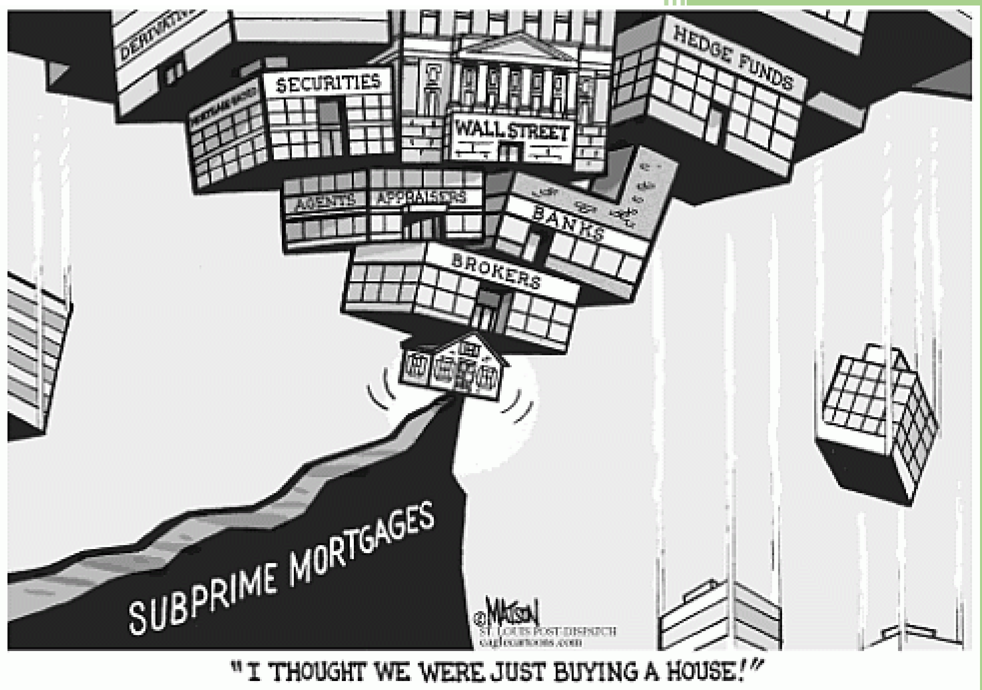
Explaining the 2008 financial crisis with a System Dynamics model



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I am proud of the end result of this thesis and I hope everyone will find this thesis enjoyable and useful to read. I know I do.

Table of contents

Table of contents ... 3

Abstract ... 5

1. Introduction ... 6

2. Methodology ... 11

2.1 Choice of modelling technique ... 11

2.2 System Dynamics ... 12

2.3 Group Model Building ... 14

2.4 Expert modelling ... 14

2.5 How to build a banking model ... 15

2.6 Research strategies ... 16

2.7 Research Subjects ... 17

2.8 Summary ... 17

3. Theoretical background ... 19

3.1 Choice of central entity ... 19

3.2 Definitions related to banking ... 19

3.3 Simplified model ... 21

3.4 Type of shock induced ... 22

4. Explanation of the model ... 24

4.1 Steps in building the model ... 24

4.2 Explanation of final model ... 24

4.3 Variables needed to induce the shock ... 32

4.4 Most important feedback loops ... 32

4.5 Assumptions ... 33

4.6 List of parameter values ... 37

5. Validation ... 40

5.1 Validation tests ... 41

5.2 Real world comparison 44
5.3 Health indicators 48
6. Results 50
6.1 Reading guide for this chapter 50
6.2 Baseline model behaviour 50
6.3 Shock without run on RMBS notes 52
6.4 Shock with run on RMBS notes 55
7. Conclusion 62
8. Discussion 65
References 68

Abstract

In this thesis, the effects of a write-off of mortgages will be shown for a banking system. Literature shows that certain causes for the financial crisis of 2008 were being named. One of those causes will be explored in a System Dynamics model. This reason is the sudden write-off of mortgages. It will be explored what magnitude of write-off will cause a bank, and subsequently other banks and the system to fail, as well as make investors lose their money. This write-off will be tested in the scenario of a run on Retail Mortgage Backed Securities (RMBS) notes and in normal circumstances. It will be shown that a sudden write off of mortgages could cause a bank to fail, but not the system. It will also be shown that in the scenario of RMBS notes run, the bank and consequently the system will fail if not for the actions of governments and central banks. Thus, it will be shown that the banking system would have failed in 2008 were it not for the interventions of governments and central banks.

1. Introduction

The financial crisis of 2008 has left its marks upon the world and has made the fragility of banking systems painfully obvious. This caused authors such as Crotty (2009) to call this financial crisis the worst since the Great Depression. Banks and federal supervisors of financial markets scrambled to save the system from crashing. 'Unprecedented interventions' (Crotty, 2009) were used to bail out different institutions. The world economy fell into a recession characterized by a sharp decline in economic growth (Tani, 2016) which caused an increase in unemployment (Worldbank, 2016) and decreasing trust in financial institutions (Fungácová, Hasan & Weil, 2016). After the crisis started, the rules and regulations surrounding banks were critically reviewed. From this, it was concluded that apparently rules and regulations were not deemed sufficient enough. This meant that new regulations, namely Basel III were developed. Basel III entailed a packet of rules, regulations and standards that banks should meet in order for a new crisis to be prevented. These crises usually induce a shock to the system which the banks were not prepared for. A shock, for a bank, is an unforeseen change in the external or internal environment that leads to changes in the value of assets and/or liabilities. This causes the bank to suddenly have to take measures to try and mitigate the effect of this shock. In the banking world, rules and regulations are used to improve the resistance of banks with regard to shocks. The various Basel accords are the most important framework in this field.

The reason this crisis was so severe was due to not only its impact on the financial markets, but also its impact on the real economy. Reinhart & Rogoff (2009), in their study with different financial crises, conclude that asset market collapse, decline in output and employment and the rise of real value government debt are real world spillage. Shiller (2012) shows that a sharp decline in trust in government and supervisors is another important spillage effect of the recent crisis. This goes to show that financial crises can have an important and measurable effect on the real economy too.

Governments and banking regulators concluded that it would be best if another of these crises could be avoided and/or shocks causing it could be mitigated. These measures should improve the survivability of banks, with survivability being defined as the ability of a system to mitigate shocks that the system encounters. And although that sounds good, preceding reforms in rules and regulations surrounding banks have not led to the prevention of financial crises as the 2008 financial crisis was not the first one to hit banks. The 1997 Asian financial crisis, 1990 Scandinavian crisis, the Japanese asset price bubble and the Great Depression are all examples of major financial crises. Stephens, Brian Atwater & Kannan

(2013) show that all these crises might be the result of the same mistakes. This consequent failure of banks and expanding of rules and regulations on the sector might just be indicative of a system that is inherently fragile, no matter how large buffers are. Martinez-Moyano, McCaffrey & Oliva (2013) argue that recurring regulatory problems and recurring crisis could be structurally similar, indicating just that. And whilst Martinez-Moyano et al. (2013) focus on the rule structure within and around banks, it might also be interesting to look at the system of a bank itself. If we know how the system works, we might be able to build a system that is inherently more resistant to shocks, even without having large buffers. Larger buffers will only protect the current system whilst not looking at other options. If, every time something bad happens, the government has to bail out banks in order for the system to work, can it be concluded that the underlying system does not work?

To be able to answer that question, an overview should be given of what is being named as underlying reasons for the financial crisis to happen in the first place. When looking at the literature, numerous reasons are being put forward by different authors as to why the financial crisis happened. Taylor (2009) shows that monetary excesses and government policy caused this crisis, Crotty (2009) shows that the crisis was caused by deeply flawed institutions and practices that give incentives for risk-taking, as well as the non-transparency and complexity of retail mortgage backed securities (RMBS notes) and Shiller (2012) names the belief in ever upwards going house prices and the crisis surrounding sub-prime mortgages as primary causes and stresses the importance of deteriorated public trust in financial institutions. Acharya & Richardson (2009) show that the off balance securitization of mortgages and the trade in them were major causes from which the financial crisis happened. Martinez-Moyano et al. (2013) show that the deterioration of rule compliance and the creation of situations where no rules apply caused this crisis. The sheer variety in reasons shown is indicative of the complexity of the problem.

The conclusions of the authors described before all highlight different aspects of what they saw as the primary causes of the financial crisis. Because of this discrepancy, it would be interesting to see if one of these authors can be proved right. Thus, not all of the causes described above will be tested. Instead, just one of these will be chosen. This will be the cause put forward by Acharya & Richardson (2009), namely the securitization of RMBS notes and the trade in these securities. RMBS notes will be further explained in the theoretical background. This cause was chosen, because the process around it is something that is still in place. Also, this cause can be quantified, modelled and tested in different situations. The last reason for choosing this cause is that it interests the author and there would not be enough time to test all of these reasons. When looking at the different reasons put forward by the authors, there is one element that always comes back, which is also in the name of the crisis itself: mortgages. Mortgages appear to be the most important factor through which the crisis happened. Securitized mortgages, as will be explained in chapter 3, were a derived product of that and pivotal in the financial crisis happening. The results from this research could thus indicate whether or not the cause put forward by Acharya & Richardson (2009) was important enough to incite a crisis on its own.

As said before, the global banking system is a very complex system, which is the reason only a part of it will be addressed in this thesis, namely the part directly related to the cause described by Acharya & Richardson (2009). The complexity arises from the large numbers of stakeholders involved such as shareholders, clients, customers, corporations, governments or rating agencies. Next to that, a single bank is entangled with other banks, governments and investors, who also increase the complexity of the system. Also, banks are inherently complex entities with different business units not necessarily knowing what other units do or contribute. Another important notion with regard to banks is the feedback loops inherent in their system. Actions from different stakeholders induce actions from other stakeholders, resulting in feedback loops in a bank. These feedback loops might promote pro-cyclical behaviour. Given the complexity of the system and the number of stakeholders involved, as well as the presence of important feedback loops in the system, the need arises for a modelling technique that allows for the building of a model whilst still being able to test for different possible scenarios. The modelling technique that will be used in this paper will be System Dynamics. System Dynamics provides a way to deal with this complexity in a comprehensive and clear way. Thus, this is the modelling technique that will be used here. This technique and the motivation will be further elaborated upon in chapter 2.

To investigate whether the reason put forward by Acharya & Richardson (2009) was indeed central to the crisis, the fictional country of Bankistan will be created. This country is characterized by no inflation, no ties with other countries, the existence of only three banks and passivity of investors who will take any investment as long as it yields positive returns. Also, there are no deposit guarantees and a passive central bank. The reason to use this country is that it leaves external processes out of the equation and instead focusses on the internal processes in a national banking system. By eliminating a lot of uncertain factors from the outside such as currency swap rates, international banking or governmental actions, the behaviour of a single banking system can be observed when they are not being influenced from the outside. There should only be one external event happening to this bank, namely the shock. Obviously, there are some externalities that cannot be eliminated such as public trust in a bank, the sale of mortgages to clients and the inflow of savings to a bank, but these are relevant externalities. In this country, the financial crisis on off-balance sheet assets and mortgages will be tried to be recreated with as many externalities eliminated as possible. This should provide insight in how the internal processes of a bank, firstly, react to a shock on a bank without other actors immediately stepping in. Secondly, it might provide insight in how the internal processes of a bank might prolong and amplify or, in contrast, shorten and flatten out the impact of shocks incited on the system.

To be able to test the system for the impact of a shock, a model of a bank is required. A bank model is a simplified expression of the changes that happen to a bank's balance sheet when different internal and external processes take place over time. After building a bank model, it should be placed in the context of Bankistan, together with two other banks, since three large banks in a country can show effects on each other. In doing this, a national banking structure is created for the land of Bankistan. When the model of the bank is validated and the banking system of Bankistan is validated, it can be used to test the impact of a shock induced on this system. When inducing shocks of different magnitudes, it can be shown what the magnitude of a shock has to be before the system fails. This method has been used more often in studies such as the one by Lansink (2010). He showed that a series of shocks had to happen before his bank failed. For this research, the effects of a shock on a single bank, as well as the effects on the banking system are looked at. If the magnitude of shock that would cause the banking system in the model to fail to the magnitude of shock in the real world, a conclusion can be drawn. A conclusion could be that the magnitude of shock causing the model to fail is comparable to the magnitude of shock that was observed during the crisis. That conclusion could mean that the cause put forward by Acharya & Richardson (2009) might well have induced the financial crisis. When this magnitude is not comparable, it might be concluded that this cause would not have incited the crisis on its own.

Following this all, the research objective for this thesis will be to build a national banking system that explains financial behaviour observed before the crisis of 2008 and inducing a shock onto that banking system to be able to see if similar behaviour to the 2008 financial crisis arises in the system.

The research questions accompanying this objective will be: "Which national banking structure explains financial behaviour observed before the 2008 financial crisis? To what extent and in which scenarios does a shock in mortgages lead to the failure of one bank and subsequently a national banking system and investment entities?”. Subquestions to this question are:

- Which structure describes the behaviour of a bank before the 2008 financial crisis?
- Which structure describes the behaviour of a banking system before the 2008 financial crisis?
- How large must a shock on the mortgages of one bank be to cause that bank to fail?
- How large must a shock on the mortgages of one bank be to cause another bank to fail?
- How large must a shock on the mortgages of one bank be to negatively influence investment entities?
- In what scenario will a shock on a bank cause the system to fail?

These questions, the research question and subquestions, are limited to one country, the country of Bankistan. Finding the answer to these questions can be really useful for banks and governments to strengthen their financial systems. From a theoretical perspective, this research can create more clarity in the discussion surrounding the causes of the financial crisis, because it gives clear results based on a model. In most research into the causes of the financial crisis, supposed relationships are shown from data and then linked to events. In this research, the influence of one event (the shock on mortgages) on the banking system will be shown in a system dynamics model.

In the following, first, the methodology will be discussed. Second, the theoretical background will be explained. Third, the explanation of the model will be done. Fourth, the validation of the model will be explained. Fifth, the results of the model will be presented. Sixth, the conclusion will be drawn and last, the limitations and discussion will be presented.

2. Methodology

In this section, first the choice of modelling technique will be explained. Second, system dynamics will be explained. Third, Group Model Building will be explained. Fourth, expert modelling as a technique will be discussed. Fifth, the different ways to build a banking model and how the model was built will be shown. Sixth, the research strategies will be presented and seventh, the research subjects will be presented.

2.1 Choice of modelling technique

The global banking system is characterized by being comprised of many elements and being difficult to understand. Islam, Vasilopoulos and Pruyt (2013) show that banks can be considered as highly uncertain and dynamically complex systems that are permanently facing risks. There are many factors influencing each other, creating feedback loops in the system, with a feedback loop being the original action influencing another action, which in turn affects the original action again. As described in the introduction, banks seem to keep having hard times and crises hitting them. Although some people would say that the banking system is inherently fragile such as Demirgïc-Kunt & Detragiache (2002), others, usually banks themselves and the Basel committee, will say that forming new rules and regulations will keep the banking system healthy. Next to that, as described in the introduction, different authors reach different conclusions as to what the cause was for the financial crisis. Thus, the causes, the problem and solutions are not clear. The situation described above is indicative of a messy problem as described by Vennix (1999). Messy problems are characterized by many stakeholders, many interrelations and, distinctively, a lack of a definition on what the problem is and whether there is a problem at all. In his view, a way to deal with messy problems is Group Model Building (GMB), which will be further explained in chapter 2.3. GMB is a method commonly used in conjunction with System Dynamics (SD).

To show why SD is going to be used, the phrase ‘complex system’ will be defined. From that, the choice for SD will be made clear. This will be done by defining complexity and defining the word system. First, we deal with the word complexity. ‘In general, the word complexity is used to describe a certain arrangement of elements in which the state of one or more elements influences the state of one or more other elements’ (Lansink, 2010, pp. 12). The problem with defining complexity is that there is no widespread definition of complexity, nor is there a measure of how complex a model is (Chwif, Baretto & Paul, 2000). There are, however, some common elements in definitions with regard to complexity such as the difficulty of understanding the system that is being modelled (Golay, Seong & Manno, 1989) or the number of parts or elements that the system contains (Simon, 1991). Second, we deal with the word system. A system is defined here as a set of a set of elements that are related to each other. The boundary of a system is set by the one defining the system. From these two definitions, the definition of a complex system that will be used here is: A system with many different elements that is difficult to understand with the entire system producing behaviour that is generated by, but not necessarily the same as, the behaviour of elements that produce system behaviour.

Several authors addressed the issue of how to deal with complexity, which led to the creation of techniques such as systems theory, cybernetics, complexity science and also SD (Castellani & Hafferty, 2009).

SD is the technique chosen for this thesis since it offers us a way to deal with the characteristics of the system described earlier. In addition, when following the definition of Vennix (1999) and his view on dealing with messy problems, GMB and SD are an appropriate technique to deal with the problem.

2.2 System Dynamics

The goal of SD is to foster learning in dynamic complex systems and to help decision makers in making decisions about these systems. SD does this by discovering and representing the stock and flow structures, delays, variables, feedback processes and non-linearities of the system. Before continuing on with an explanation of system dynamic, these components will be explained. A stock and flow structure is representative for the state of an element and the change in it, where the stock is the element and the flow represents the change in it. This can be compared to a bathtub, where the level of the water in the bath represents the stock. The drain and tap are the respective out-and inflows to the stock bath. Delays are a way to represent time that is needed to make a decision or change something about how large your flows are. For example: say there is a constant and equal amount of in-and outflow in the bathtub. If the inflow were to be changed, there would be a need to open the tap further in order for the bath to slowly fill. Since the hand required to open the tap further cannot instantly make changes, the time it took the hand to get to the tap would be considered a delay. Variables are elements of the system that help regulate the stocks and flows. They can be in the form of parameters, for example the movement speed of the hand moving to the tap, or of stocks and flows influencing the variables directly, which lead to an effect on the other flow. For example, if the warmth of the bad were added as a variable, the kind of opened tap would have an effect on that variable, depending on whether the warm or cold tap was opened. A feedback process could then be described as a circle of variables, stocks and flows that have an effect on each other and then on themselves again. For example, opening the tap increases the water level, which increases the amount of water drained, which decreases the water level. Most complex behaviour arises from causal feedback loops and the interaction of more than one causal feedback loop. Causation can have two directions: an increase in one variable increases another (positive) and the increase in one variable decreases another (negative). The smallest feedback loop possible is when one variable has a positive or negative effect on a second, with the second having a positive or negative effect on the other, as can be seen in figure 1. When the dotted arrow from variable two to variable one is positive, there is a positive feedback loop in place. This means that an increase in one, leads to an increase in the other, which leads to an increase in the one, etc. This is called a reinforcing feedback loop. When the dotted arrow is negative, there is a negative feedback loop in place. This means that an increase in the one lead to an increase in the other, which lead to a decrease in the one, which leads to a decrease in the other, etc. This is called a balancing feedback loop.

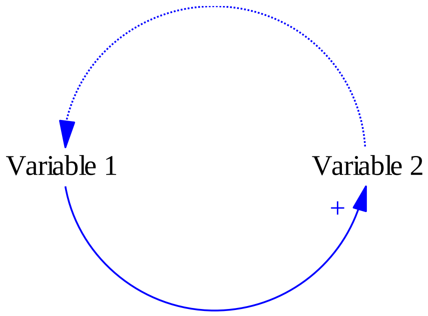

Figure 1. The smallest feedback loop.

A linear relationship is one wherein an increase in an independent variable will always lead to a proportionally same increase or decrease in the dependent variable. A non-linearity is a relationship wherein an increase in an independent variable will not lead to a proportionally equal increase or decrease in a dependent variable. These are important relationships because they are often qualitative in nature, but can usually be quantified. Also, when a non-linearity exists in a model, it can greatly influence behaviour of the model when the effects of one variable on the other suddenly become heftier.

As mental models of human beings are unable to grasp all the above stated components, SD uses simulation to challenge mental models. This often leads to radical changes in the way human beings understand reality. It also strengthens and speeds up the learning processes of the system the decision maker is operating in (Sterman, 2000).

One of the meta-assumptions of SD modelling holds that an endogenous structure is responsible for the behaviour of the system. In order to understand the development over time of the key problematic variable, such as mortgages or net income, it is therefore necessary to understand the structure that created the behaviour. From this, the structure generating the behaviour is modelled and simulated. The simulated behaviour should match the real behaviour of the key variable for the right reasons. This means that the structure should be as close as possible to the real system.

2.3 Group Model Building

GMB is a decision support tool in which a group of stakeholders together with a modelling team try to solve a focused problem in a complex system (Franco & Rouwette, 2011). This tool is especially of value in problems that are characterised by a high degree of uncertainty, complexity, and cognitive conflict. GMB sessions are usually planned with the participants wherein participants come together and go through a set of exercises. The approach assumes that participants in a session hold a different view on the problem, and therefore might not agree on what the problem is or what the solution should be. The facilitator leads the participants to a series of small group exercises which help to make the views on the problem explicit, and consequently to model them. Moreover, the approach implies that these different views are needed in order to come to a correct model of the system.

2.4 Expert modelling

Another option from an SD perspective is to engage in expert modelling. As outlined by Franco and Montibeller (2010) the expert modelling approach differs on numerous aspects related to problem formulation, data collection, results and the aim of the intervention. '*In this model, the problem situation faced by the client is given to the operational research consultant, who then builds a model of the situation, solves the model to arrive at an optimal (or quasioptimal) solution, and then provides a recommendation to the client based on the obtained solution'* (Franco & Montibeller, 2010, pp 489). The information still comes from the company that the assignment was from, but can also come from different sources then. Next to that, confirmation of structure can still be done by the company giving the assignment. Building the structure, however, becomes the task of the modeller instead of the group as opposed to GMB sessions.

2.5 How to build a banking model

There are three ways to build a banking model structure. One is the elicitation of a model by going to a bank and have GMB sessions with experts and decision makers in the issue at hand. In this way, experts in the field will tell us how a bank is structured and are also doing parts of the validation for us. A banking model has to represent reality and this can only be done by validating it. When experts in the field tell a modeller that the structure that was elicited represents reality, their word can be used as validation. Second, existing bank models can be compared and a new model can be built based upon these models. For validation, if the structure built is similar or the same to the model it was used from, the original validation can be used and validation can be found in literature. Certain relationships and modelling structures that were validated can, if they were used in the same or a similar way, be used to validate the model. Last, a theoretical model can be built, that has some foundation in literature, but is also modified based upon what would make sense from a modelling perspective and from the theory perspective. This would be a model that is less powerful than building the other two, because it is less grounded and embedded in literature and expert opinions.

For this thesis, a combination of the above-mentioned techniques was used. First, a bank was visited, and GMB sessions were done. After that, the model was updated and the bank was consulted about whether the model is still in line with the actual system they work in or not. The second part can thus be considered to have been the expert modelling. In doing this, the model is validated with experts, which gives confidence in the built parts. Next, banking models linked to financial crises like those of Lansink (2010), Pruyt (2010), Moscardini, Loutfi & Al-Qirem (2005), Kassem & Saleh (2005) and Pruyt & Hamarat (2010) provide interesting insights that can be used to build and validate the model too. When the model is validated like this and does what it has to do, the real question can be addressed. To do this the assumption has to be made that banks largely have the same way of working. When they work in the same way, a cluster of banks can be made using only one model. A cluster of banks is required because in that we way we can see the interaction of the different banks on each other too. This is where Bankistan as a country comes in. In this country, the effects of the interactions between banks can be seen, because other countries and even central banks and governments are not considered. The interactions that banks have with each other in this country is that they buy RMBS notes from each other.

The reason to look at one country is simple. This thesis tries to look at the ties that banks have with each other from a different angle. Instead of looking at all the ties they have with each other, a few ties are taken out specifically. These ties are of particular importance when trying to induce the shock that was explained in the introduction. The shock itself will be further elaborated upon in chapter 3.4. There are different starts for the financial crisis named that go back as far as ten years, but the start that is going to be used here is the writing off of a portion of the mortgages of Lehman Brothers. They had to suddenly write of roughly 1 percent of their mortgages. This proved to be the cause for Lehman Brothers to go bankrupt just shortly after. The banking sector was influenced by this shock on Lehman Brothers, but no one is completely sure how. In this thesis the land of Bankistan is used because it will be tried to be shown that the shock on one bank can cause other banks to fail. Building a model with more than three banks would become too large and other factors are probably going to play more important roles too. The goal is to look purely at the impact of the shock of writing of a portion of mortgages in different scenarios. Bankistan is then purely a tool to help with keeping other factors that could also play a role out of the equation.

2.6 Research strategies

For this research, the aim is to build a formal SD model that uses the inputs of different stakeholders. These inputs are incorporated in the model in order for us to create a model that represents the reality of a bank in an accurate manner. Next to some GMB sessions, these stakeholders have to provide us with quantitative data. Different stakeholders that need to be addressed are bankers, workers, mortgage sellers, modellers, etc. Basically, anyone working for a bank is a potential source of information as well as quantitative data. For more data, the financial statements of the bank would also be a good source of information as they provide us with a detailed outline of the company’s financial state and thus with quantitative data too. Next to that, there have been more bank models that can be used to improve the model and as such these researches are an interesting topic of study for this model too.

By using the strategy of document analysis, with for example annual reports, financial statements and government law and policy a lot of understanding about the system was gained. These documents can be obtained from the bank that the GMB sessions were done at, but also from other banks in the world. Next to that, by using GMB sessions, it can be seen how people who are part of the bank’s system view the system and show how they think it works. This gives valuable insights in how the system actually works. Last, a short literature study on banking models was done to see how many could be found and how relevant they were.

2.7 Research Subjects

The subjects that will be used for this research can be put in two groups. As was explained in this chapter, there were some sources available to be used for information. The first group of subjects are people working at a Dutch bank that is subject of the GMB sessions that will provide an SD model. These were selected on the basis of variety and availability. Availability, since there was no possibility to have more experts joining the GMB sessions and variety because there is a need for different inputs from experts with a different background. In total, five experts from different fields were available. These experts were the chief risk integration, a consultant in the field of banking models, an information analyst, senior market risk analyst, senior credit risk analyst & capital modeller. Three sessions were done with a varying group of these five experts. The group was varying, because it was not always possible for all participants to participate in the sessions. They were all from different fields in the company and possess a wide variety of knowledge. According to Forrester (1992), experts from the field have the most valuable information both in quantity and significance, because they have mental models that contain knowledge about the bank.

The second group consists of authors of other banking models which were compared and are a source of information.

2.8 Summary

In the previous, the choice of modelling technique, the modelling technique (SD), group model building, expert modelling, the building of a banking model, research strategies and research subjects were presented. In this section it will be summarized how they link to each other.

To be able to make a model, there is a need for a modelling technique. It was shown that SD is the technique that is highly applicable and thus the one that was used here. Next, the techniques associated with SD as well as SD itself were explained as to provide insight in how a banking model can be built. Last, it was shown what research strategies and research subjects were used.

The goal of chapter two is thus to show how the banking model was built. First, GMB sessions were done, then expert modelling and last theory and other models were used to build the final model. To be able to build the final model, there is a need for a model of just one bank. Since the goal of this thesis is to look at how internal processes of a bank and a banking sector react to a particular shock on a bank, a model of a single bank was built.

When the model of only one bank works, it can be used to build a banking sector. In the introduction Bankistan was introduced. This is a country that has a banking sector consisting of three banks. After building a model of one bank, this model is tripled and linked to each other, thus creating the land of Bankistan in which the banking sector is shocked.

3. Theoretical background

In this section, first the choice of central entity will be explained. Then the definitions related to banking will be given. Next, the simplified model will be explained and last, the type of shock induced is explained.

3.1 Choice of central entity

Banks were chosen as the central entity, because they are the entities most affected by the crisis. From the shocks on their systems, the crisis spread to other entities. Obviously, there were more actors involved or influenced, but for the building of the basic bank model these are not required. They are included in the model by being a part of the parameters that drive behaviour of the banking model and also the parts that make up the investment pool. In this way, the role of big investment entities such as pension funds, investment banks or big companies can be shown. These are the entities from which spillage into the real economy also came. To do that, a big investment pool was added wherein all funds being invested in banks were pooled. This pool starts with a fixed amount of cash in it. Upon receiving returns, the total amount of investments + the leftover pool should be a growing variable. If it starts declining because of the shock induced in the model, it can be shown that this shock influences the total investment pool and thus the people who invested in this pool. In doing this, there is no need to model for example an entire pension fund company or an investment bank. Any negative change in this investment pool will be indicative of investors losing money and the real-world implications that come with this notion. If for example a pension fund loses money, it will start to get into trouble with regard to actually paying pensions, thus affecting pensioners. In this thesis, it is thus shown what happens to banks when they are being shocked like that and indirectly what happens to investors. The notion that investors could lose money is something that would be interesting to see, which is why the investment pool was added. The model itself, however, will be a banking model and although there is room to observe some effects on society, these can only be indirectly seen.

3.2 Definitions related to banking

Retail Mortgage Backed Securities notes (RMBS notes) are securitized mortgages that can be sold to investors. "*In its most basic form, the process of securitization involves two steps. In step one, a company with loans or other income-producing assets—the originator—identifies the assets it wants to remove from its balance sheet and pools them into what is called the reference portfolio. It then sells this asset pool to an issuer, such as a special purpose vehicle (SPV)—an entity set up, usually by a financial institution, specifically to purchase the assets* *and realize their off-balance-sheet treatment for legal and accounting purposes. In step two, the issuer finances the acquisition of the pooled assets by issuing tradable, interest-bearing securities that are sold to capital market investors. The investors receive fixed or floating rate payments from a trustee account funded by the cash flows generated by the reference portfolio. In most cases, the originator services the loans in the portfolio, collects payments from the original borrowers, and passes them on—less a servicing fee—directly to the SPV or the trustee. In essence, securitization represents an alternative and diversified source of finance based on the transfer of credit risk (and possibly also interest rate and currency risk) from issuers to investors*" (Jobst, 2008, pp. 48-49).

A bank is considered to be failing when it becomes insolvent. Insolvency means that the total value of savings and debt exceeds the value of assets. That means that the value of savings is no longer fully covered by the value of the assets. This could cause bank runs, because savings entrusted to a bank can no longer be fully repaid, causing people to scramble for their money. The first one to get their money back, could still get it whilst for the last one to claim his savings, the assets could have dried up in which case the bank cannot repay that claimant.

Bank insolvency usually happens for one or two reasons. The first one is a bank run scenario. When faced with a bank run, the liquidity of the bank rapidly diminishes, forcing it to fire sale its illiquid assets in sales as to acquire new liquid assets to be able to pay its depositors. By being forced to fire sale illiquid assets, usually an amount lower than the actual valuation of the asset is gained in cash. For example, an illiquid asset may be valued at 100 euros, but will only be able to be sold in a fire sale for 50 euros. By being forced to take this offer, a loss of 50 euros is incurred on the asset side of the balance. When having to sell off too many assets, eventually the value of assets will become lower than the value of deposits, also rendering a bank insolvent. The amount lost when forced to sale assets varies, but and assets is almost always sold for a lower value than it was originally valued at as Shleifer & Vishny (2011) confirm.

The second reason a bank can be rendered insolvent is an increase in the amount of defaults incurred on outstanding loans. These defaults decrease the value of outstanding assets. If enough defaults happen, asset value will start to decline. When asset value reaches the point where assets are worth less than outstanding deposits, a bank is rendered insolvent.

Health indicators are very important to banks as they show the survivability of the bank. They usually are ratios of important values in the real world. In the model, they can be used in the same way: as health indicators which are ratios between important stocks and variables. The most important health indicators are the leverage ratio, the Liquidity Requirements, Return On Equity (ROE) and the total capital ratio. The leverage ratio deals with how much equity a bank has with regard to their total liabilities and equity. A minimum of 3 percent capital compared to the total liabilities and equity is required. The Liquidity Coverage Ratio (LCR) is a measure of how much cash a bank has compared to total savings. It was introduced under Basel III and means that 30 percent of total savings have to be covered by cash, cash equivalents and high quality liquid assets. However, before Basel III was introduced, the liquidity requirement was 10 percent of total savings (Bouwman, 2013). For the model, cash, investments and bonds were used to determine whether the ratio was high enough. A value of 1 is associated with adequate Liquidty requirements. The ROE is a measure of how much you are earning for every euro invested. For the model, it was assumed that investors would take any investments as long as they yielded positive returns. The total capital ratio is a measure of total capital compared to the risk weighted assets. This means that a minimum of 8 percent of Risk Weighted Assets (RWA) have to be covered by the common equity.

3.3 Simplified model

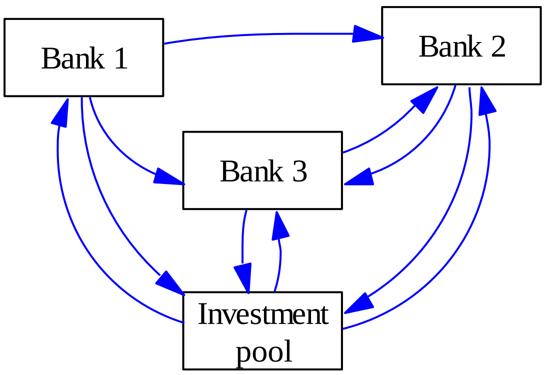

Figure 2. Simplified model.

The simplified model, as shown in figure 2, depicts the final model in its simplified form. Before, it was shown that a model of one bank was required to build the banking model. In the simplified model, this model of one bank is named Bank 1, Bank 2 and Bank 3. These three banks are all models of one bank. The investment pool is the sum of all investments done in banks and the available funds for investing. The banks are linked to each other through the RMBS notes they buy from each other. The investment pool is linked to the banks through buying stock, wholesale funding and RMBS notes. The shock on the system in the form of the write off of mortgages will be applied to Bank 1 from which banks may or may not fail. May & Arinaminpathy (2010) describe the following phases in bank failure, namely phase 1, phase 2 and phase 3. Phase 1 failure means that the shock induced on one bank will cause that bank to go fail. Phase 2 failure means that the shock induced on the first bank will cause another to fail as well. Phase 3 failure means that the second bank falling induces a bankruptcy in a third down the line. The arrows in the simplified model depict bank 1, after a shock is induced on it, having a possible influence on bank 2 and bank 3. After that, bank 2 and bank 3 could be influencing each other too. If the total amount of money in the investment pool and invested in banks declines, we can argue that investing parties such as pension funds are losing money and thus could be experiencing difficulties too.

3.4 Type of shock induced

The type of shock induced on the bank will be the writing off of a portion of its mortgages. The choice for this type of shock is appropriate because the writing off of a portion of mortgages actually happened in the financial crisis due to the housing market collapsing. This meant that more people defaulted (which causes writing off of mortgages) and also collateral was valued at a lower price, which causes the writing off of mortgages. Thus, instead of modelling for example the housing market and its implications on the model, the results of these events are induced as a shock. To be able to look at when a shock is significant enough to cause different phases of failure as described by May & Arinaminpathy (2010) in the simplified model, shocks of a different magnitude will be induced. In doing this, the effects of different shocks can be shown in the model output as to be able to address the research question and sub questions. As will be shown later in the explanation of the model, perceived health significantly dropped during the financial crisis. Perceived health will thus be linked to the writing off of a portion of assets. In table 1, the type and magnitude of shocks are specified.

Table 1. Type of shocks and characteristics.

Type of shock	**Written off %**
Light	1
Medium light	5
Medium	10
Medium heavy	15
Heavy	20

To be able to test these different scenarios, a few variables need to be added to the model. These are a shock on written off % for mortgages and subsequent effects of solvency, LCR and written off% on perceived health. These are the variables that are required to execute the shock induced on the system, as further explained in chapter 4.1.

Next to that, these shocks will be placed in the scenario that a shock on one of these banks will cause banks to do a ‘run’ on RMBS notes. Acharya & Richardson (2009) point out that banks were forced to put some mortgages back onto their balance sheet. For this scenario, banks will be required to put all of their RMBS notes outstanding back onto their balance sheet. Although this did not happen in that way during the crisis it serves to show the effects if a run on RMBS notes would really have happened. Next to that, no one was really sure how much these RMBS notes were worth anymore. They were packaged, sold, resold, resold and repackaged again. Prices went down as much as 65 percent during the period of 2007-2008 (Acharya & Richardson, 2009). It was unclear who even owned a particular mortgage (Edstrom, 2010). Thus, the shocks described before will be induced with and without a run on RMBS notes. This should provide insight in what happened during the crisis. The initial shock on mortgages of bank will thus be the instigation of all banks having to take back all of their RMBS notes onto their balance sheets again.

This is important, because it serves to show what could have happened. The market for RMBS notes was on the verge of collapse and government programs such as the ‘Housing and Economic Recovery Act (2008) and the Term Auction Fund (Federal Bank of Reserves, 2007) were started to stop this market from collapsing. Similar programs were started across the world with for example the European Central Bank also providing cheap liquidity for banks that needed it. Running this scenario could thus provide interesting insights in the crisis which is why this scenario will be run.

In the next chapters, the model will be explained. Then, the validation of the model will be explained. In the chapter after that, the baseline behaviour of the model will be explained. This baseline will be used to compare the different kinds of shocks on the model and their effect on the bank. To be able to induce the shock to the model and also to show what actions happen, a few variables were added to the complete model. Since they are directly related to the type of shock, they should prove to be necessary to be able to induce the shock.

4. Explanation of the model

In this section, it will be described how the model was built, after which the final model will be presented. It will be shown partitioned here to clarify the different parts and elements of the model. A full size model can be found in Appendix 1. After that, the variables needed to induce the shock, the most important feedback loops, assumptions as well as a list of parameter values will be presented.

4.1 Steps in building the model

As was explained earlier in the methodology, three techniques were used to build the final model. First, GMB sessions were done with the participants described in chapter 2.7. The group built a basic model that was not yet finished. It was able to do some basic runs and show basic model behaviour. It was thus already quantified for the parts that were built. This model was not yet validated. No validation tests or comparisons were done with the model. This is where the expert modelling and comparison to other models part came in. From the end of the GMB sessions, the author started working on building a model that could test for the effect of mortgages on a banking system. During the first period, the bank was consulted about whether or not the model was still in line with their mental models. In the last period leading up to the completion of the final model, the bank was no longer consulted and other sources of information had to be used to validate and build the banking structure. In the final version of the model, it can be seen that not all the parts have a specific function for inducing the shock. These are parts that were added in the GMB sessions and later in the expert modelling. For purposes of completeness and clarity, these parts were left in. These parts could later be possibly used for future research and, since they were elicited from the GMB sessions, could prove to be valuable.

The result of the GMB sessions was thus a fully functioning, although not validated or complete, model of a single bank. The value of building a model of a single bank was that it could be used, as was said before, to build a banking system. In appendix 2, three versions of the model can be seen including the one at the end of the GMB sessions. These are not versions of the model that were fully validated or complete yet, but they serve to show how the model was built.

4.2 Explanation of final model

For this part, the final model is shown in Appendix 1. Here, it can be seen where the different elements shown in the following come from in the final model. In figure 3, one of the most important parts of the model is shown. Basically, what happens is that every RMBS note issue is divided between the banks. Before the RMBS notes are issued, they are securitized. Securitization is the process of transforming mortgages into RMBS notes, as described in chapter 3.4. Thus, the flow in figure 5 named ‘mortgages sold off via RMBS’ is also the inflow for securitized mortgages in figure 4. This outflow of mortgages is not linked to mortgages, but to the flow ‘selling mortgages to client per month’. Where banks traditionally are the intermediary between lenders and borrowers, they shifted their position to also be an intermediary between investors (Acharya & Richardson, 2009). Securitization also allowed for RMBS notes to be put off-balance prompting reduced or no capital requirements to be held, making them hugely interesting for banks (Acharya & Richardson, 2009). In figure 4, the process of securitization is shown. The securitized mortgages come from the stock of mortgages, becoming retained and eventually issued RMBS notes, which is all off-balance. A total of 25 percent of all mortgages are securitized. Then, when they are issued, they go to figure 3, wherein a bank and also the investment pool can buy them. Every bank buys 20 percent of all RMBS issued as Acharya & Richardson (2009) described them to be the largest buyer of RMBS notes. Thus, 40 percent of all RMBS issued is bought by the investment pool. Bought RMBS notes are also off-balance. In other words, the process made with these two figures is one wherein the off-balance sheet activities are described. Revenue is created without having to have capital or liabilities to back them up. Next to that, figure 3 also shows the process of buying equity and wholesale funding. The available investment funds buys all equity offered and all wholesale funding offered. Since all these investments generate returns, the total investment pool is a continuously growing factor. The total investment pool is different from available investment funds in the sense that it incorporates the stock of bought investments too such as bought RMBS notes and total equity.

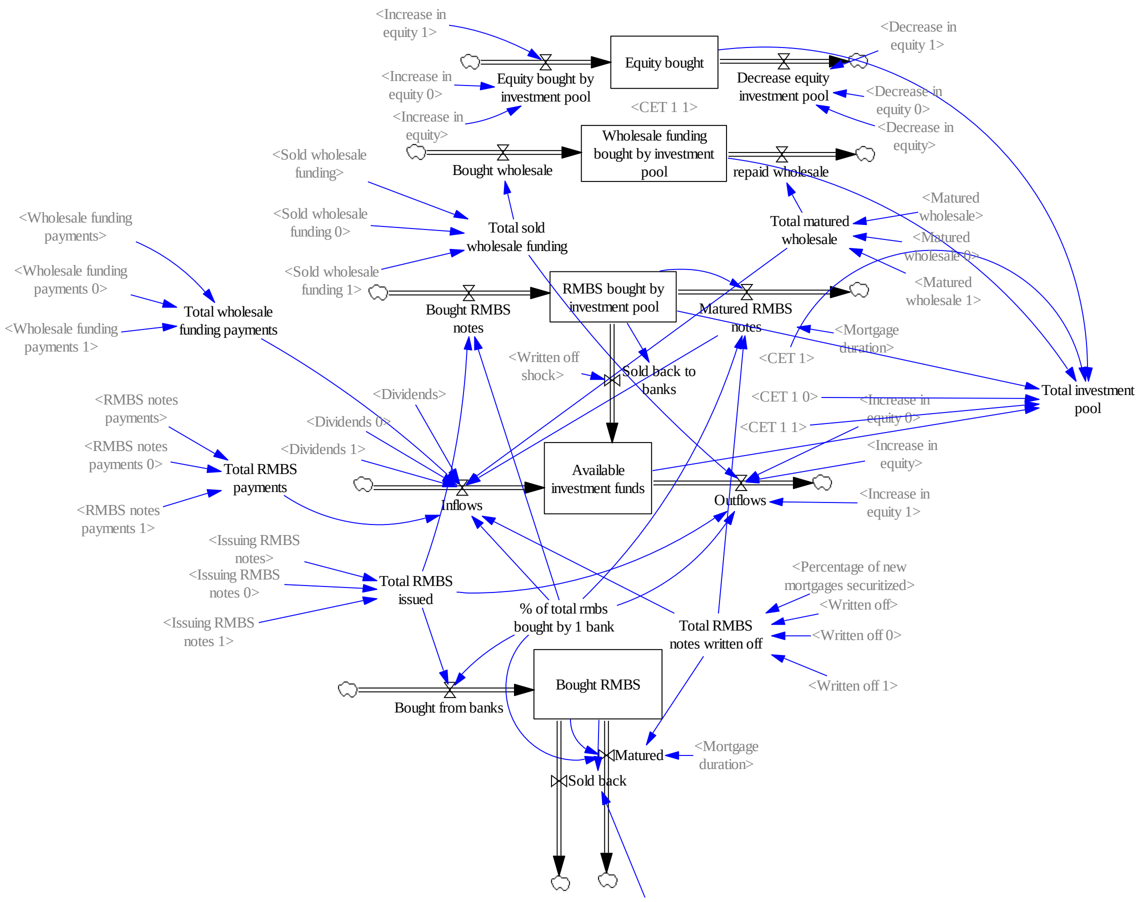

Figure 3. An overview of the investment pool and the RMBS notes bought by one bank.

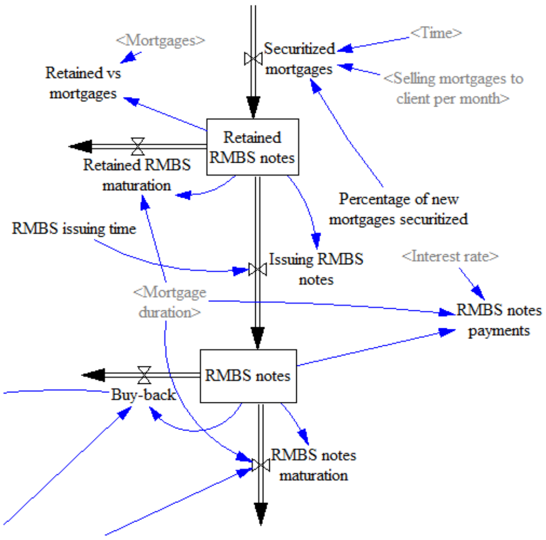

Figure 4. Securization process of RMBS notes.

In figure 5, the process of buying, selling, defaulting and repaying mortgages is shown. Mortgages are being sold to customers. The mortgages can then be either repaid, written off or securitized. Mortgages that are securitized become the retained RMBS notes in the previous figures. It's a simple process wherein the stock of mortgages grows to the size of a medium bank. The interest is modelled separately from the mortgages, because in doing so, we allow for changes in the interest rate to be delayed in the interest earnings. If we would not do this, the interest earnings would increase by a certain percentage instantly when the interest rate were to be changed. In the assumptions section later, a few other things important in this view will be discussed. The variable marked yellow in the model is the variable that will induce the shock on the model.

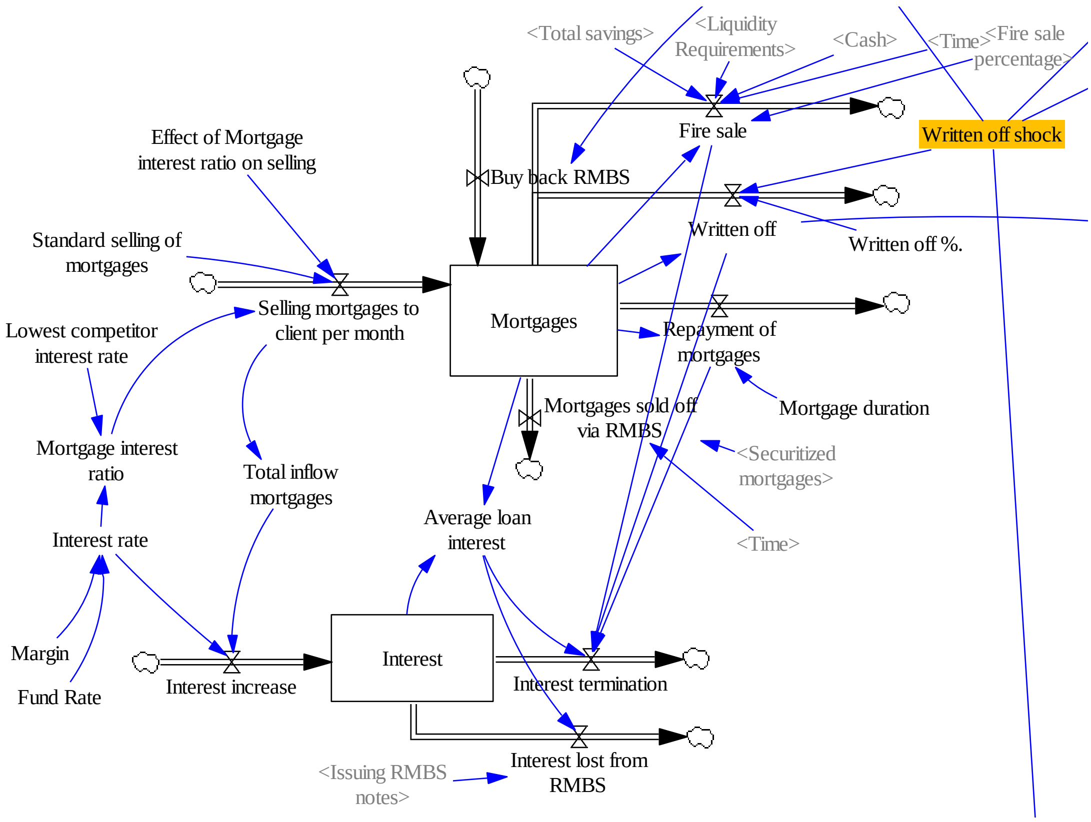

Figure 5. Overview of the stocks and flows related to mortgages and interest on mortgages.

Bonds and consumer lending, as shown in figure 6 are modelled similarly to the mortgages in the previous figure. The interest is also taken separately and modelled as a stock and flow as to ensure changes in interest will not instantly change the interest returns. For consumer lending, the assumptions section will have some things of note.

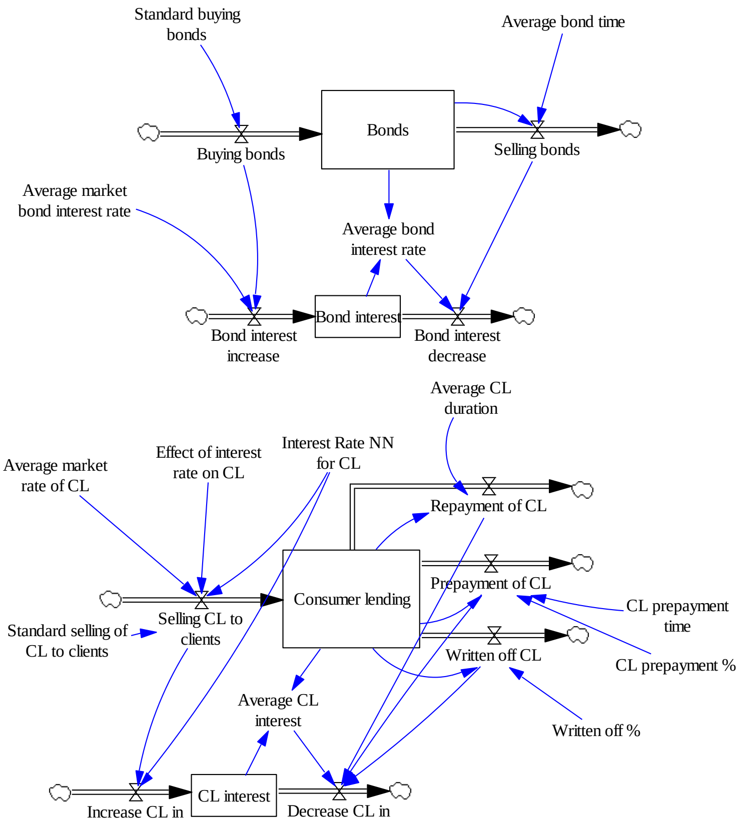

Figure 6. The bought bonds and the stock and flow structure around Consumer Lending.

Cash is also an important variable in the model. In figure 7, we see the structure surrounding cash. Cash dictates how much money you have and how much can be spent. Next to that, there is the necessity of keeping some money in stock to remain liquid. Different variables cause the total cash stock to increase or decrease. A lot of other variables in the model use or generate cash.

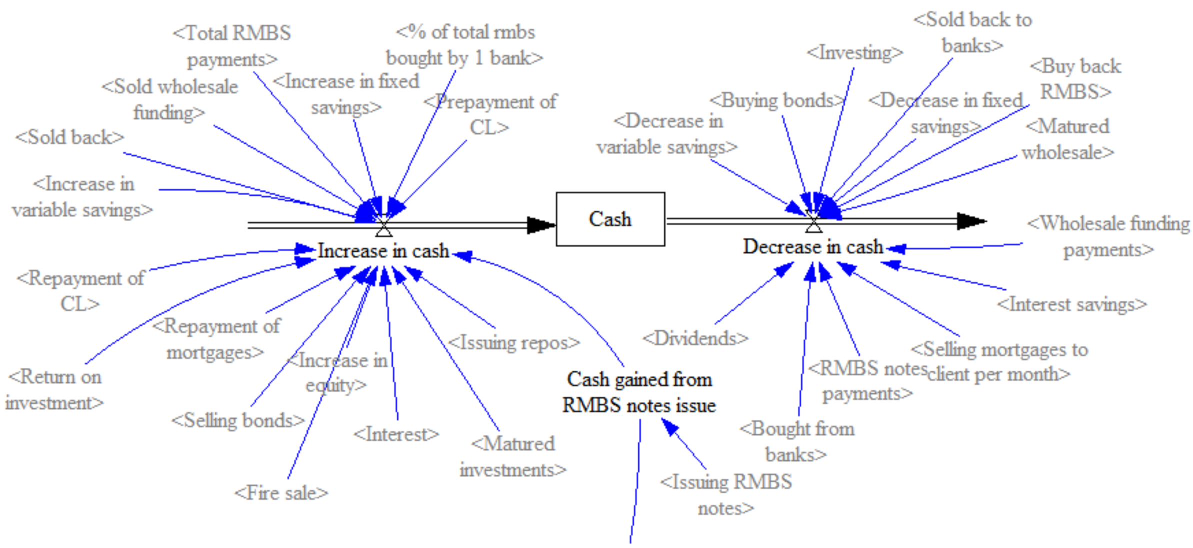

Figure 7. Stock of cash and variables influencing the in-and-outflow of cash.

In figure 8, the calculation for net income is shown. Here, we see the gross income, which is the total interest income minus interest cost per month. The gross income is then subjected to operation costs. After that the risk costs are deducted and, lastly, the tax costs. This view is also briefly mentioned in the assumptions regarding the fixed operation costs.

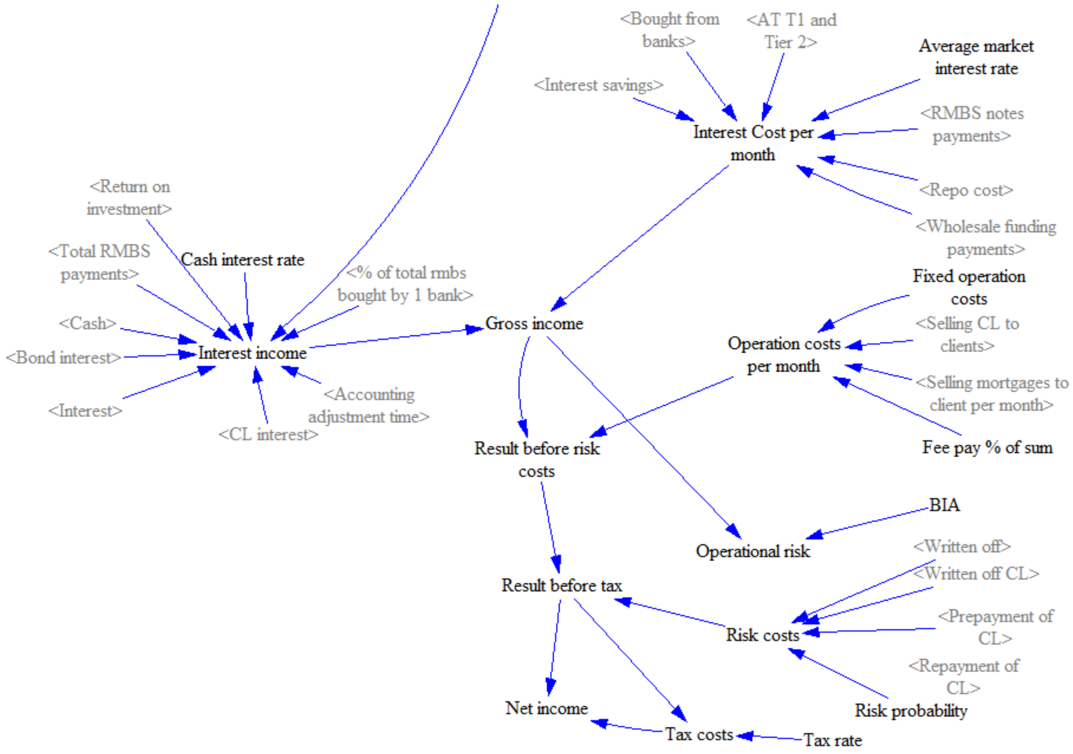

Figure 8. Overview of the different variables influencing net income.

In figure 9, the calculations regarding Common Equity Tier 1 are done, because a bank is a limited company that sells shares at a stock market. There is a required value of CET1, which is imposed upon banks. Additionally, dividends are paid based upon the net income. The dividend payment percentage is 80 percent, which means that 80 percent of net income is being paid out to investors, in this case the investor pool. As can be seen in figure 3, one of the incomes of the investment pool is dividends. In figure 3, the total amount of dividend is calculated, which is then allocated to the investment pool. Also, the writing off of mortgages directly influences the decrease in equity. In figure 10, the savings flows as well as the perceived health is shown. The perceived health is also addressed in the assumptions. Perceived health enlarges the savings in-and-outflow. Research has shown that the public trust in banks can be severely undermined when banks are shown to be (in danger of) failing. Fungácová et al. (2016) that 'trust in banks is considered essential for an effective financial system, yet little is known about what determines trust in banks (pp. 4). They also note that ‘trust in banks during the financial crisis deteriorated significantly during the financial crisis’ (pp. 8) in a study by Knell & Stix (2009) in 2000 Australian households. The choice to go with marketing comes indirectly from Lansink (2010). He noted the important role of media and marketing with regard to how stable a bank is believed to be.

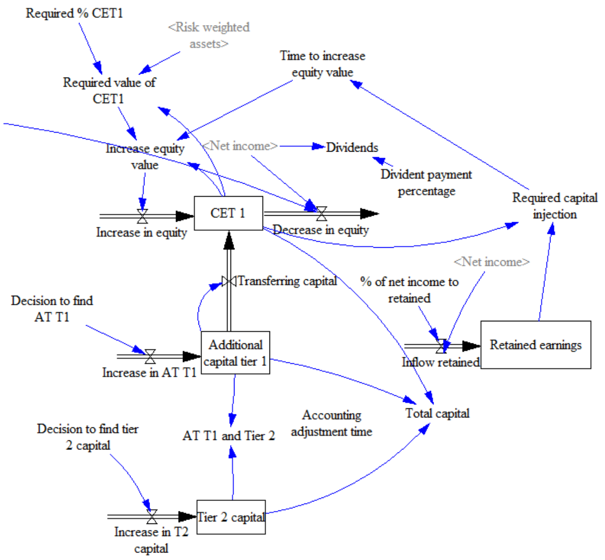

Figure 9. Overview of the different forms of capital as well as retained earnings.

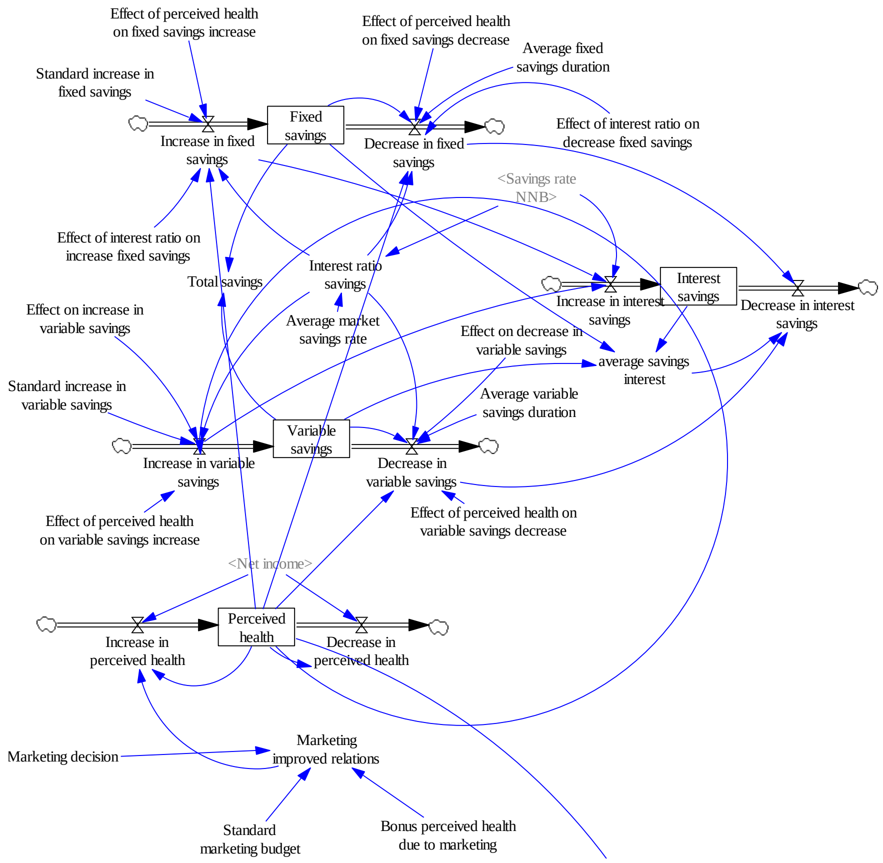

Figure 10. Overview of the stocks and flows determining savings and perceived health.

The variable savings and fixed savings are an important part of the bank's liabilities. Off course, interest has to be paid on savings, thus prompting to build a construction similar to mortgages with regard to how interest is calculated. Savings will further be addressed in the assumptions. The construction around savings is shown in figure 10.

Wholesale funding, as can be seen in figure 11 is the term used to denote other sources of funding than equity and savings. '*These funds are typically raised on a short-term rollover basis with instruments such as large-denomination certificates of deposit, brokered deposits, central bank funds, commercial paper and repurchase agreements*.'(López-Espinosa, Moreno, Rubia & Valderrama, 2012, pp. 3). Basically what they do is they provide a source of funding other than equity or savings. Wholesale funding is subject also to the perceived health of the company as interest rates dramatically increase as the bank has a lower perceived health. Typically, wholesale funding is short term, which is why the wholesale average maturity time is set at one year.

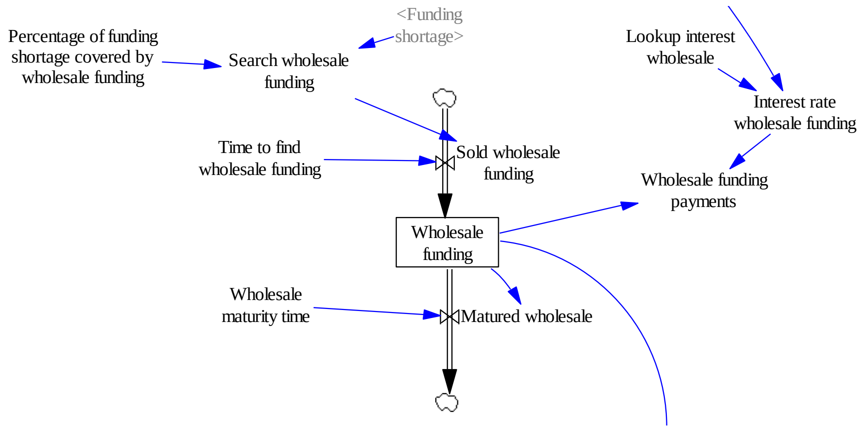

Figure 11. Overview of the process of acquiring wholesale funding.

Last, the model includes the calculation for the risk-weighted assets and the funding shortage or funding surplus. Next to that, the health indicators are being calculated that proved useful and important in the GMB sessions being the Liquidity requirements, the Return On Equity, the Leverage ratio and the total capital ratio as described in chapter 3.2. Apart from those important ratios, a few other ratios are calculated that include the savings to mortgage ratio, CET1 to mortgage ratio and wholesale funding to mortgage ratio. These last few ratios, namely savings to mortgage, CET1 to mortgage and wholesale to mortgage, are used for validation and are thus not a part of the theory. The first set of ratios are the health indicators of a bank. If one of these indicators drops below the mark that has been set as healthy, a bank is considered less healthy and might be indicative of problems inside the bank. The other ratios are used to compare the model to real world banks as will be shown in the validation.

4.3 Variables needed to induce the shock

A few variables were added to be able to induce the shock onto the model. In figure 12, the shock on perceived health is shown. This is driven by the initial writing off shock, solvency and fire sales. Perceived health is affected when a bank has to do fire sales, writing off or becomes insolvent. Insolvency has the largest effect of the three because this can cause panic with savers. Next to that, in figure 3 and 4, it can be seen that buy-back, sold back and sold back to banks have been added as flows. These are required to induce the RMBS run. When the writing off shock happens on bank one, all RMBS notes are bought back by all banks in the system. The buy-back flow empties RMBS notes to mortgages, the sold back gives a bit of cash back from the sale of bought RMBS and the sold back to banks flow sells all its RMBS back to banks. Last, the fire sale flow has been added that induces an inflow in cash if mortgages were to be sold.

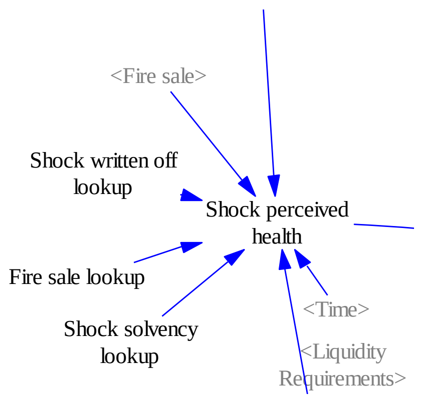

Figure 12. Lookup functions that determine shocks on perceived health.

4.4 Most important feedback loops

The most important feedback loop in the model is the one directly related to the shock induced on the model. The writing off of mortgages causes a lower value for the stock of mortgages. This causes imbalance on the balance sheet, which creates a funding surplus. The funding surplus causes more investments to be bought, which decreases cash and the Liquidity Coverage Ratio (LCR). Because the LCR drops, the need arises to get liquid assets again, which calls for mortgages to be fire sold, which again lowers the mortgage pool.

Another important feedback loop is also directly related to the shock induced on the model. The writing off of mortgages causes a drop in perceived health and a drop in the mortgage stock. This drop in perceived health causes people to deposit less savings and withdraw more. This deteriorates the cash position of the bank, which decreases the LCR, which in turn causes mortgages to be fire sold. This again decreases the value of the stock of mortgages.

The most prominent feedback loop linking the three banks is this one: the writing off of mortgages and fire sale of mortgages causes a portion of RMBS notes to also have to be written off. This causes banks to start losing money to the point where they are not profitable anymore. This causes perceived health to slowly deteriorate. When perceived health deteriorates, the cash position, as was shown before, deteriorates, which causes fire sales, which causes more RMBS to be written off.

For the second scenario in which the RMBS run will play a role, another important feedback loop arises. This loop is activated for that scenario. The writing off of mortgages prompts a run on RMBS notes, causing a bank to have to buy back all its outstanding RMBS notes. This causes cash to drop, decreasing liquidity, which prompts fire sales. Fire sales increase liquidity whilst decreasing solvency and perceived health. Decreased solvency causes decreased perceived health and decreases total savings, causing cash outflows. This decreases liquidity again. This feedback loop only arises when the writing off happens.

4.5 Assumptions

For the model to work, we need to make a few assumptions. First of all, the purpose of the thesis is to build a representative structure of a bank. This structure is then tripled and linked to each other to be able to create the national banking system of Bankistan. This link was explained in the beginning of this chapter. What we need is a good model of a bank that also fits the purpose of this thesis. Since no reference mode of behaviour was available, some assumptions had to be added to the model. This was also necessary to be able to create a bank that would be representative of a real life bank with the growth pattern of a bank too. Thus, we had to make some assumptions about growth. The first assumption here is:

1. A bank will seek to grow, resulting in growing standard sales of mortgages and growing standard increases in savings.

A bank, as can be observed in the real world, is an institution seeking to grow, get more clientele and generally increase its balance (Martinez-Moyano et al, 2013). It is assumed that a bank will have a standard amount of sales when it starts, which will increase as it grows because it can reach more potential customers. As it can reach more potential customers by setting up new places where clients can reach the bank, be it physical or non-physical, a larger clientele will have access to this bank. This will increase the number of clients a bank will get, thus growing its balance and clientele. To show this assumption is actually what we find in the real world, it was found that the business model of numerous banks such as ING, ABN

AMRO and ICBC incorporate growth into their strategies. The word ‘growth’ was used over 20 times in different contexts, such as overseas expansion, in the first six pages of one of the annual report of ING (ING, 2015), implying the importance of growth for banks.

As a bank grows, its operation costs will also increase. This was also added to the model.

It has to be noted here that in order for the growth to be plausible and explainable, research was done into financial statements of real banks. Simply stated, this meant that the balance in their yearly financial statements was checked for scale as well as proportions of for example savings compared to mortgages.

The second assumption that had to be made is:

2. For the mortgage interest ratio, effect of interest rate on consumer lending, interest ratio savings and the effect of perceived health an assumption had to be made. When the determining variable of these effects is higher than the average value, inflows are increased while outflows are decreased. When the determining variable of these effects is below the average value, inflows are decreased and outflows are increased. This effect is stronger for negative effects.

The direction of these effects is pretty clear and also confirmed by experts. The strength and impact of these effects is less clear. Thus, the direction has been modelled, but the strength had to be assumed. This assumption, however, can be worked with if we vary the strength of the effects. This would have to be a subject for another thesis though. For this model, we assume the strength of effects, although the direction and discrepancies for positive and negative effects are confirmed by experts. The general form of the effects is shown in figure 13. In figure 13, the effect of an independent variable or ratio on a dependent variable is shown. These effects were confirmed by experts during the GMB sessions, but the exact magnitude of the effects was not. Thus, they are approximated.

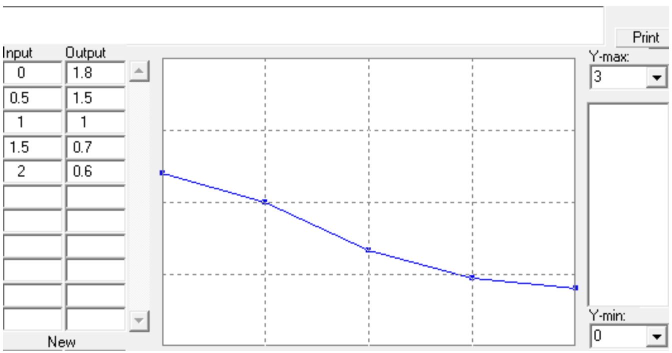

Figure 13. General form.

For example, when looking at the effect of perceived health on variable savings inflow, a lower perceived health would result in decreased variable savings inflow. At the same time, variable savings outflow is increased. For all the effects mentioned above, a similar construction was made.

The third assumption that had to be made is:

3. The legal construction of Retail Mortgage Backed Securties notes is assumed to have no effect on the model.

The legal process of securitizing mortgages and issuing them is not relevant for what actually happens to the model. The legal process around RMBS notes is pretty lenghty with legal constructions such as Special Purpose Vehicles (SPV) that buy and sell RMBS notes. Since the bank is the owner of that SPV, they get all the profit that SPV generates. Since the legality around it does not affect what practically happens, only the effects of these constructions have been modelled instead of the entire legal construction around it. What actually happens was explained pretty well by Acharya & Richardson (2009) and has been modelled to their explanation. For clarity and simplification purposes, the legal construction was left out.

The fourth assumption that had to be made is:

4. Perceived health is an important variable in the financial system as was explained before. We assume that a healthy bank doing normally has a value of 1. A bank doing great inches towards a value of 2, whilst a bank doing poorly goes to 0.

Perceived health is measured on a scale from 0 to 2. The normal and starting value of 1 increases and decreases based on net income. As long as the bank has a positive net income, the value increases little by little. If the net income is negative, the value decreases with potentially strong effects on the savings inflow and outflow. This kind of construct is called a dummy. The value of the dummy doesn't necessarily have real life meaning, but for the model it represents an important variable. It is needed to test for bank run scenarios and also to test for the effects of a sudden decrease in perceived health. Experts confirm that perceived health is an important factor, but they are unsure how to measure it (Fungácová et al., 2016). To improve the perceived health, the choice was made to use marketing as Lansink (2010) gave this a large role in his bank failure scenario.

For the complete model, we assume the land of Bankistan. In this country, the effects of shocks on one bank and its effect on subsequent investors or other banks will be tested. The choice for Bankistan was made as to be able to only look on the effect of shocks on mortgages. In this setting, the banks are unhindered by for example shocks in other countries, currency shocks or global economy shocks. They operate in the same way without competition in the base model, although they could be considered competitors. For this thesis, they will not actively engage in competition. This means that they grow in exactly the same pace to exactly the same size. Their interaction comes from the sale of RMBS notes to each other and the investment pool and the perceived health of the banking sector in Bankistan.

In summary, in the final model, banks grow at the same pace to the same size in the country of Bankistan. The assumptions discussed before hold true in this country. We have shown here that although some assumptions had to be made in the basic model, these assumptions are highly plausible and for the largest part confirmed by experts or literature.

The fifth assumption is:

5. Only a percentage of the total value of assets is returned in cash when fire sales are done.

When faced with only a short time to sell assets, a bank will never get the full price for it. The particular assets that have to be sold in the model are mortgages. During the crisis, trust in the value of these assets was low as indirectly and directly pointed out by Acharya & Richardson (2009). They show that RMBS notes lost as much as 65 percent of their value. Next to that, fire sales of assets always yield a lower return in cash than if they were to be sold during normal times (Coval & Stafford, 2007). The percentage of the total value of assets returned is unclear though. Thus, it will be varied in this thesis to see the effects of this.

4.6 List of parameter values

Table 2. Parameter values.

Variable name	**Value**	**Unit**	**Source**
% of total RMBS bought by one bank	20%	Percentage/month	Acharya & Richardson (2009)
Accounting adjustment time	1	Months	GMB sessions
Average bond time	120	Months	GMB sessions
Average fixed savings duration	120	Months	GMB sessions
Average market bond interest rate	1,67%	Percentage/month	GMB sessions
Average market interest rate	4,5%	Percentage/month	Hypotheker.nl (n.d.)
Average market rate of CL	0,067%	Percentage/month	GMB sessions
Average market savings rate	0,2%	Percentage/month	Geldreview.nl (n.d.)
Average variable savings duration	72	Months	GMB sessions
Cash interest rate	0%	Percentage/month	-
Decision to find AT T1	0	Euros/month	-
Decision to find tier 2 capital	0	Euros/month	-
Dividend payment percentage	0.8	Percentage/month	-
Fee pay % of sum	5%	Percentage/month	GMB sessions
Fixed operation costs	10+RAMP(2, 0, 180)	Euros/month	*4.2 Assumptions*
Interest rate	4,5%	Percentage/year	Hypotheker.nl (n.d.)
Interest rate for CL	0,67%	Percentage/month	GMB sessions

Variable name	Value	Unit	Source
Liquidity requirements	0.10 of total savings	Percentage	Bouwman (2013)
Lowest competitor interest rate	4,5%	Percentage/month	Hypotheker.nl (n.d.)
Marketing decision	0	Euros/month	-
Mortgage duration	240	Months	gemiddelden.nl (n.d.)
Percentage of funding shortage covered by wholesale funding	1	Percentage/month	-
Percentage of new mortgages securitized	25%	Percentage/month	Acharya & Richardson (2009)
Required % CET1	11%	Percentage/month	Expert modelling
RMBS issuing time	1	Months	Expert modelling
Savings rate	0,2%	Percentage/month	Geldreview.nl (n.d.)
Standard buying bonds	13	Euros/month	*4.2 Assumptions*
Standard increase in fixed savings	RAMP(8, 0, 180)+30	Euros/month	*4.2 Assumptions*
Standard increase in variable savings	RAMP(13, 0, 180)+120	Euros/month	*4.2 Assumptions*
Standard marketing budget	4	Euros/month	-
Standard selling CL to clients	150+RAMP(4, 0, 180)	Euros/month	*4.2 Assumptions*
Standard selling of mortgages	RAMP(20, 0, 180)+200	Euros/month	*4.2 Assumptions*
Tax rate	25%	Percentage/year	GMB sessions
Time to find wholesale funding	1	Months	López-Espinosa et al. (2012)
Time to increase equity value	12	Months	-

Variable name	Value	Unit	Source
Wholesale maturity time	12	Months	López-Espinosa et al. (2012)
Fire sale percentage	50%/70%	Percentage	*4.2 Assumptions*
% Return on investment	0,46%	Percentage	-
Correlation within portfolio	15%	Percentage	GMB sessions
Investment maturity time	60	Months	-
Written off percentage	0.1%	Percentage/month	GMB sessions

In this list of parameters, two are of particular note, namely percentage of new mortgages securitized and percentage of total RMBS bought by one bank. A large part of the mortgage market was securitized before 2008, going up to 66 percent for some forms of loans in the United States financial markets (Acharya & Richardson, 2009). A comparably low value of 25 percent was taken here. This is a somewhat arbitral value, chosen due to the fact that we deal with the land of Bankistan here, wherein less securitization was done. The percentage of total RMBS bought by one bank is set at 20 percent here, which means that the three banks in Bankistan buy 60 percent of all issued RMBS notes. 40 percent is bought by the investment pool. This percentage was indirectly taken from Acharya & Richardson (2009), who called banks the biggest player on the RMBS note market.

A few parameters do not have a source. This is because they can be a decision such as the decision to find AT T1 and tier 2 capital. Next, they can have a value of 0 or close to it, such as cash interest rate, the standard marketing budget and the marketing decision. Parameters such as investment maturity time and return on investment were unclear and do not have a large impact on the system for the way the system was modelled. The percentage of funding shortage coverered by wholesale funding is 1, because there is no other way for the system to fund a funding shortage. Thus, the entirety of the funding shortage gets funded by wholesale funding. Next, there is the time to increase equity value. The value of 12 was chosen because it would be highly unusual if the value of equity could change almost instantly. Last, there is the dividend payment percentage, which is an educated by the author guess and also does not really matter for model behaviour what percentage it is.

5. Validation

The validation of the model has, at first, been done in the GMB sessions. In these sessions, the inputs of different experts have been used to create a first working model. Next to that, data and additional information was given as to ensure the model would work. Not everything was validated by the experts though. Since no reference mode of behaviour of any of the key variables was provided, there has been a need to make a few assumptions about the basic bank model which could potentially weaken this thesis. Since in SD one of the key points of validation is the comparison of the model behaviour to reference mode of behaviour, a reference mode of behaviour has to be obtained. We use data from the balance sheet of three banks in different markets to show that the behaviour of the bank falls within the expected range of possibilities found in the balance sheets of banks. This process does not provide a direct reference mode of behaviour, but it does provide valuable insight, because we compare the model to real banks. This could thus be considered a validation as the goal of the thesis is to build a national banking structure that explains behaviour before the crisis.

Next to that, we will describe the results of some validation tests. Barlas (1996) describes a few tests split into two categories: direct structure tests and structure oriented behaviour tests. In this section, we will briefly address a few of these structure tests. The tests addressed in the following are all derived from Barlas (1996). Figure 1 in Barlas (1996) describes the most important validation tests in SD. They are shown in table 3.

Table 3. Validation tests (Barlas, 1996).

Direct structure tests	Empirical tests	Structure confirmation test	v
		Parameter confirmation test	v
	Theoretical tests	Structure confirmation test	v
		Parameter confirmation test	v
		Direct extreme condition test	v
		Dimensional consistency test	v
	Implementation methods	Formal inspections	x
		Walkthroughs	v
		Semantic analysis	x
Structure oriented behaviour tests		Extreme condition test	x
		Behaviour sensitivity test	v
		Modified behaviour prediction	x
		Boundary adequacy test	v
		Phase relationship test	v
		Qualitative features analysis	x
		Turing test	x
Behaviour pattern tests			x

5.1 Validation tests

Structure confirmation test: although the final structure of the model was not reviewed with experts, earlier versions have most certainly been verified. Small changes can have large effects on the overall behaviour of the model, but the original structure, made in the GMB sessions has largely remained the same. The savings view, consumer lending, mortgages, cash, CET1, bonds and calculation of net income have all came from the GMB sessions. In some cases the numerical values had to be added such as the standard buying or selling of different variables. The structure of the model was only partially confirmed in the case of perceived health, wholesale funding and partially the securitization process of RMBS notes. For these parts, literature was used to show why the structure of these parts makes sense. These parts were largely explained earlier in chapter four. The structure of the model, when compared to other banking models is similar. Different elements that are used in those models can also be found in this model, thus confirming model structure.

Parameter confirmation test: Not all of the parameters of the model have been verified. In the model, a standard buying and selling for some inflows can be found. These parameters have not been verified, but since the objective is to grow a bank, these are built to grow the bank to a decent size, thus making it less necessary to confirm these parameters. It has been made clear before though that growth is important for a bank. Also, some effects such as the effect of perceived health on the inflow of savings have not been confirmed either. For these effects, the direction has been given, but the strength of the effect was not. Other parameters such as mortgage duration have been confirmed though. In chapter 4.1 these issues have been addressed. An overview of parameters and their sources can be found in chapter 4.3. As can be seen in table 2, the confirmation of different parameters has been done from theory and directly. Thus, the parameter confirmation was done in both the theoretical and direct form.

Direct extreme-condition test: For this test, most of the parameters were varied but nothing that could not be expected happened. When testing the reaction of the rest of the system, again, nothing that could not have been expected happened, except for changing the mortgage duration to a factor ten larger. Since mortgages almost do not expire, the stock of mortgages grows much quicker. This leads to a funding shortage which is funded with wholesale funding. Since this is a costlier source of funding, cash decreases to a point where fire sales are required, thus leading to system collapse. More paramater changes lead to system failure, but this one seemed counter-intuitive at first. In the real world though, more mortgages would be securitized to make up for this funding shortage then though.

Dimensional consistency: All stocks are in euros except for perceived health and unemployment, which are a dummy and a percentage. The interest stocks are in euros/month. The flows are all in euros/month, except the ones concerning perceived health and unemployment. The flows to perceived health are points per month and for unemployment change in percentage per month. All variables not mentioned in the parameter list, assumptions or health indicators are in euros with the exception of the calculation for the risk weighted assets. Seven lookup function can be found that calculate percentages for the variables. Also, the correlation within portfolio is a constant. Exposure at default is in euros and Risk Weighted Assets is too. Next to that wholesale funding payments and RBMS notes payments in is euros/month. Barlas (1996) notes that '*to be meaningful, the test requires that the model has no 'dummy' scaling parameters that have no meaning in real life'* (pp. 192). Since for example perceived health is a dummy, we can conclude this test is not meaningful.

Balci (1994) describes what kind of validation, verification and testing techniques should be used. In the expert modelling phase of this thesis, mostly informal validation, verification and testing techniques were used such as the walkthrough and review. These were used to gain information for confirmation tests. Other techniques were not possible such as formal inspections and semantic analysis.

The extreme condition test with regard to structure was not done since its purpose is to serve as a kind of stress test. Since the purpose of this thesis is to do just that, it is not necessary or useful to do this test.

Behaviour sensitivity test: Net income can be heavily influenced by the interest rate of savings as well as the interest rate of mortgages. The behaviour of the model also drastically changes when the percentage of new mortgages that are securitized rises. At 60 percent, the system fails after about 10 years. After some testing, it seems that the other parameters do not dramatically change system behaviour within a reasonable bound of how much that parameter was changed.

Modified behaviour prediction: no data were found to be able to compare the system to data of a modified version of the system. Thus, this test was not done.

Boundary adequacy test: The boundary for the system is set as to be able to test the system for a certain, specific scenario. All elements required to play out this system are in place. The boundary of the system is set at the country of Bankistan, with its characteristics as described before. This country suffices to be able to play out the scenario done in this thesis. There are a few elements in the model that are a part of a bank's portfolio, but do not play a specific role right now. However, it can be concluded that the boundary of the system is adequate, since it incorporates the most important elements to be able to play out this scenario.

Phase relationship test: the phase relationship test can be considered to be the real world comparison described below.

Qualitative features test: the comparison which the article described in Barlas (1996) from which this test comes was impossible to do. The requirements are specifying major qualitative features of the expected behaviour under specific test conditions. Although for tests such as the extreme condition test or behaviour pattern test, the results of those test had an expectation with them, the behaviour of the system does not necessarily have an expected pattern as is required for this test. Thus, this test could not be done.

Turing test: unfortunately, there was no possibility to get people to be able to try and distinguish model behaviour from real world behaviour. Thus, this test was not done.

Behaviour pattern tests: these test revolve around the reproduction of major behaviour patterns exhibited by the real system. Since there was no reference mode of behaviour available, the comparison of the model to patterns exhibited by the real system was impossible. It can be argued though that the results of the model as shown later are indicative of the model reproducing system behaviour.

5.2 Real world comparison

As a final validation test, since the reference mode of behaviour was not obtained, we compared the range of savings to mortgages, investments to mortgages, equity to mortgages and wholesale funding to mortgages ratios of some real life banks to the behaviour of the model as to ensure that the behaviour of the bank falls within the expected range of possibilities observed in real banks. In tables 4, 5 and 6, the calculations for the range of possibilities was done. In these tables we see, first, the year the ratios apply to, then the value of the corresponding variable and last, the calculation of the ratios. These table provide two kinds of data. First, the numerical values of the different balance sheet assets or liabilites and second the ratio of this value compared to mortgages. For example, in 2015 for ING the ratio of savings to mortgages was 0.932 because € 500.777,00/€ 537.343,00 = 0.932. These ratios give us an indication of how different banks organize their assets and liabilities and give insight into what kind of proportions they use. Since these banks seem to hold fairly constant ratios over time in one bank, this might be considered as a sort of business model. Three banks were chosen to represent real banks. ING, ABN AMRO and ICBC were chosen, because their ratios differ from each other and this gives a good impression of the range of possibilities in real banks that might be encountered. Also, ICBC is the largest bank in the world at the time of writing, ING was one of the biggest banks during the crisis and ABN AMRO was a bank that had to get bailed out. That is why their balance sheets were chosen. It also provides a way to test the basic model for its plausibility to represent real banks. The choice for ratios was made because it provides a way for banks to be compared, however large or small they are. Since no two banks is exactly the same size, ratios provide information on the business model choices made. And although the nominator and the denominator are both variable, the ratio still gives good information on a bank. For ABN, a shorter timespan was taken as ABN was nationalized during the crisis of 2008. Thus, the data after that event are not included in these data. Simply put, the maximum range that come out of the tables shown below are compared to the range of the same indicators in the model. When the indicators of the model stay within the range of possibilities taken from the data in the tables, the model can be said to at least stay in the range one could expect from a bank.

Table 4. ING financial ratios (ING, 2015).

ING	2015		2014		2013		2012	
Mort	€ 537.343,00	1,000	€ 517.478,00	1,000	€ 531.655,00	1,000	€ 563.385,00	1,000
Savings	€ 500.777,00	0,932	€ 483.871,00	0,935	€ 474.312,00	0,892	€ 454.930,00	0,892
Invest	€ 87.000,00	0,162	€ 95.402,00	0,184	€ 137.897,00	0,259	€ 193.584,00	0,259
Equity	€ 47.832,00	0,089	€ 50.424,00	0,097	€ 45.776,00	0,086	€ 51.303,00	0,086
Whole	€ 121.289,00	0,226	€ 126.352,00	0,244	€ 127.727,00	0,240	€ 143.436,00	0,240
	2011		**2010**		**2009**		**2008**	
Mort	€ 602.525,00	1,000	€ 613.204,00	1,000	€ 578.946,00	1,000	€ 619.791,00	1,000
Savings	€ 467.547,00	0,776	€ 511.362,00	0,834	€ 469.508,00	0,811	€ 522.783,00	0,843
Invest	€ 217.407,00	0,361	€ 222.547,00	0,363	€ 197.703,00	0,341	€ 258.292,00	0,417
Equity	€ 50.440,00	0,084	€ 41.555,00	0,068	€ 33.863,00	0,058	€ 28.928,00	0,047
Whole	€ 139.861,00	0,232	€ 135.604,00	0,221	€ 119.981,00	0,207	€ 96.488,00	0,156
	2007		**2006**		**2005**		**2004**	
Mort	€ 552.964,00	1,000	€ 474.437,00	1,000	€ 439.181,00	1,000	€ 321.258,00	1,000
Savings	€ 525.216,00	0,950	€ 496.680,00	1,047	€ 496.680,00	1,131	€ 368.015,00	1,146
Invest	€ 275.897,00	0,499	€ 293.921,00	0,620	€ 324.644,00	0,739	€ 185.619,00	0,578
Equity	€ 37.208,00	0,067	€ 38.266,00	0,081	€ 38.425,00	0,087	€ 13.977,00	0,044
Whole	€ 66.995,00	0,121	€ 78.133,00	0,165	€ 81.262,00	0,185	€ 70.746,00	0,220

Table 5. ABN AMRO financial ratios (ABN AMRO, 2007; ABN AMRO, 2004).

ABN AMRO	2007		2006		2005		2004	
Mort	€ 572.458,00	1,000	€ 578.074,00	1,000	€ 488.883,00	1,000	€ 299.051,00	1,000
Savings	€ 569.686,00	0,995	€ 550.372,00	0,952	€ 484.904,00	0,992	€ 293.557,00	0,982
Invest	€ 338.712,00	0,592	€ 331.117,00	0,573	€ 325.829,00	0,666	€ 133.869,00	0,448
Equity	€ 30.709,00	0,054	€ 25.895,00	0,045	€ 24.125,00	0,049	€ 14.972,00	0,050
Whole	€ 174.995,00	0,306	€ 202.046,00	0,350	€ 170.619,00	0,349	€ 82.926,00	0,277
	2003							
Mort	€ 296.843,00	1,000						
Savings	€ 289.866,00	0,976						
Invest	€ 132.041,00	0,445						
Equity	€ 13.047,00	0,044						
Whole	€ 71.688,00	0,242						

Table 6. ICBC's financial ratios (ICBC, 2015).

ICBC	**2015**		**2014**		**2013**		**2012**	
Mort	¥11.652.812,00	1,000	¥10.768.750,00	1,000	¥9.681.415,00	1,000	¥8.583.289,00	1,000
Savings	¥16.281.939,00	1,397	¥15.556.601,00	1,445	¥14.620.825,00	1,510	¥13.642.910,00	1,589
Invest	¥4.666.691,00	0,400	¥4.086.409,00	0,379	¥3.949.688,00	0,408	¥3.862.216,00	0,450
Equity	¥356.407,00	0,031	¥353.495,00	0,033	¥351.390,00	0,036	¥349.620,00	0,041
Whole	¥306.622,00	0,026	¥279.590,00	0,026	¥253.018,00	0,026	¥232.186,00	0,027
ICBC	**2011**		**2010**		**2009**		**2008**	
Mort	¥7.594.019,00	1,000	¥6.623.372,00	1,000	¥5.583.174,00	1,000	¥4.436.011,00	1,000
Savings	¥12.261.219,00	1,615	¥11.145.557,00	1,683	¥9.771.277,00	1,750	¥8.223.446,00	1,854
Invest	¥3.763.694,00	0,496	¥3.719.282,00	0,562	¥3.579.026,00	0,641	¥3.014.669,00	0,680
Equity	¥349.084,00	0,046	¥349.019,00	0,053	¥334.019,00	0,060	¥334.019,00	0,075
Whole	¥204.161,00	0,027	¥0,00	0,000	¥0,00	0,000	¥0,00	0,000
ICBC	**2007**		**2006**		**2005**		**2004**	
Mort	¥3.957.542,00	1,000	¥3.533.978,00	1,000	¥3.205.861,00	1,000	¥3.705.274,00	1,000
Savings	¥6.898.413,00	1,743	¥6.351.423,00	1,797	¥5.736.866,00	1,789	¥5.060.718,00	1,366
Invest	¥3.073.007,00	0,776	¥2.860.798,00	0,810	¥2.305.689,00	0,719	¥1.255.550,00	0,339
Equity	¥334.019,00	0,084	¥334.019,00	0,095	¥248.000,00	0,077	¥162.983,00	0,044
Whole	¥0,00	0,000	¥0,00	0,000	¥0,00	0,000	¥0,00	0,000

The data from the tables do not show the same time frame as the data from the model. The data of the tables are purely to provide a range in which one could expect a real bank to be in. In these tables, the real values of the different indicators are given. Mort stands for mortgages, invest stands for investments and whole stands for wholesale funding. The value of savings, investments, equity and wholesale funding is divided by the value of mortgages to create a ratio. The ratio is then presented behind the value of savings, investments, equity or wholesale funding.

We see that the range for ratios goes from 0.776 to 1.854 for the savings to mortgage ratio. The range for investments to mortgage ratio is 0.162 up to 0.81. For equity to mortgages from 0.031 up to 0.097. Last, the ratio for wholesale funding goes from 0 to 0.350.

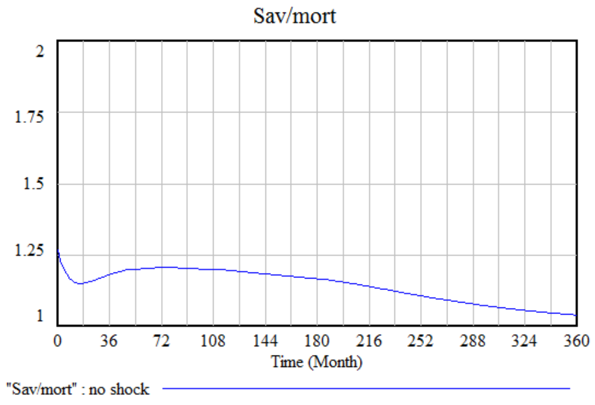

Figure 14. Savings to mortgages.

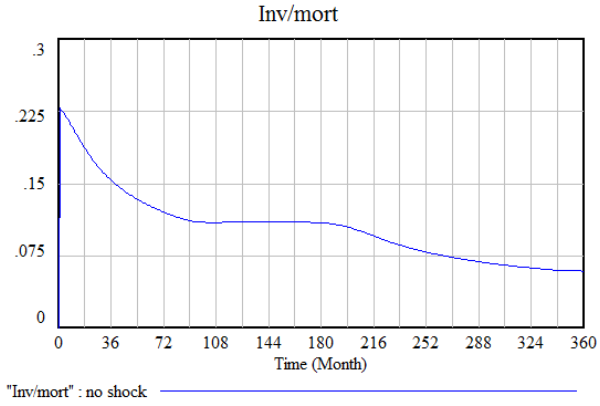

Figure 15. Investments to mortgages.

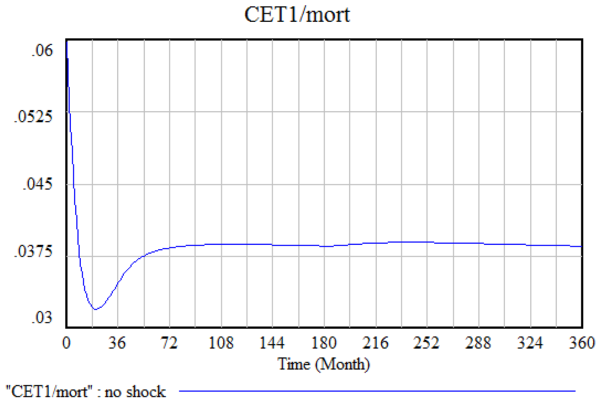

Figure 16. CET1 to mortgages.

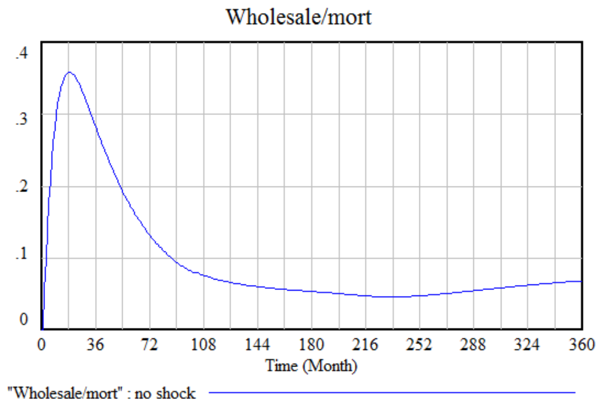

Figure 17. Wholesale to mortgages.

In figures 14 through 17, the behaviour of the ratio of the named variable to mortgages is shown over time. These are the values taken from the model. As can be seen from figures 14 through 17, the ratios fall into the acceptable range of possibilities in the real world. The only ratio that doesn't fit the range of possibilities is the investments to mortgages ratio. This is due to the fact that investments is modelled to only grow when there is a funding surplus. This is not problematic for the model. Investments do add to the net income of the bank, but they are modelled in a way for them to get rid of funding surplus when the shock is induced. A bank should have the opportunity to try and mitigate the shock somewhat and this is what investments do for the model. In that sense it is not too important that the ratio is somewhat below the lowest value in the real life financial statements. Also, wholesale funding is somewhat high in the first three years, this is due to some adjustment time required. After the initial bump, they fall into the acceptable range.

5.3 Health indicators

The health indicators at time 300 as discussed in chapter three can be seen in table 7. Time 300 was taken because that is the moment at which the shock will be induced upon bank 1. These are also important measures of how well the model represents reality. The liquidity requirements should be above the value of 1, which means that ten percent of all savings are covered by cash and highly liquid assets. The total capital ratio should be above 0.08. The leverage ratio should be above 0.03 and the return on equity is preferably as high as possible.

Table 7. Health indicators at time 300.

Indicator	**Value**
Liquidity Requirements	1.586
Total capital ratio	0.082
Leverage ratio	0.033
Return On Equity	0.217

As can be seen from table 7, the health indicators are all above the minimum requirements. Although ROE does not have a minimum requirement, it is an important indicator of how well a bank is doing in terms of how attractive they are for investors. The higher the yield, the more interesting a bank is. Calculations for these ratios are given in appendix 3[1]. One could argue that it would be better for a bank to be far above the minimum requirements and that would be a very valid point. However, when working with the minimum requirements, a bank is a lot more profitable. The health indicators shown here are very much a representation of how some banks treated the requirements. Thus, when building a model of a banking system that represents the situation before the financial crisis, it is highly appropriate to create banks that would want to adhere to the minimum requirements, but not necessarily go above and beyond. At that time, these requirements were viewed as appropriate.

[1] Appendix 3 is available on demand by the author due to the length of it.

6. Results

In this section, the results of the shock will be described. The different shocks as described before will be induced on the system under the different scenarios described before and the results of those shocks will be described here. First, the results of the shocks will be described without a run on RMBS notes and after that the results with a run on RMBS notes will be described. All numbers stated are in million euros.

6.1 Reading guide for this chapter

In this chapter, a lot of figures can be found. On the vertical axis of all figures except the ones related to solvency is the value in millions of euros. For solvency, the value on the vertical axis is the ratio of assets to savings and wholesale funding. A value higher than one is associated with a solvable bank, a value below one is associated with an insolvency problem for the bank. On the horizontal axis, the time in months is shown. The timespan of all figures is 360 months. In almost all of the figures, multiple lines are shown. These lines represent the different values of shock imposed upon the model as well as the case of no shock. Below the figures, there is a small ledger showing with what shock the different coloured lines are associated. In a few cases, the values on the vertical axis are represented a little bit different. A value of 1 M is associated with 1000000. Sometimes values drop below zero and stay there, which means the system fails.

6.2 Baseline model behaviour

The baseline behaviour of the model shows growth. Total assets as show in figure 18 grow steadily which is to be expected from the kind of bank that was built. The bank starts at a really small value for the total assets and steadily grows to a large bank. In comparison, Lehman Brothers had a balance sheet of around 500 billion in total assets. The banks shown earlier ING had a balance sheet that was about double the size, ABN was one and a half times larger and ICBC was little over double the size of this bank. Thus, it is a large bank, but not as big as the largest banks in the world. The net income for this bank is pretty good as seen in figure 19. It makes a steadily increasing profit that falls off a little bit later, but is still very much healthy. Note that behaviour for the three banks is completely the same and their net income, total assets and other stocks and flows are exactly the same. Thus, it will suffice to describe just one bank here. As was shown in the previous chapter, this is a healthy bank that adheres to all the rules imposed on it at that time. The total investment pool grows steadily over time as can be seen in figure 20 although it might have been expected that it would grow larger more quickly. This is due to the fact that the investment pool is larger than the amount of money needed to do all the investments in these banks. The outstanding investments, the ones that are generating returns, total 300000. The investment pool starts at 1 million. Thus, only a portion of the investments actually generate returns. If that is taken into account, the money in investments actually generates a return of almost 40 percent over 25 years.

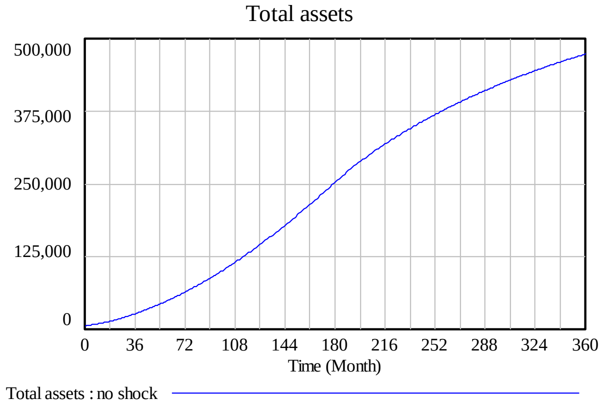

Figure 18. Total assets, no shock.

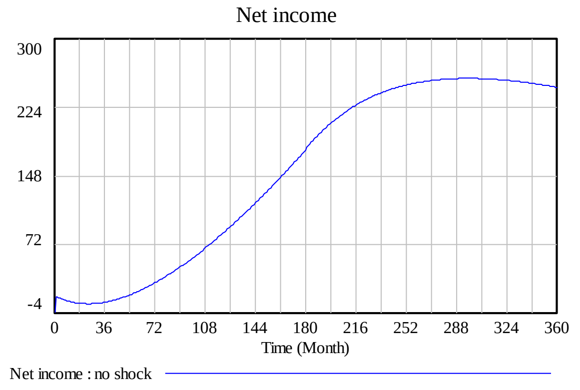

Figure 19. Net income, no shock.

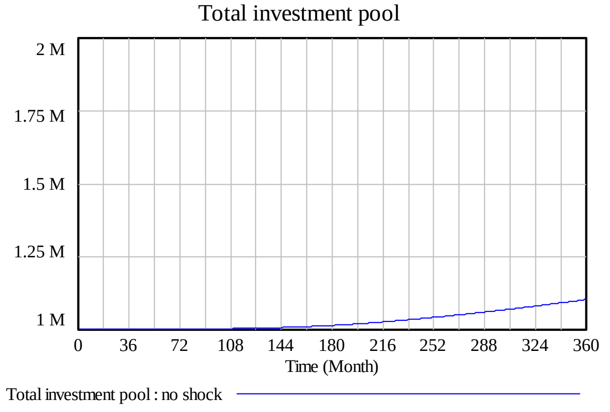

Figure 20. Total investment pool, no shock.

6.3 Shock without run on RMBS notes

As described earlier, 6 types of shocks on the writing off of mortgages were done, namely a shock of one percent, five percent, 10 percent, 15 percent and 20 percent. These will all be compared to the base run of the model. The shocks are induced at time=300.

In figure 21, it can be seen what happens to mortgages when the shock is induced. The initial drop in mortgages is the moment the shock is induced. Drops after that indicate that there has been a fire sale of mortgages to get cash. As can be seen from this figure, in the case of the 20 percent and 15 percent shock, most of the mortgages have to be sold off. This is due to a decrease in perceived health causing savers to get their money back from the bank. This causes liquidity problems for the bank that require assets to be sold off in order for the bank to be able to pay savings back to savers. As can be seen clearly from figure 22, there isn't a clear bank run in the start, except for the case of 20 percent written off. The reduced inflows from people bringing their savings to the bank causes liquidity problems. In the case of the 20 percent shock, it can clearly be seen that savings decline rapidly in what could be seen as a bank run. This, in turn, causes a bank to become illiquid, insolvent and unprofitable as figures 23, 24 and 25 show. It is important to note here that although the bank does not collapse immediately with a shock of 10 percent, it does cause severe liquidity and solvency problems for the bank. In the case of a shock of 10 percent, the bank does have to fire sale some of its assets. This causes severe solvency issues that would need to be resolved if the bank were to continue to exist. The fluctuations in cash are caused by the fact that only when liquidity is below the required value, fire sales have to be done. This induces the fluctuating behaviour of cash when fire sales are required.

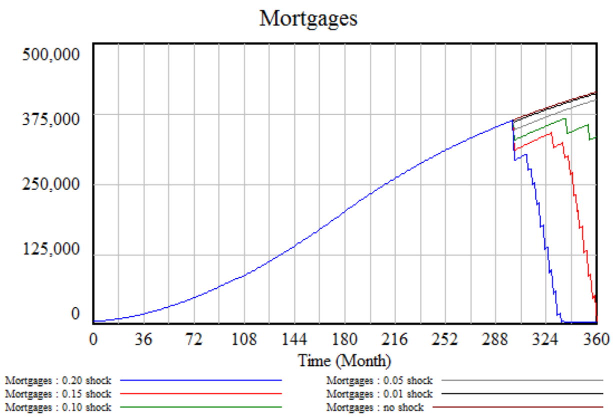

Figure 21. Mortgages under shock without run on RMBS notes.

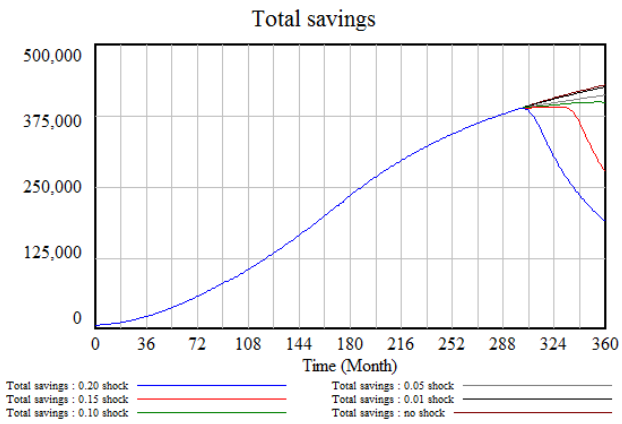

Figure 22. Savings under shock without run on RMBS notes.

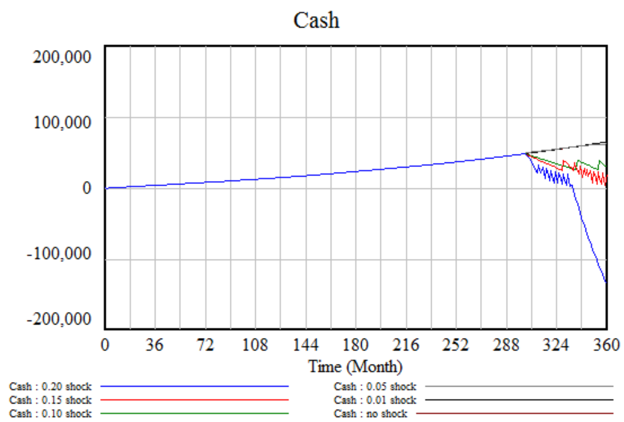

Figure 23. Cash under shock without run on RMBS notes.

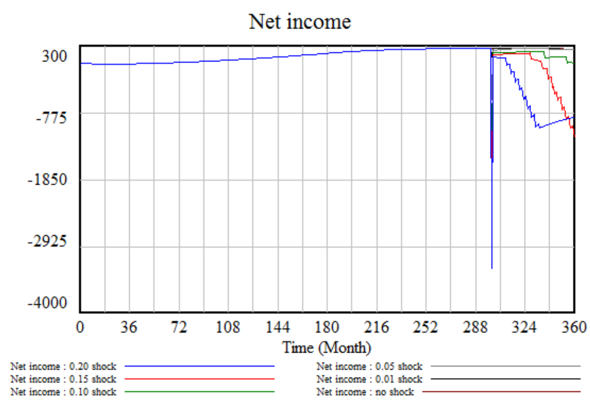

Figure 24. Net income under shock without run on RMBS notes.

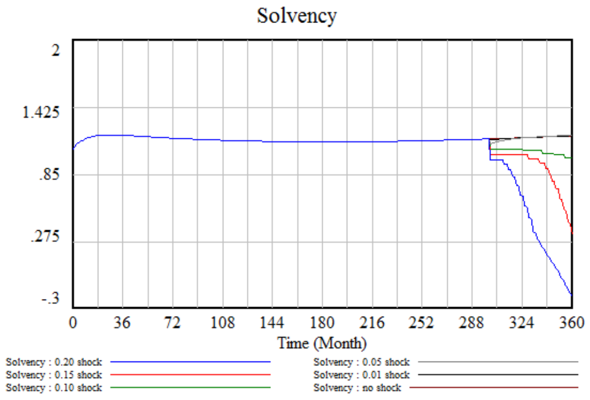

Figure 25. Solvency under shock without run on RMBS notes.

Next, what happens to the other two banks and the investment pool is shown. As can be seen from figure 26, the total investment pool shrinks somewhat. This is mostly due to the fact that equity and outstanding RMBS notes decline. The sharpest decline is from 1.1 million to 0.9 million. This shock could indicate serious issues for investors. The smaller shocks are less important, but it is clear that investors do lose money and quite a substantial amount too. The shock for the other two banks is mainly one on net income. Net income does see a decline of about 10 percent in the 20 percent scenario, but this does not endanger the profitability, solvability or liquidity of the bank. There is a slight decline in the return on equity too as net income drops. Although there are slight declines in solvability, liquidity and profitability for the 20 percent scenario for bank 2 and 3, these changes will not endanger the system in any way. They are almost not worth mentioning. The first bank will fall here, the investment pool will take some losses, but it will not cause the other banks to fail as well.

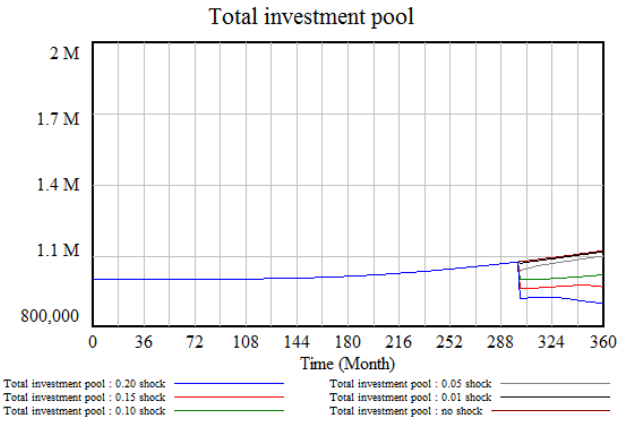

Figure 26. Total investment pool without run on RMBS notes.

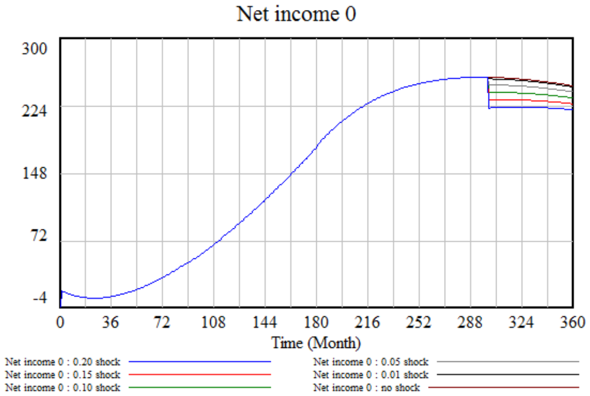

Figure 27. Net income bank 2 and 3 without run on RMBS notes.

6.4 Shock with run on RMBS notes

In the following, the results of a shock with an ensuing run on RMBS notes will be presented. These shocks, again, are 1 percent, 5 percent, 10 percent, 15 percent and 20 percent. Important to note is that in this first scenario, 50 percent of the value of fire sold mortgages is gained as cash.

The stock of mortgages for bank 1 as can be seen in figure 28 completely depletes due to fire sales required to improve liquidity. In three years, even in the scenario of 1 percent, bank 1 completely collapses. At time=300, all RMBS notes have to be bought back and sold back to the issuers, resulting in a large decrease in cash and an increase in the stock of mortgages. To mitigate the decrease in cash, assets are fire sold, which increases cash and makes the bank liquid again. In figure 29, the decrease and increase in cash can clearly be seen. In the end, the bank is rendered insolvent, illiquid and unprofitable as can be seen in figures 29, 30 and 31. Important to note here is that the process goes very quickly. For the three most serious scenarios, the bank is practically bankrupt after a few months. In none of the scenarios, this bank can mitigate the effects on itself.

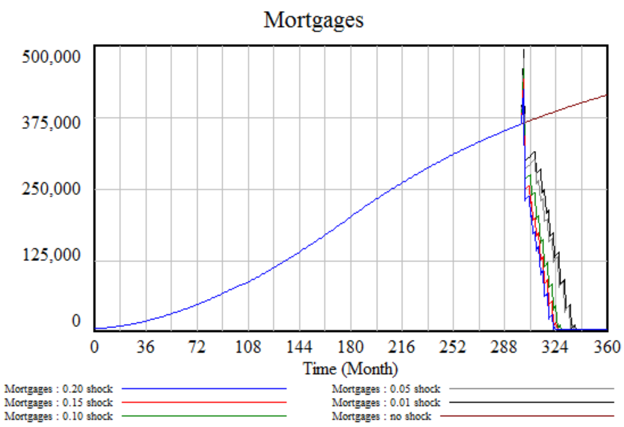

Figure 28. Mortgages with RMBS run.

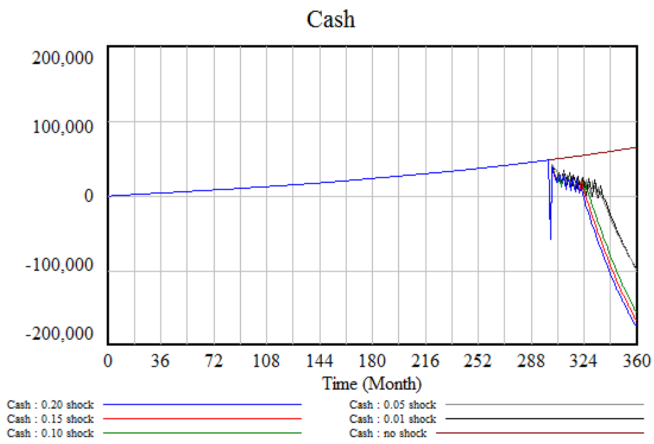

Figure 29. Cash with RMBS run.

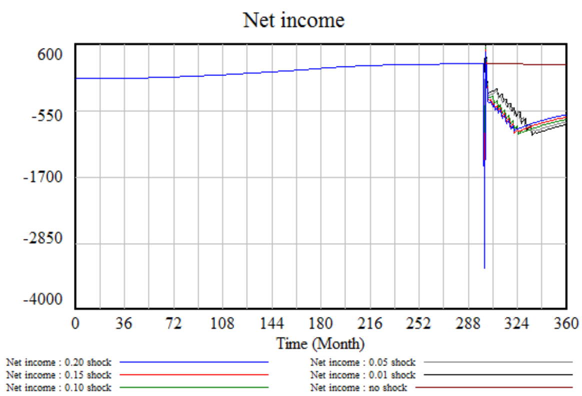

Figure 30. Net income with RMBS run.

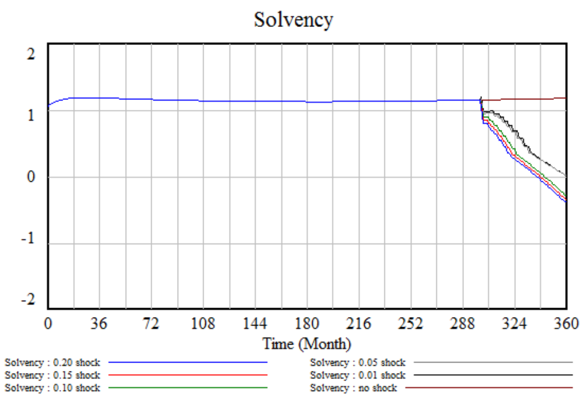

Figure 31. Solvency with RMBS run.

Next, the effects on bank 2 and 3 and the investment pool will be described. The shock on banks 2 and 3 is now really prominent. Since the same kind of shock now hits all banks, namely the run on RMBS notes, banks 2 and 3 suddenly also fail. As can be seen in figures 32 to 35, the mortgages of bank 2 and 3 drop sharply as they have to sell their assets in order for the bank to remain liquid. It can be seen from the cash position, the solvency and the net income that bank 2 and 3 suddenly are liquid, profitable nor solvent anymore. The run on RMBS notes would thus cause the entire system to fail. In the figures, the lines fall together which makes it look like there is only one line shown here. This is due to the nature of all banks being completely equal.

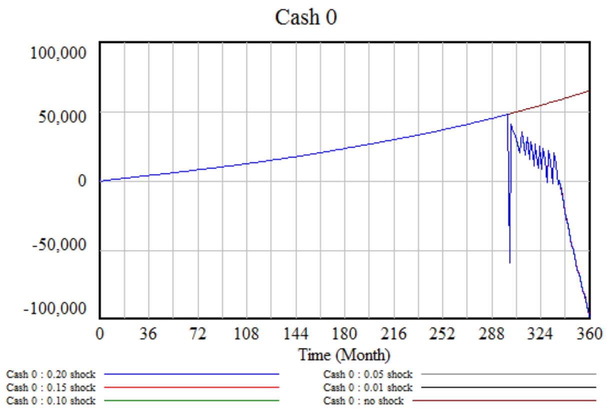

Figure 32. Cash with RMBS run bank 2 and 3.

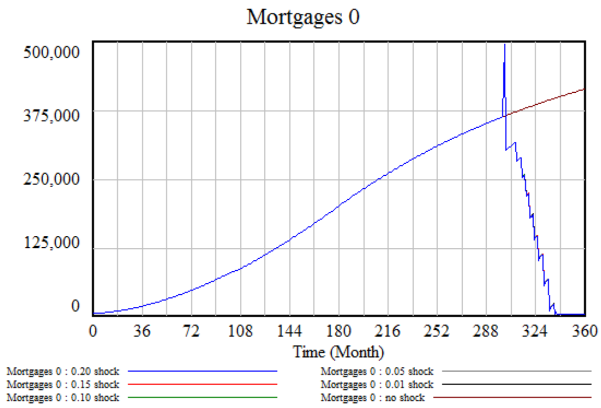

Figure 33. Mortgages with RMBS run bank 2 and 3.

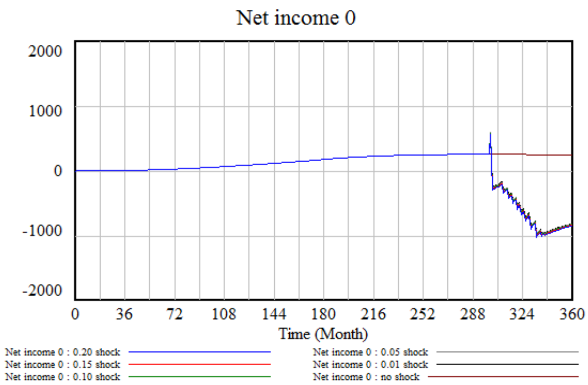

Figure 34. Net income with RMBS run bank 2 and 3.

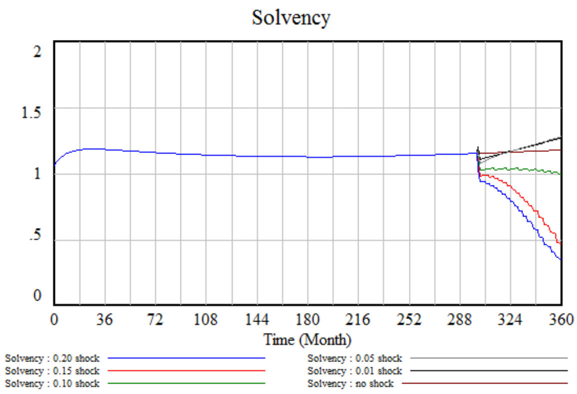

Figure 35. Solvency with RMBS run bank 2 and 3.

The effects on the total investment pool are also clear and more severe. Where in the first scenario the investment pool recovered from the effects of the collapse of one bank, now, there is clearly a downward slope for the total investment pool. All in all there is, in the 20 percent scenario, a loss of almost 36 percent after five years which can be considered a heavy decline in investor value. But even in the 1 percent scenario there is a sharp decline in the investing pool value of 19 percent over five years which is really severe. It can clearly be seen in figure 36 that the investment pool suffers heavily from the failure of these three banks.

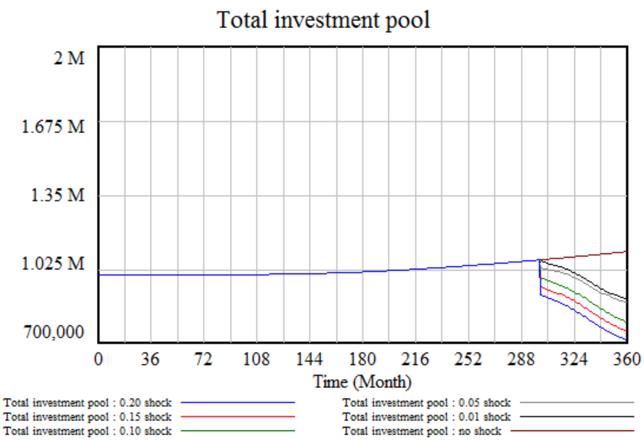

Figure 36. Total investment pool with run on RMBS.

Now the same scenario will be played out wherein the fire sale of assets get 70% of the value in cash. The results are staggering. For bank 1, as can be seen from figure 38, this slight adjustment means that it suddenly survives the 1 percent, 5 percent and 10 percent scenarios again although the 10 percent scenario comes dangerously close to failure. The 15 percent and 20 percent scenarios, as can be expected, still cause bank 1 to fail. Bank 1 still becomes insolvent, illiquid and unprofitable in the 15 percent and 20 percent scenarios as can be seen from figures 38 to 40. In the 10 percent scenario, the bank becomes unprofitable, but not insolvent or illiquid. This could mean that with good management, bank 1 might pull through.

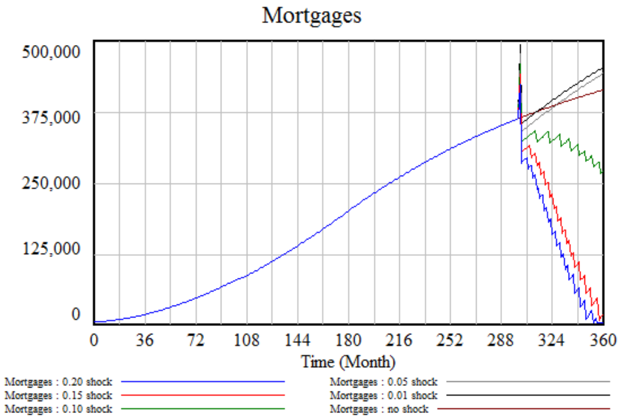

Figure 37. Mortgages with RMBS run.

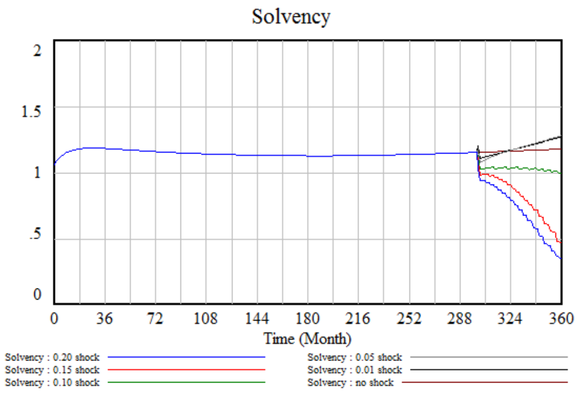

Figure 38. Solvency with RMBS run.

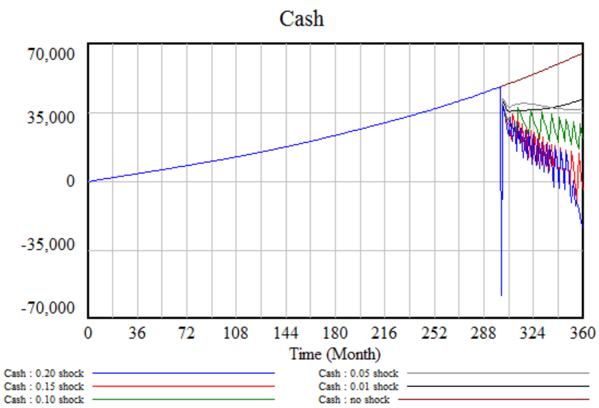

Figure 39. Cash with RMBS run.

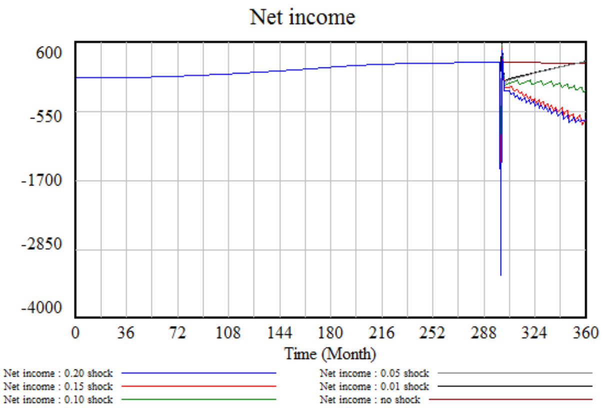

Figure 40. Net income with RMBS run.

Next, the results of bank 2 and bank 3 will be shown. What is immediately clear is that when the fire sale yields more cash returns, bank 2 and 3 actually pull through. Only one fire sale is required for these banks to push their cash position back to the requirements. After that, mortgages are increasing too which is due to the fact that the securitization of mortgages has halted and thus, more mortgages are kept instead of sold. A small funding shortage is developed though, but this should not be a problem in the real world where more investors could be attracted or mortgage production could be slowed down. The banks remain profitable, liquid and solvent though after the run and fire sales. A light shock on the system does not cause the entire system to fail then. Solvency increases slightly too because securitization is halted too.

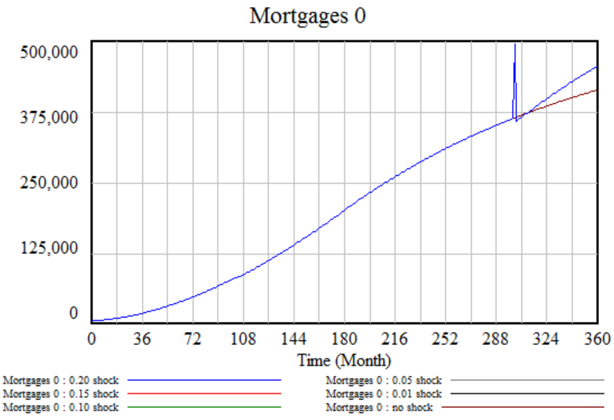

Figure 41. Mortgages with RMBS run bank 1 and 2.

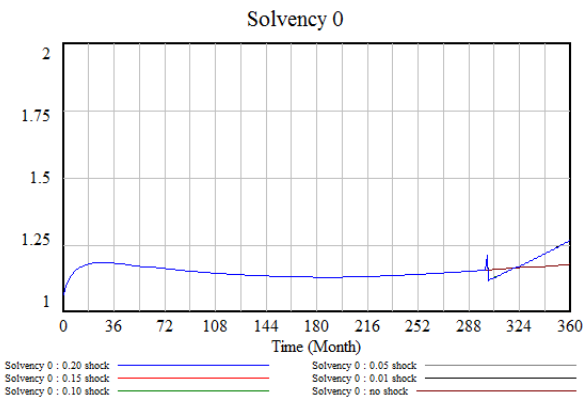

Figure 42. Solvency with RMBS run bank 1 and 2.

The effects on the investment pool, however, are still pretty hefty. Although much less heavy than in the scenario where all banks failed, there is still a sizeable decrease in the value of the total investment pool. In the 20 percent scenario, the investment pool loses 25 percent of its value over 5 years. In the 1 percent scenario, the investment pool loses 6 percent of its value over five years. In the heaviest scenario, this is still a really substantial amount of this pool. In the lightest scenario, this is a percentage that can be overcome, but not one happily seen by investors.

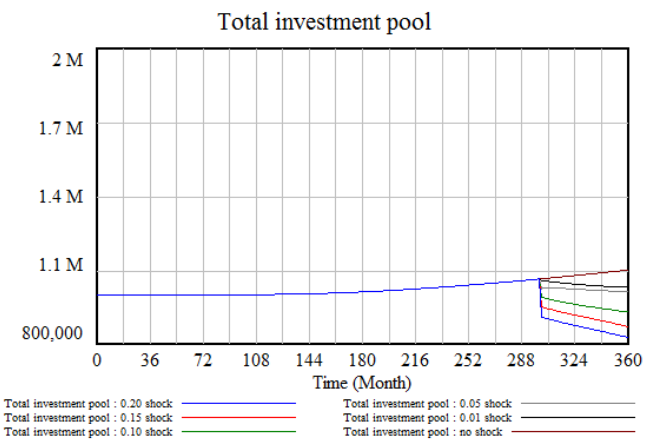

Figure 43. Total investment pool with RMBS run.

7. Conclusion

The research question was: ""Which national banking structure explains financial behaviour observed before the 2008 financial crisis? To what extent and in which scenarios does a shock in mortgages lead to the failure of one bank and subsequently a national banking system and investment entities?". Sub-questions to this question were:

- Which structure describes the behaviour of a bank before the 2008 financial crisis?
- Which structure describes the behaviour of a banking system before the 2008 financial crisis?
- How large must a shock on the mortgages of one bank be to cause that bank to fail?
- How large must a shock on the mortgages of one bank be to cause another bank to fail?
- How large must a shock on the mortgages of one bank be to negatively influence investment entities?
- In what scenario will a shock on a bank be able to cause the system to fail?

Before answering the research questions, it will be shown here first what the answers are to the sub-questions. The building of the structure of a bank before the financial crisis of 2008 has been shown in chapters 4 and 5. There, it has been shown what the model of one bank looks like and also why that structure is valid. In chapter 2 and 3 it was shown how that structure would be built and what it was going to look like.

For the second question, it was shown in the simplified model how one bank model would translate into a banking system. This was also explained in chapter 2.

For the third question, it was shown in chapter 6.3 that a bank would fail when a shock of at least 10 percent was imposed upon it. The shocks of 15 percent and 20 percent will most certainly cause a bank to fail.

The fourth question can be answered quite simply. It was shown in chapter 6.3 that a shock on mortgages of one bank would not cause another bank to fail.

For the fifth question, it was shown that in the case of the 15 percent and 20 percent shock, investment entities would be negatively influenced. However, this would most likely not incite a crisis in investment entities on its own.

The last question was shown in chapter 6.4. In the scenario of a run on RMBS notes, the banking system would most likely fail. The shock on one bank causes, through the inciting of a run on RMBS notes, the failure of a bank 2 and 3.

So what do these results actually mean? Well, a shock of 20 percent, 15 percent or ten percent is very unlikely to happen. This does not mean that it is not interesting to see what magnitude of shocks a bank could survive. The shock to Lehman Brothers which some argue to be the real start of the crisis was a shock of a little over one percent of their assets. It had to write of 5.6 billion on a balance of about 500 billion.

When introducing the RMBS run, a lot of interesting things happen. First and foremost, the possibility arises that the first bank and, consequently, the entire system fails with large effects on the investment pool. The magnitude of the shock on one bank becomes much less important as the shock itself induces a run on RMBS notes. The shock on the first bank can be as small as 1 percent and the system fails. However, when fire sales yield a high enough return, the system is saved from failure. The effects on liquidity from the buy-back of RMBS notes can be mitigated in that case. The important thing of note here is that this can only happen when fire sales yield a high enough return. The other possibility would be to acquire liquidity through other means. It hinges so much on the returns of fire sales, that the survival of the system could be said to solely be dependent on fire sales generating enough returns. The difference between a value of 50 percent returns to 70 percent returns means the difference between a total failure of the banking sector and the total survival of the banking sector. It could be argued that if everyone knows this, then banks will just agree that they need a high enough return to survive. The problem here is that since the entire industry has is in turmoil, these returns cannot be guaranteed by the sector since everyone is in trouble. The financial input thus has to come from a player outside the banking sector. Coval & Stafford (2007) confirm that this is usually what is required.

In Bankistan, there is no active government or central bank. In the real world there are several. The three most important actions governments and central banks took were 1. extra guarantees on savings (i.e. 'Depositogarantiestelsel Rijksoverheid' (Wet Financiëel Toezicht, 2007)), 2. guarantees on securitized mortgages (i.e. 'Housing and Economic Recovery Act'(2008)) and 3. providing cheap liquidity for banks (i.e. Term Auction Fund (Federal Bank of Reserves, 2007)). When looking at what the banking system of Bankistan required to survive there are a few possibilities: preventing bank runs, getting cheap liquid assets or selling of mortgages for the right price. The first intervention helps preventing bank runs, since deposits are guaranteed by the government. The second intervention means that less mortgages have to be written off or at least for smaller percentages. The third intervention provides liquidity to banks. When comparing the real life measures with measures that could have saved the system of Bankistan, there is remarkable overlap. Apparently the measures required to save Bankistan were the measures governments and central banks took to ensure the survival of the system. If the system would have been left to its own with the decrease in value of RMBS notes with 65 percent, the system would probably have failed. This value of 65 percent would mean that fire sales would have only yielded a 35 percent return in the model. This is much lower than the 50 percent used in the model that resulted in total system failure.

From this, it can be concluded that the shock in mortgages was indeed an important factor in the financial crisis of 2008, but not directly. The shock in mortgages induced a run on RMBS notes that created large liquidity problems with a lot of banks. Where the liquidity problems in the model were fixed with fire sales and resulted in failure, the liquidity problems in the real world were fixed with the measures described above. Although the result of the shock on the model, namely total system failure, was not observed during the financial crisis, the measures required to save it from failure were observed. Thus, the behaviour of the model describes what would have happened to the banking system, were it not for ‘unprecedented interventions’ (Crotty, 2009).

8. Discussion

The strength of the conclusions that were drawn is limited to the assumptions that had to be made in order for the model to work. In the chapter 4.2, important assumptions were discussed and also explained. Furthermore, the assumptions surrounding the land of Bankistan were no inflation, no ties with other countries, the existence of only three banks and passivity of investors who will take any investment as long as it yields positive returns. Also, there are no deposit guarantees and a passive central bank. In the real world, this is obviously not realistic. If the effects of these assumptions were to be tested, they would have to be added to the model. For the purpose of this thesis, this was not required. For future research, it could be interesting to see if the model could also provide insight into other types of crises such as monetary crises. There would probably be a need to further expand the model if researchers want to use it for that.

In this thesis, Acharya & Richardson (2009) were proven right in the assessment they made with regard to how the crisis happened. The contribution of this thesis to the literature can be seen as a confirmation of the issues pointed out by Acharya & Richardson (2009). Next to that that, the model that was built might be able to be used to explore other parts or issues with regard to financial systems too. Although the scope of one country might seem limited, the effects in one country can be indicative of important relationships in the outside world too. Where one could argue that the role of certain effects is not clear in the real world because there are more factors involved that could have an influence too, the role of certain effects is much more clear in a closed setting with clear boundaries to the system. The role of a model is also to try and quantify what other authors speculate about and try to make it work in coherence with other factors. In the personal opinion of the author, until you can prove or simulate the effect of a certain variable on another variable or a system, naming different possible causal relationships is useful only to the extent that these relationships can then be tested. Thinking of new reasons is easy, proving them is not.

The assumptions with respect to perceived health could potentially weaken the conclusions drawn, because its affect could have been over-or underestimated. As shown before, research did show that it was an important factor in the crisis and also a factor that determines whether bank runs will happen. This variable is specifically addressed, because future research into this variable could provide valuable insights for modellers. It is a concept that is not that hard to grasp, but seriously hard to model. The fact that it has an effect on the banking system is clear, the precise strength of this effect is not. Since a dummy had to be made for this variable and because it has an important effect on the banking system, it is a valuable topic for future studies.

The interventions that were used by governments and central banks used in the conclusions are not the only interventions done during the crisis. The interventions shown are, however, highly applicable to the situation that is created in the model. The strength of the effects of these interventions is hard to measure and it is unclear whether they even helped at all, but the model show that these were the interventions required to keep the model from failing.

There were more reasons for the financial crisis that could have been explored. Other reasons would have to be explored in future research though. The purpose of this thesis was to try and explain behaviour of the system during the financial crisis and to show the effects of a shock on the system via mortgages.

For the research design, the choice was made to go with modelling and to try and prove Acharya & Richardson (2009) right or wrong in the argument that they presented in their article. This was done by building a model, but other techniques might have also been appropriate such as a more extensive literature study on the topic or qualitative research with experts from the field in an interview setting. The choice for a model came from the possibility of doing GMB sessions and expert modelling. A model can provide a lot of insight and hard outcomes into what is or isn't true. Obviously, models are also limited as they cannot keep taking new things into account. When trying to model the real world, one will, in the end, be unable to make sense of what was built. Thus, models look at a part of a larger system and explore what happens to that part of the system. Also, in the SD philosophy, the structure of the model drives behaviour. The structure of the model should, in the end, show the same kind of problematic behaviour as can be observed in the real world and for the same reason. The lack of problematic behaviour to build the original banking model made validation harder. Even if the data in tables 2, 3 and 4 were normalized and used to build a reference mode, it would have been hard, because none of the data cover a time span of 25 years. Next to that, the behaviour of banks from 2007- cannot really be used as that is when the crisis happened. That would mean that the largest series of normal bank growth was 4-7 years which is too short to provide a meaningful reference mode.

For the model itself, there are a few limitations as well. Some of the elements of the model do not really have a role in the model right now. These elements are the macro-economic factors, bonds and consumer lending. The effect of these elements as well as other elements that can be found on the balance sheet of larger banks such as trading commodities and repurchase agreements could be further expanded upon in future research.

The conclusion of the research is clear: the shock itself does not cause the banking system to fail, but it could have induced a run on RMBS notes that would have caused the banking system to fail if not for certain government interventions. These interventions are the logical actions that should be taken by the government to prevent the banking system from failing. These were also the interventions that were observed in the real world. Some authors such as Taylor (2009) would argue that these interventions were not the right ones. He talks about counterparty risk vs. liquidity problems. For future research it would be interesting to expand the model to be able to include these notions to explore the validity of statements like these.

The thing about this research is that, in relation to other researches, the data used and coming out of a model is different from the data used in other researches. It is important to note this as the data used in most other researches was usually linking causality to trend data and data over time. Ups and downs in data are linked causally to reach a conclusion about what causality was probably there. In a model, this causality is tested in a setting wherein possible conclusions can be reached and proven from a model. Taking into account the limitations of a model in itself, the outcomes of a model are much different from outcomes of for example empirical or statistical research.

Last, the anonymity of the bank where the GMB sessions were done is kept here. This is done because of the confidentiality agreement that was signed by the author. The results can be used, but the bank and the experts working in the GMB sessions will not be named.

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