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Monetary Reform: System Dynamics Modeling of Full Reserve Banking System

Technical and conceptual specifications of the Full Reserve Banking system model and an analysis on the effect of the Full Reserve Banking system

Master of Science in Engineering and Policy Analysis

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Faculty of Technology, Policy and Management

Delft University of Technology

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Technical and conceptual specifications of the Full Reserve Banking system model and an analysis on the effect of the Full Reserve Banking system

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Preface

This research has been motivated to understand better the full reserve banking system using system dynamic model. The current monetary system and Full Reserve Banking system as an alternative of the current monetary system have been an interesting topic to study for me. It was a challenging but a fascinating field to study.

This study is a product of my great passion in the field of economics. I have learned a lot doing the research. This research is intended to give an insight for the further quantitative study on the full reserve banking system. As Van Egmond and De Vries's model is appreciated for including a complicated households default mechanism and house price fluctuations, the improvements of the model are expected to increases the usefulness of the model.

I would like to thank the graduation committee who helped me to finish this research. They provided me valuable guidance and advices to complete this thesis. I would also like to thank Prof. ir. Klaas van Egmond and Prof. dr. Bert de Vries for offering me their model to do the research and dedicating their time for me to answer many questions that I have asked. I would like to thank Prof. Kaoru Yamaguchi for offering his model which helped me to find model problems in Van Egmond and De Vries's model.

I would also like to say thank you to my boyfriend, friends and family for their great support during this journey. I would not have made it without their support. Furthermore, I would like to dedicate this thesis to the memory of my late grandmother. She is the kindest and the most heart-warming person I have ever known and will ever know.

Although it was a long and hard journey, I have learned and grown through this journey. I would like to thank everyone who has supported me academically and emotionally during my research.

Boeun Park

Delft, November 2018

Summary

In this thesis, the System Dynamics (SD) model of the Full Reserve Banking (FRB) system built by Van Egmond and De Vries (2016) has been reviewed and improved. The improved model is used to see the effect of FRB system in preventing a long-lasting recession as one occurred in 2008.

FRB system is a monetary reform which has been proposed during the great depression and has been revisited recently after the financial crisis 2008. FRB system is an attempt to separate private banks' monetary and credit functions. In the current system, money is created when banks give loans in a form of bank deposit. Many scholars have suggested that a main cause of 2008 financial crisis is provision of too much bank lending which contributed to rising house prices (asset inflation) (Jackson, 2016; Krugman, 2014; Mellor, 2015; Positive Money, 2018; Turner, 2015; van Egmond & de Vries, 2016). It is suggested that money which is created when the loans were given was used to raise house prices and therefore, the household debt level increased as well. Excessive debt and repayment become a burden for households when the economy is in slump. The households default and following long-lasting recession are considered to be consequences of the excessive debt by some scholars (Positive Money, 2018; Turner, 2015; van Egmond & de Vries, 2016; Jackson, 2016).

Under FRB system, money creation is controlled by a central bank. Central bank increases, or decreases money depending on the price level. In Van Egmond and De Vries's model, FRB system is called Debt Free Money (DFM) system as the money creation and debt issuance are disentangled under FRB system. Under DFM system, banks are no longer able to give loans by creating money but can only give loans out of existing deposit.

Theoretically, DFM system can prevent recessions by maintaining the price level constant. When the price level goes down due to households default, the central bank creates more money and the government can use the money to expand their expenditure and decrease tax rate. When the price level goes up, the central bank decreases the money creation and the government can reduce the expenditure and increases the tax rate.

In the financial crisis 2008 when many households default on the bank loans, big banks that lost significant amount of outstanding loans were rescued by governments with a large amount of tax money. In DFM system, defaulted loans are written off not against the bank equity but against the deposit from which the loans were given. In this way, governments no longer have to bail out banks. Therefore, governments can spend more during recession in order to stimulate the economy.

Van Egmond and De Vries have modeled DFM system including the major economic agents such as consumers, firms, government and banks, using System Dynamics (SD) modeling technique. Their model has significance as it includes a complex relation between private debts and house prices unlike other SD models of full reserve banking system (Jackson, 2016; Mellor, 2015; Positive Money, 2018; Turner, 2015; van Dixhoorn, 2013; van Egmond & de Vries, 2016; Yamaguchi, 2010).

However, their model has a few model problems which reduce reliability of the model; Ⅰ) the model crashes in different conditions, Ⅱ) the model is based on some assumptions that are less realistic or logical Ⅲ) the measurement units of the model are not specified.

Therefore, the objective of this study is to fix the model problems and see the effect of DFM system to prevent recessions in the improved model. The thesis tries to answer the following research question:

How to improve the System Dynamics model of FRB system from Van Egmond and De Vries (2016) in order to give more insight into the effect of FRB system in the economy? How does this improvement change the model results and how does FRB system work in different scenarios of the economy?

In this thesis the solutions for these model problems were sought through a model review and desk research. The model problems are solved with the solutions found through the model review and desk research.

The improved model and the original model show different perspectives on how the recession is initiated and what contributes to the long lasting recession. In the original model, the recession is initiated when households default due to excessive house prices. Consumption level goes down and price falls when the households default. Furthermore, government reduces its expenditure and increases tax rate in order to fill the deficit in rescuing banks. The recession lasts until wage level falls low enough that firms start increasing employment. In summary, high house prices are a direct and definite reason why the recession begins.

However in the improved model, the recession is initiated when economic slump begins. High house prices and resulted excessive debts are not direct reasons of the recession but contributors for the recession to last long. In the improved model, the wage level increases fast during economic boom. The firms then start reducing the employment as the labor is too expensive. At some point, the labor demand of firms decreases further than the labor supply and the wage starts decreasing. Subsequently, the economic growth is stagnated as the consumption level and the price fall. During this economic slump, the households default on their debt as they cannot afford the debt repayments with their stagnated or fewer wages. This brings a long lasting recession in the economy.

In summary, the improved model shows that high house prices and debt level can make the economy vulnerable to economic growth stagnation.

According to the improved model, the Dutch economy entails a potential long-lasting recession as there is a possibility for price to fall as production (supply) is growing faster than demand and household debts grew exceptionally faster than wages.

DFM system can be a solution for this by sustaining the demand level with the government expenditures. In the improved model, it is shown that DFM system is effective in preserving the price level and therefore, eliminating the future recession. DFM system allows more money to be distributed through government expenditures and tax reduction when the economy is stagnated and in slump.

However DFM system is not effective in every circumstance in the improved model. DFM system is found to be not effective in stabilizing the price level when the firms' dividend payout ratio is high. Furthermore, DFM system was not necessary when the firms' dividend payout ratio is low.

In the model, price level remains very low when dividend payout ratio as low as around 30 - 40%. Because of this, the wage level also remains very low and house prices do not increase. The economy remains really stable showing no economic growth or slump. Therefore, DFM system is not necessary to stabilize price level. Thinking dividend payout ratio in reality is around 40%, this kind of behavior is unrealistic as the households defaulted during the economic crisis in 2007. When dividend payout ratio is high, around 60 – 70%, the price fluctuate too much DFM system fails to maintain the price level constant.

The reason that DFM system's effectiveness is decided by dividend payout ratio is because the model was calibrated by the Van Egmond and De Vries without considering the fact that the dividend plays such important role in the model. The model is calibrated only with dividend payout ratio of 100% which is unrealistic in the real world.

Therefore, the model still needs to be calibrated properly especially focusing on dividend payout ratio in a future work. Furthermore, the model does not include importation and exportation. As imported goods and services can play an important role in relationship between consumption level and price level, it is recommended to include trades with other countries in the model in further work.

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List of Abbreviations

FRB: Full Reserve banking

DFM: Debt-free Money

MaD: Money as Debt

MPI: Model Performance Indicator

SD: System Dynamics

GDP: (nominal) Gross Domestic Production

RQ: Residence quote

01 Introduction

1. Introduction

1.1 Introduction to the current monetary system

What is money? The first thing that would come up in everyone's mind is cash, such as coins or bank notes. However, in current monetary system, money in a physical form is only less than 3 percent of entire money (Positive Money, 2018). 97 percent of money exists as bank deposits in bank accounts. Then where does this money come from? Unlike commonly thought, most money is created not by central bank but by commercial banks (Jackson, 2016; Mellor, 2015; Turner, 2015).

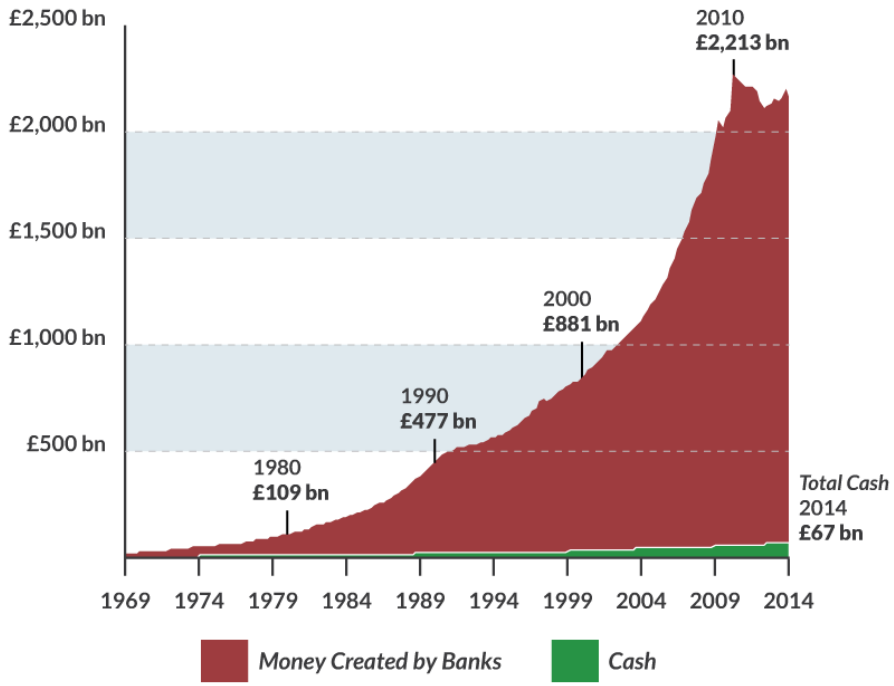

Fig 1. A graph of money created by commercial banks as deposit (red) and money created by central bank as cash (green). Reprinted from positive money, by n.d., 2018, Retrieved from www.positivemoney.org.

Money is created as bank deposit following the below process (Ryan-Collins, Greenham, Werner & Jackson, 2011):

1. When a customer wants to take a loan from a commercial bank, the bank does not use the money that is deposited by the other customers. Instead, they make a bank account for the borrower and put the requested amount of money (loan) in it. In this case, the money is not taken from somebody else's deposit but just created by the bank. The borrower can spend this money in the market of goods and services and the money moves from the borrower's bank account to other's bank accounts. In this way, the money is put in the circulation within the economy moving from one bank account to the other. When the borrowers repay their loans to the bank, the money comes back to the bank (see fig 2). Therefore, money is created out of loans and destroyed when they are repaid.

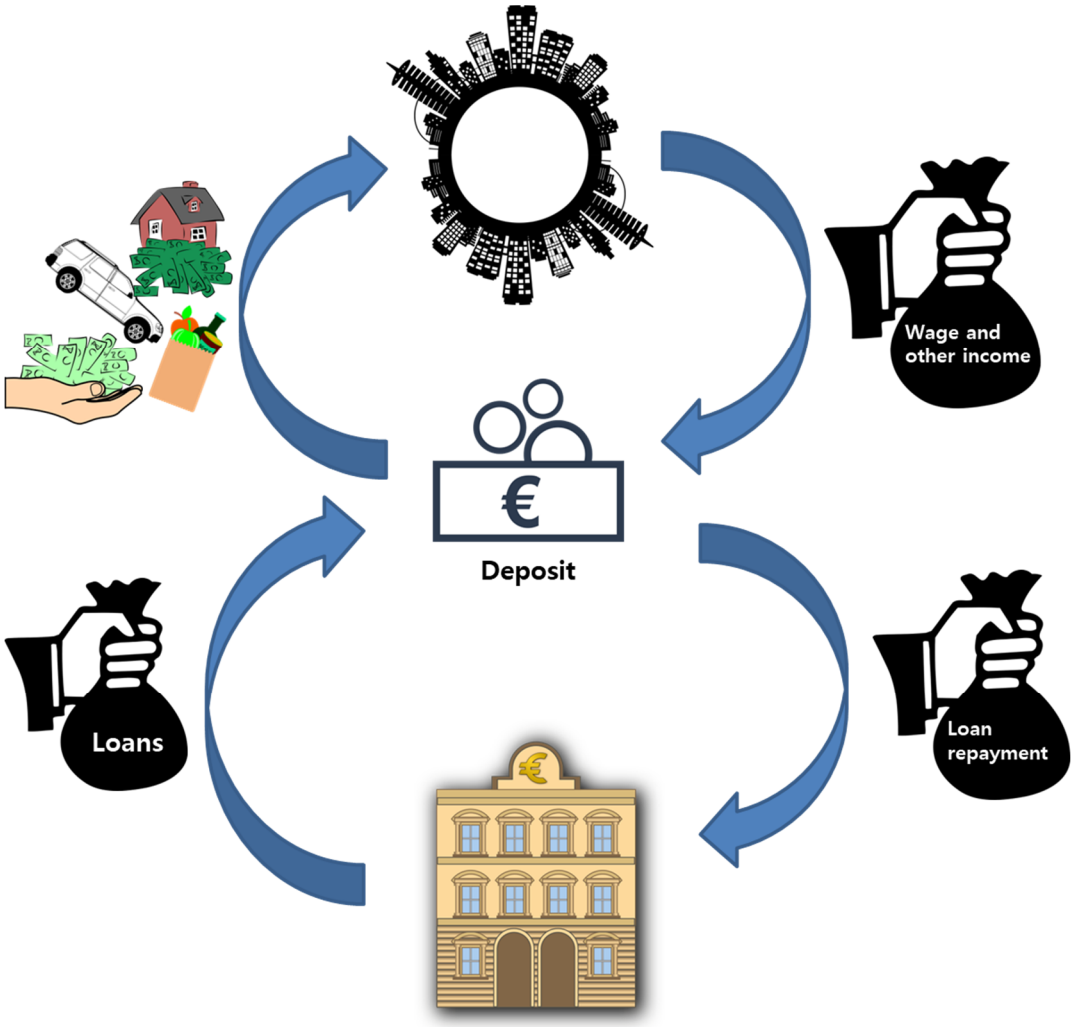

Fig 2. Money circulation. Money is created by banks and given to borrowers as loans. The borrowers use money in the market of goods and services. Money comes back to the banks when the borrowers pay back their loans with their income.

2. Below figure 3 shows that the most of household debts were mortgage since 1997 in England. This means that the most of created money is used to buy houses. Figure 4 shows that the mortgage has been increasing since 1995 in the Netherlands.

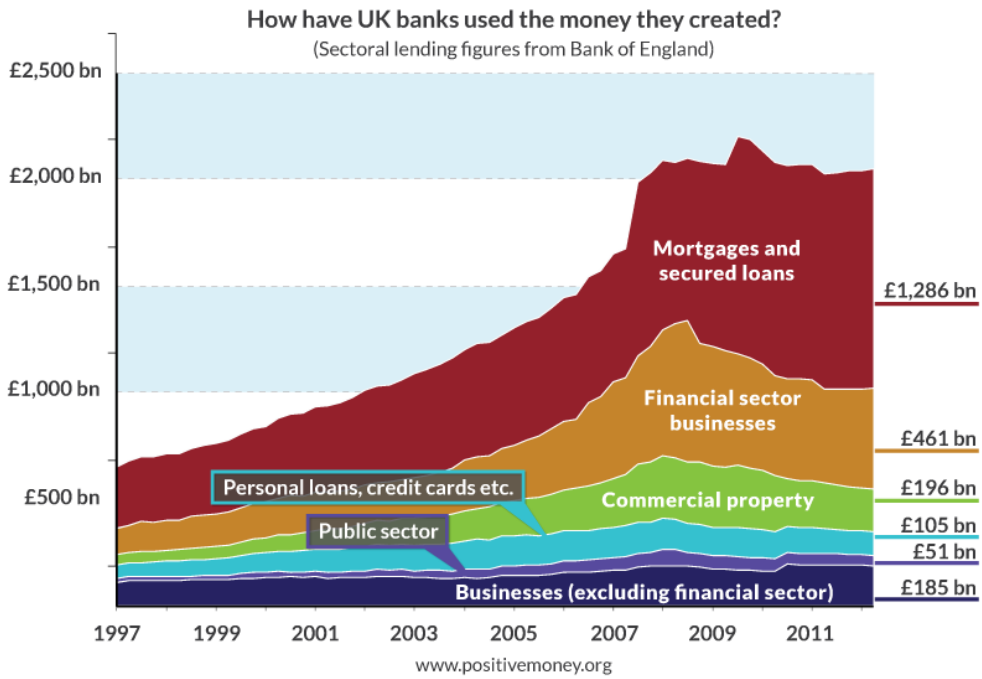

Fig 3. A graph of the sectors where the created money is used in the UK. Reprinted from "How have UK banks used the money they created?", by Positive Money, 2018, Retrieved from www.positivemoney.org**.**

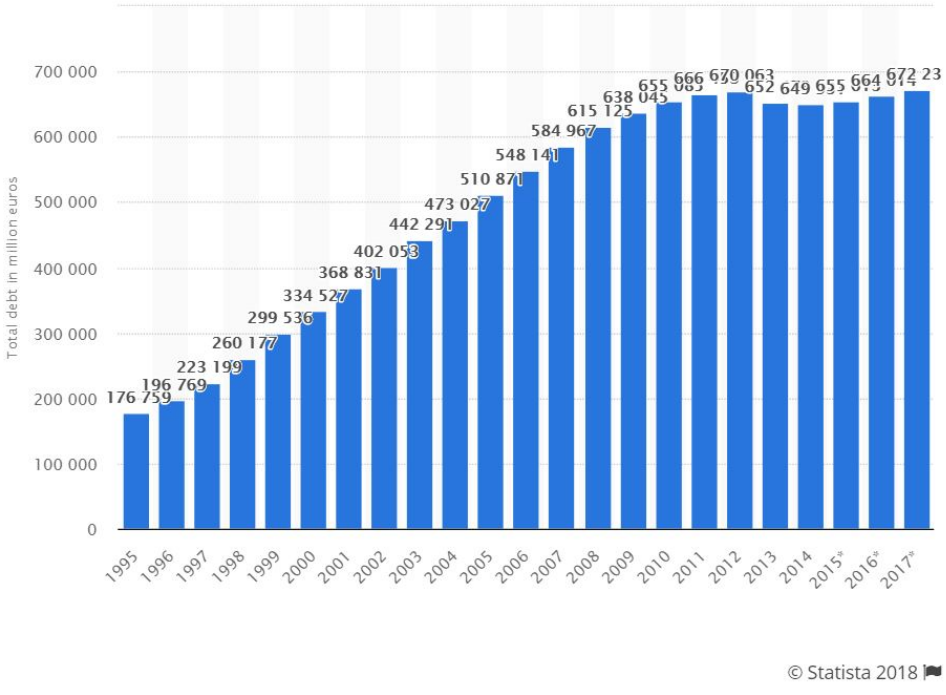

Fig 4. Mortgage increase graph in the Netherlands. Reprinted from "Netherlands: mortgage debt 1995-2017", by Statista, 2018, (https://www.statista.com/statistics/590299/total-mortgage-debt-from-households-in-the-netherlands/).

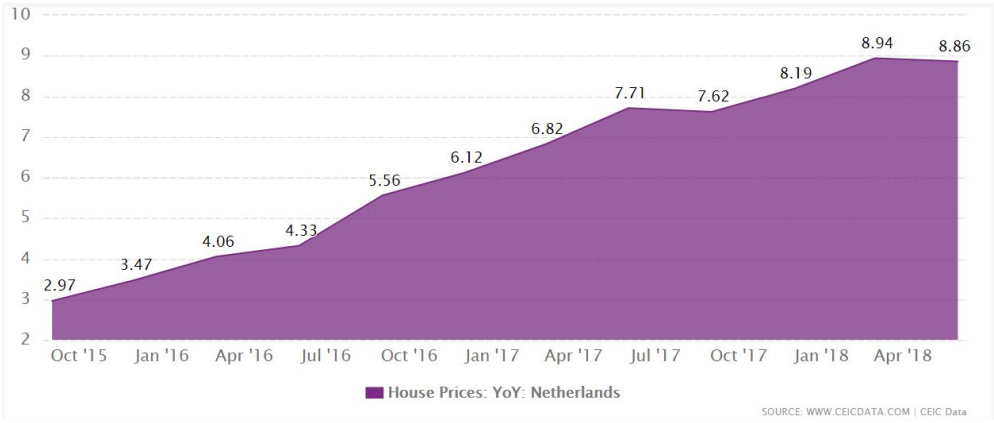

Fig 5. House price increase graph in the Netherlands. Reprinted from "House Price", by CEIC, 2018 (https://www.ceicdata.com/en/indicator/netherlands/house-prices-growth).

3. When people demand houses and borrow more, house prices increase. Figure 5 shows that house prices increased from 2015 to 2017 and figure 4 shows that the mortgage has increased in that period as well. When demand on houses increases, the prices increase and when the prices increase, they attract speculation (Zheng, Wang, Wang, & Wang, 2017). Not only people who are looking for a house to live but also people who are looking for a chance of high-return investment start buying houses with an expectation that they can sell them in higher price in future. This accelerates the house market boom. A borrower who intends to buy a house has to take a bigger loan when house prices increase. Therefore, a positive feedback loop is created between house prices and private loans (mortgage) as shown in below figure 6.

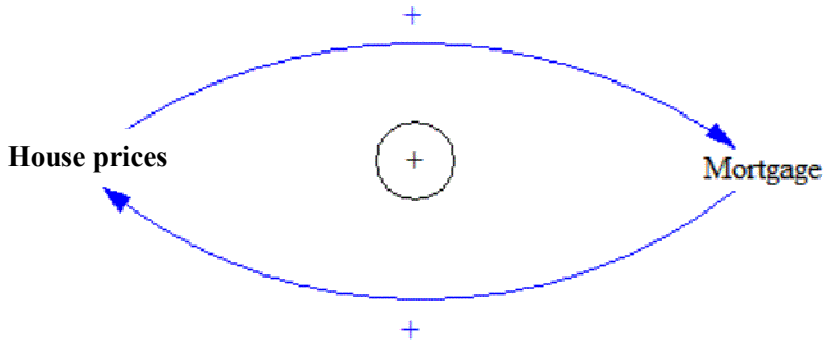

Fig 6. A positive feedback loop between house price and debt (mortgage) level.

4. When there is an expectation that house prices will keep rising and therefore, wealth will be expanded, the households spend more and the economy is in boom (Andersen, Duus & Jensen, 2016). The borrowers can demand more money because banks are less sensitive to the credit risk during the economic boom and supply more money.

Minsky (1970) has argued in his paper, "Financial Instability Revisited: The Economics of Disaster", that the successful functioning of an economy will inevitably lead to 'euphoria', in which expectation grow irrationally high. Once euphoria sets in, financial institutions tend to accept a risky credit that, in a normal situation, they would have rejected.

Therefore, the amount of the money created depends on how the banks see the current economic

state. During the economic boom banks foresee that the households default risk is low and create more money. In contrast, during the economic recession, banks are reluctant to give loans and thus they create less money.

5. Another reason that banks become less sensitive to the risk when they give loans is because the government bails out banks if they become insolvent. When debts increase too much and households cannot afford the debt repayments with their income, households default on their debt. Banks then have to write off a large amount of the outstanding loans which are their asset. After losing a significant amount of asset, the banks become insolvent and are put in risk of a bankruptcy. In a fear of a tragic consequence of big banks' insolvency, government bails out the big banks by injecting money into the banks so that the banks can avoid the insolvency. During financial crisis 2008, governments bailed out many big banks that were close to insolvency (Haldane, 2012).

When governments spend a lot to bail out banks, government debts increase and they inevitably have to decrease other expenditures such as investment on infrastructure or social payment. This worsens the recession.

In summary, the danger of the increasing private debts is that it can cause a mass households default. The household debt increases when house prices increase and house prices increase when the household debt increases. This vicious loop continues until the debt level exceeds a certain point that the households cannot afford with their income. If the debt level goes beyond what the households can afford or households' income does not grow as fast as the debts do, households are left with a huge amount of debt repayments that they cannot afford (Turner, 2015). The households then default on their debt and the debts are written off by the banks. The government bails out the banks that lose a large amount of the asset loans. In order to bail out the banks, the government uses a significant amount of tax income and subsequently, it has to contract spending in, for example, infrastructures and welfare system.

There is a risk that the consumption level of households decreases significantly due to the excessive debt repayment when private debts increase disproportionately. Together with the decreased government spending, the lower consumption level puts the economy in a long-lasting recession when households default (Turner, 2015).

1.2 MaD and FRB system

After observing the households default and the government bail-outs during 2008 financial crisis, Full Reserve Banking (FRB) system has been revisited and reconsidered as an alternative of the current monetary system by numerous economists (Benes & Kumhof, 2012; Jackson, 2016; Mellor, 2015; Positive Money, 2018; Turner, 2015; van Dixhoorn, 2013; van Egmond & de Vries, 2016; Yamaguchi, 2011). In FRB system, commercial banks cannot create deposit (money) in order to give loans. They can only give loans from existing deposits. In this way the banks' money creation power is taken away.[1]

Since the banks cannot create money, money is created in a different way in FRB system. In FRB system, money is created by the central bank[2] based on price level[3]. The created money is used by the government and channeled into the real economy. Van Egmond and De Vries have clarified two ways[4] for governments to channel the created money into the real economy:

- By spending: Money can be invested directly in democratically chosen projects without interference of the financial system. Such investments can be in physical infrastructures (renewable energy, transportation etc.) and social infrastructures (health, education etc; in this thesis, it is called "social payment"). This will increase aggregate demand[5] and stimulate the economy (Keynes, 1964).
- By tax reduction: The government can reduce the tax rate. By doing so, not the government,

[1] In more detailed theory, the banks have to keep full amount of the clients' demand deposit. The demand deposit is the deposit that the depositors can withdraw in any time when they need money. The banks, instead, can utilize the time deposit to give loans. The time deposit is the type of deposit that is promised not to be withdrawn for a certain period on condition that the higher interest rate is applied on the deposit.

[2] The prior researchers on FRB system, such as Van Egmond and De Vries (2016) and Yamaguchi (2011), have specified that a new type of public institute will be required for the money creation. Van Egmond and De Vries have argued that the institute is a distinct governmental body (e.g. a Reformed Central Bank – RCB), as a separate (4th) power of government. Yamaguchi specified that the structure of the current central bank has to change to create money. In this study, it is assumed that the money is created by the central bank for the simplicity.

[3] The price of goods and services in the economy is decided by difference between demand and supply. If the demand (consumption, investment and government spending) is higher than the supply (goods and services production), the price goes up and vice versa.

[4] In there paper "Monetary Reform: dynamics of a sustainable financial-economic system", Van Egmond and De Vries have referred three ways instead of two. However, the last option, "by lending to the commercial banks who in their turn commercially lend it out to finance the real economy", is not included in their model and therefore, it is ignored in this thesis.

[5] Aggregate demand = Consumption + Investment + Government spending + (Export – Import)

but the consumers (are expected to) stimulate aggregate demand.

When the price of goods and services is high and there is a risk of inflation[6], the central bank creates less money. The government then decreases its spending on physical and social infrastructure and increase the tax rate. In this way the amount of money in the economy reduces.

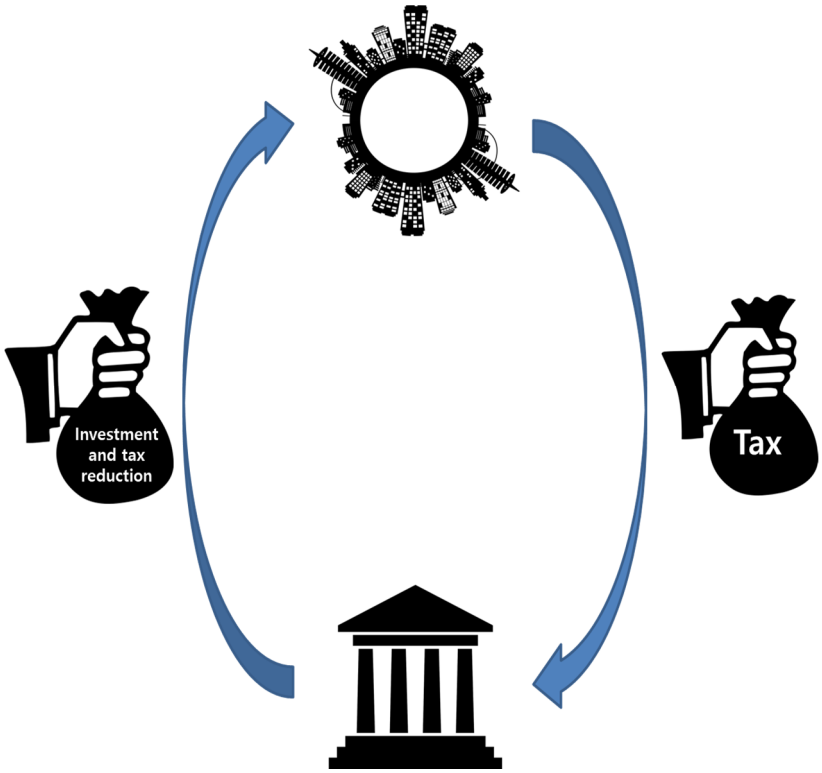

Fig 7. The money circulation in FRB system. When the price falls, money is created by the central bank and used by the government through investment in physical and social infrastructures or tax reduction. When the price level goes up, the central bank reduces

When the price of goods and services is low and there is a risk of deflation, the central bank creates more money. The government then can increase their expenditures and decrease the tax rate. In this way the amount of money in the economy increases and it pushes the price level up again. The figure 7 shows how the money creation is controlled by the central bank

FRB system can change the current monetary system in two ways. Firstly, the government no longer has to bail out the banks with tax. In MAD system, the loans were given from the banks' money creation. Therefore, when the households default on the loans the banks lose their equity[7] (Ross, 2018). The banks face the bankruptcy risk when they do not have enough equity and the government then has to bail them out.

[6] This is when too much money is in the economy.

[7] In accounting, equity (or owner's equity) is the difference between the value of the assets and the value of the liabilities of something owned. Alternatively, equity can also refer to the capital stock of a corporation (Wikipedia, 2018).

But in FRB system, the defaulted loans are written off against the deposit that the loans were given from, not against the banks' equity. In FRB system, the defaulted loans are written off against the deposit which is used to giving loans. Since the banks do not lose their equity the government does not have to bail out the banks when the households default. Therefore, when the households default, the banks lose their interest income from the defaulted loans and the depositors lose their deposit given as loans.

Secondly, the economy will not fall into recession because of the household defaults. In FRB system, the government does not have to bail out the banks and therefore, its expenditure and a tax rate are not affected by the households default. The government does not need to contract its spending on the infrastructures, social payment and other consumptions when households default.

Furthermore, in FRB system, the central bank can create money depending on the price level. When the consumption (demand) level decreases due to the households default, a deflation can be prevented by the central bank increasing the money creation. The price level is unharmed in such situation as the government will be able to spend more on the infrastructure and social payment requiring same or less tax income. In this way, the firms can maintain their employment level and the households also can maintain their consumption level relatively unharmed.

Therefore, even after the households default which causes both the borrowers and the depositors to reduce their consumption level, the economy will not be affected so much as the government will spend more and reduce tax rate in order to stimulate the economy.

1.2.1 History of FRB system

Many economists and organizations have been studying the effect of FRB system not only qualitatively but also quantitatively. FRB system is first introduced during great depression in 1939. At the height of the great depression, a proposal for a monetary reform has been released by eight Chicago based economists (Douglas et al., 1939). According to this plan, banks should hold 100% of their customers' current demand deposit. Therefore, this approach is called Full Reserve Banking. The proposal advocates that the money creation should no longer happen when commercial banks create loans. It insists that the money creation should be put under control of a public body by separating the monetary and credit functions of the banking system (Benes & Kumhof, 2012).

There are many different interpretations on the full reserve banking system, but all of them share the following three features (Yamaguchi, 2011):

- Complete governmental control over the issue of money
- Abolishment of credit creation by private banks with full reserve ratio of 100%
- Complete governmental control over the money flow to sustain economic growth and welfare

Irving Fisher (1936) claimed the following advantages for this plan: (1) Much better control of a major source of business cycle fluctuations, sudden increases and contractions of bank credit and of the supply of bank-created money. (2) Complete elimination of bank runs and bail-out. (3) Dramatic

reduction of the (net) public debt. (4) Disentangle the private debt from the money creation.

The proposal, however, did not result in any new legislation.

1.3 System Dynamics studies on FRB system – Van Egmond and De Vries (2016)

Although the Chicago plan has not been implemented as it is proposed, it has claimed an attention again in later times. It has been revisited particularly more after the financial crisis in 2008. In attempts to study the effect of FRB system, many scholars have conducted quantitative research on FRB system. In this thesis, a study from Van Egmond & De Vries(2016) was selected to research further. Reasons why their quantitative research on FRB system are chosen are as below:

- Van Egmond and De Vries have used System Dynamics (SD) modeling. SD modeling technique is useful to model a system which consists of groups of interacting, interdependent parts linked together by exchanges of energy, matter, and information. SD modeling can be a useful tool to computing the money exchange between different economic agents[8]. Furthermore, SD modeling is to model complex systems that are characterized by strong (usually nonlinear) interactions between the parts. Using SD modeling technique, Van Egmond and De Vries have effectively included and computed the linear and non-linear interactions between different economic agents in their model.
- House prices and household debt dynamics and "Minsky moment" are included in their model. In the SD model of Van Egmond and De Vries, it is possible to examine the effect of FRB system on the dynamics between the private debts and house prices. Minsky moment is when banks bankrupt due to the households default. Their model effectively computes the complicated process of the banks' bankruptcy and the government bail-out.
- The model includes both real economy (physical production) and financial system (monetary; banking) and a relation between them.
- The model is built based on the empirical data of the Netherlands.

[8] Economic agents in their model are consumers (households), firms, government and banks.

1.4 Introduction to the research problem

The attempt of Van Egmond and De Vries to examine the economic effect of switching to FRB system is appreciated. However, the model is questioned in its reliability due to the following model problems.

1.4.1 Model crashes in different conditions

The first model problem is that the model keeps crashing in different conditions. Therefore, examining the model behavior in different conditions is not possible. This reduces the reliability of the model results as it is not possible to examine if FRB system is still effective in different scenarios of economy. Since the real-world economy contains much more variables than the modeled economy, FRB system could lose credibility if it is not effective in other plausible situations.

Examining the effectiveness of FRB system in different scenarios is not possible with the original model as the model crashes in different scenarios.

1.4.2 The model includes unrealistic assumptions

A few parts of the model are based on the unrealistic of illogical assumptions. Followings are a few examples of the unrealistic or illogical assumptions that the model is based on:

- In the model, the firms are designed to give their entire net income to their shareholders as dividends. Also, the firm finance part of the model does not follow standard corporate finance/accounting measures.
- In the model, the consumers are designed to buy firm shares and government bonds prior to their consumptions. The consumers buy these securities as much as their savings and income allow. This means that the consumers' consumption level is ultimately decided by how much bonds/shares are emitted by the government and the companies.
- In the model, the households default when the current house prices are too high for the households' income. However, the households default not when the current house prices are high but when the debt that they have to repay is too high for their income.
- Under FRB system, the households do not default even when they cannot afford the debt repayment.

1.4.3 The model does not include proper units for variables

The model consists of more than 600 variables. However, the majority of them are not specified their units. Unit here is a unit of measurement such as euro or people. In total there are 477 unit errors and most of the errors are due to the absence of units. For instance, due to the absence of units, it is unclear if the firms produce billions or millions goods and services. The result can change drastically depending on whether firms produce billions or millions goods and services.

1.5 Research Objective

Therefore, there are two objectives of this study; one is to analyze the model problems in Van Egmond and De Vries's model and improve the model's reliability by fixing the model problems. The other objective is to analyze how effective FRB system is in the improved model and if it works well in various situations.

Since the model is a valuable attempt to analyze the effect of FRB system on house prices and private debt dynamics, it is believed that the improvement of the model is necessary for the further research on FRB system. Furthermore, it is also important to test how the model behavior changes in the improved model and if FRB system can still bring a positive effect to the economy in different uncertain scenarios.

1.6 Research Question

This study contributes to the improvement of the study on FRB system, by answering the following research question:

"How to improve the System Dynamics model of FRB system from Van Egmond and De Vries (2016) in order to give more insight into the effect of FRB system in the economy? How does this improvement change the model results and how does FRB system work in different scenarios of the economy?"

1.7 Thesis outline

The next chapter presents the research design, starting with the introduction of a research approach and sub questions. A methodology will be then introduced with research phases and steps.

Chapter three is for the original model description. It explains the original model in depth. It breaks down to the each part of the model, the banks, government, consumers, firms and asset (house) market. After the explanation of each part, how FRB system works in the model will be explained. After that, the model problems of the original model will be analyzed. Causes of the model problems will be found through reviewing the model and possible solutions will be suggested through a desk research.

In chapter four, the model problems will be fixed based on the information gathered in the chapter three. The details of the improved model will be given. Lastly, the Model Performance Indicators (MPIs) will be introduced in this chapter.

In chapter five, the results of the improved model will be shown in comparison with the original model results. In this chapter, it will be suggested how the results have changed in the improved model and their implication in the real-world economy.

In chapter six, the uncertainty analysis and the policy robustness test will be designed. In this chapter, the methods of uncertainty analysis and policy robustness test will be introduced. Firstly, the uncertainty variables and their ranges will be chosen up. Next, the criteria to test how effective FRB system is in different scenarios will be decided.

In chapter seven, the results of uncertainty analysis and policy robustness test will be shown. The results will be thoroughly analyzed and interpreted in its implication in the real-world economy.

In the final chapter eight, the conclusion of the research will be given and the recommendation for the further research will follow.

02 Research Design

2. Research Design

The research question that is answered by this report is "*How to improve the System Dynamics model of FRB system from Van Egmond and De Vries (2016) in order to give more insight into the effect of FRB system in the economy? How does this improvement change the model results and how does FRB system work in different scenarios of the economy?*". In this chapter, the research approach and sub research questions for answering the main research question will be introduced. Following that, the methods to answer the sub questions will be described.

2.1. Research Approach and sub research questions

This study chooses a SD modelling approach as the study focuses on the improvement of the existing SD model. SD Modelling approach is suitable to calculate both linear and non-linear behavior of economic agents. Furthermore, it is appropriate approach to illustrate the money circulation (its creation, flow and destruction).

In order to answer the main research question, the following sub-questions have been formulated:

SQ 1. What causes the model problem?

SQ 2. How the model problems can be solved?

SQ 3. How the improvements of the model problems change the model results?

SQ 4. Is FRB system effective to stabilize the price level and reduce the economic boom and bust in the improved model?

SQ 5. Is FRB system effective in different scenarios? If not, what causes the ineffectiveness and how is it expected to be improved?

2.2 Methodology

This section presents the specific methods used in this thesis and explains why each method has been chosen. The following figure depicts the phases of the research and the methods used in the each phase. Each phase includes steps which are illustrated as green boxes. In the green boxes, it is shown which sub research questions are answered in the step.

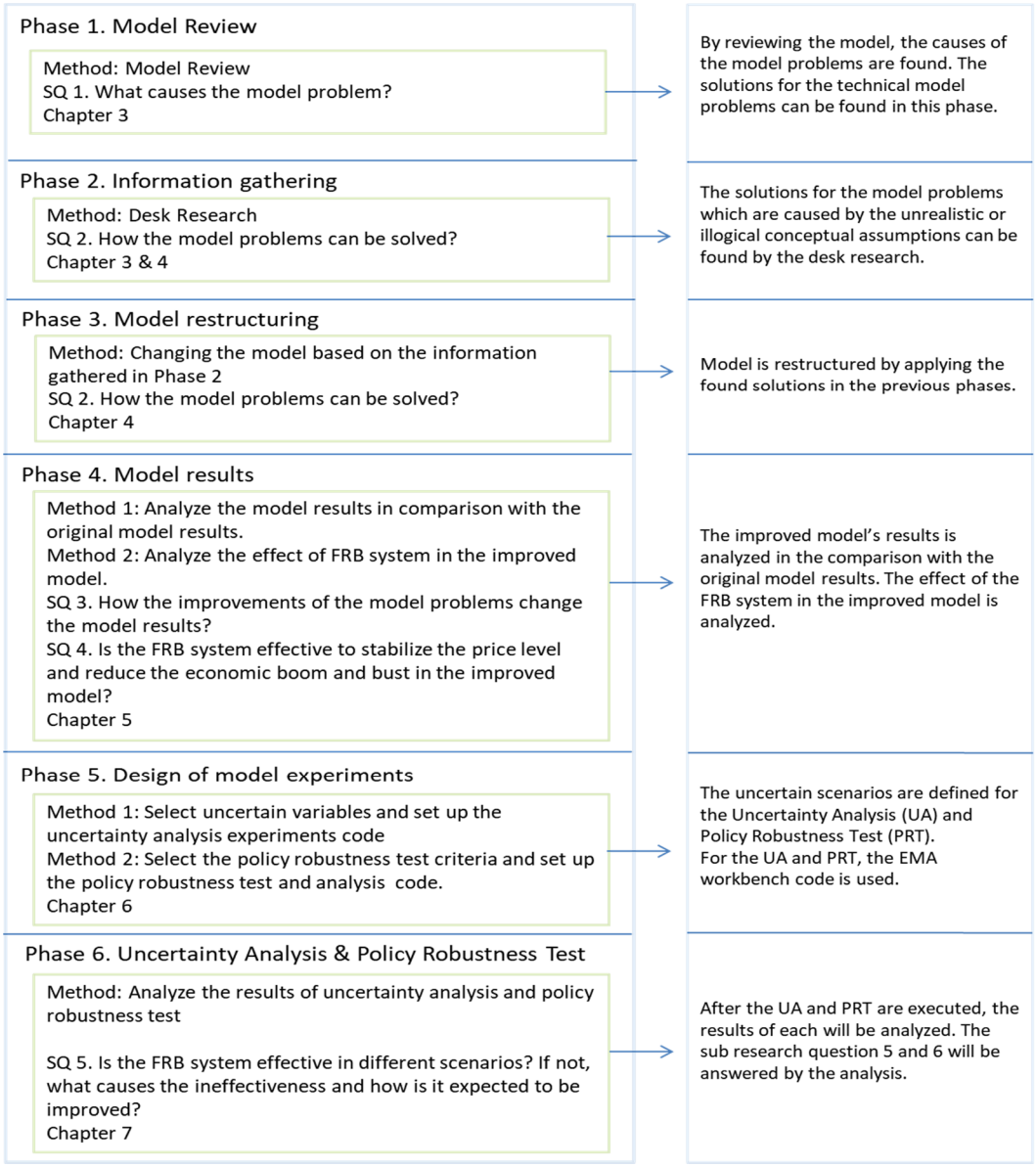

Fig 8. Research flow diagram

Model Review

In order to investigate the causes of the model problems, the model will be reviewed thoroughly. The objective of the model review is to find the model structures that are falsely designed technically and conceptually. The solutions for the technical model problems can be found in this step.

Desk Research

Desk research is to find solutions for the model problems that are caused by unrealistic and illogical assumptions. The desk research is an attempt to collect the information to correct these assumptions.

Through a desk research, a better understanding of the real-world economic system will be obtained. The model can be improved in its reliability by applying more realistic and logical assumptions. Along with the model review, the desk research seeks solutions that can improve the reliability of the model.

System Dynamics Modeling

System Dynamics (SD) modelling technique enables the user to describe, model, simulate and analyze a dynamic and complex system (Pruyt, 2013). Although SD is not a predictive approach giving exact values for future system states, it improves understanding of the complex system and its behavior (Ford, 1999). SD is designed to capture both linear and non-linear behavior, something that human beings are usually unable to do (Forrester, 2009).

This method is chosen, because it enables the user to conduct a complicated and comprehensive analysis of the macroeconomic systems. The macroeconomic system consists of different economic agents (consumers, firms, government and banks) and their interactions. In SD model, each agent's behaviors, activities and properties are connected into one complex macroeconomic system. SD modelling technique enables the user to understand the linear and non-linear behavior of a complex system with the delicate illustration, calculation and analysis tools.

The Van Egmond and De Vries's work suggests that SD modeling is a suitable method to model a complex macroeconomic system including and connecting various economic sectors. Especially, SD modeling is adequate to compute the stock and flow of the money. This is important advantage since an understanding of how the money is distributed (stock) and circulates (flow) in the economy is important to understanding the effect of FRB system. Furthermore, the tool enables the users to apply various functions in the stock-flow mechanism such as delay, smooth and integral and differential.

Uncertainty Analysis and Policy Robustness Test

Uncertainty analysis is done using EMA Workbench on Python. EMA Workbench is a toolkit for an exploratory modeling. It allows to connect a complex model made in SD modeling software to a programming language, Python, and to conduct both open exploration and directed search. Open exploration is to explore the behavior of the model in the broad space of uncertainty. The uncertain space is explored through systematic sampling of the uncertainty or decision space (Kwakkel, 2017).

Directed search is a bit different approach as it searches for the scenarios that cause the certain types of the outcomes, such as the best possible or the worst possible outcomes. Therefore, the Directed search can be considered to be an optimization approach. While the directed search can be used to discover the worst possible scenario, the open exploration can be used to get insight into the sensitivity of outcomes to the various decision levers (Kwakkel, 2017).

In this study, a directed search is used to see if FRB policy[9] is effective in different scenarios of economy. First, an uncertainty analysis has been conducted in order to see if effect of FRB policy is different in other scenarios. In order to do this, uncertain variables and the possible ranges of each variable's value are specified. This is the uncertain space to be explored. Each scenario is created from this uncertain space with systematically sampled uncertain values. The model is executed in each scenario and only the scenarios in which FRB policy is not effective are selected and analyzed.

A number of experiments can be done quickly in EMA Workbench with various samplings of the uncertain scenarios. Therefore, EMA Workbench is considered to be a proper tool to investigate the model's behavior and the policy's robustness in a vast uncertain space.

[9] FRB system is a monetary policy paradigm. Therefore, it is called as a policy here instead of FRB system.

03 Original Model Description

3. Original Model description

In this chapter, the original model from Van Egmond and De Vries (2016) will be described. In the chapter 3.1, the general structure of the original model is explained. In the following chapter 3.2, MAD system and FRB system in the original model will be introduced. In the chapter 3.3, the model problems in the original model will be explained in details.

3.1 General description of the original model

Van Egmond & De Vries model – focused on Private Debt - House price Dynamics

Klaas van Egmond and Bert van Vries are professors from Utrecht University, in the Netherlands. They are professors of Geosciences (Environment and Sustainability) having a sub-domain in sustainability of economics and finance. They have built a SD model of a macroeconomic system including the main economic agents, consumers (households), firms, government and banks. The model simulates the interactions between the economic agents in monetary terms.

Their research has been inspired by Werner's work (2012) after 2008 financial crisis. In their paper, "Monetary Reform: dynamics of a sustainable financial-economic system", they have mentioned the inspiration of their research as below:

"'a concrete model linking banking and the economy via the reflection of a fundamental, yet usually neglected fact about banks of which both finance and economic experts are often unaware for the majority of their career: banks create the money supply through the process of 'credit creation' (Werner 2014). This and similar insights have inspired the research in this report."

They agreed with the Werner's idea that the money creation is important and influential in the macroeconomic model. Their model is a system dynamics simulation model which links the real economy and the financial system. The real economy is concerned with actually producing goods and services and financial system is concerned with buying and selling on the financial markets (n.d., 2018).

Another fact that makes their model special is that it includes the private debt – asset (house) prices dynamics. The detailed relation between a house market and private debts has not been included in other FRB system SD models (Yamaguchi, 2011). Including the dynamics between house prices and private debts is important because it has been considered to be a vital determinant of the households default and subsequently, an economic crisis in 2008. It is possible observing the effect of FRB system on the private debts and house prices in the model.

In their study, Van Egmond and De Vries have defined and called FRB system as Debt Free Money (DFM) system. DFM system implies disentanglement of the money creation from the private credit. Under DFM system, the money is created without the need to pay back or to pay interest. FRB system will be hereinafter referred as DFM system.

3.1.1 Firms

The firm part is modeled as a two-sector closed economy[10]. The goods and services are produced using capital and labor. There are two sectors of industries, manufacturing and services[11]. The model simulates the interaction between the real economy and the financial system as shown in the Fig 9.

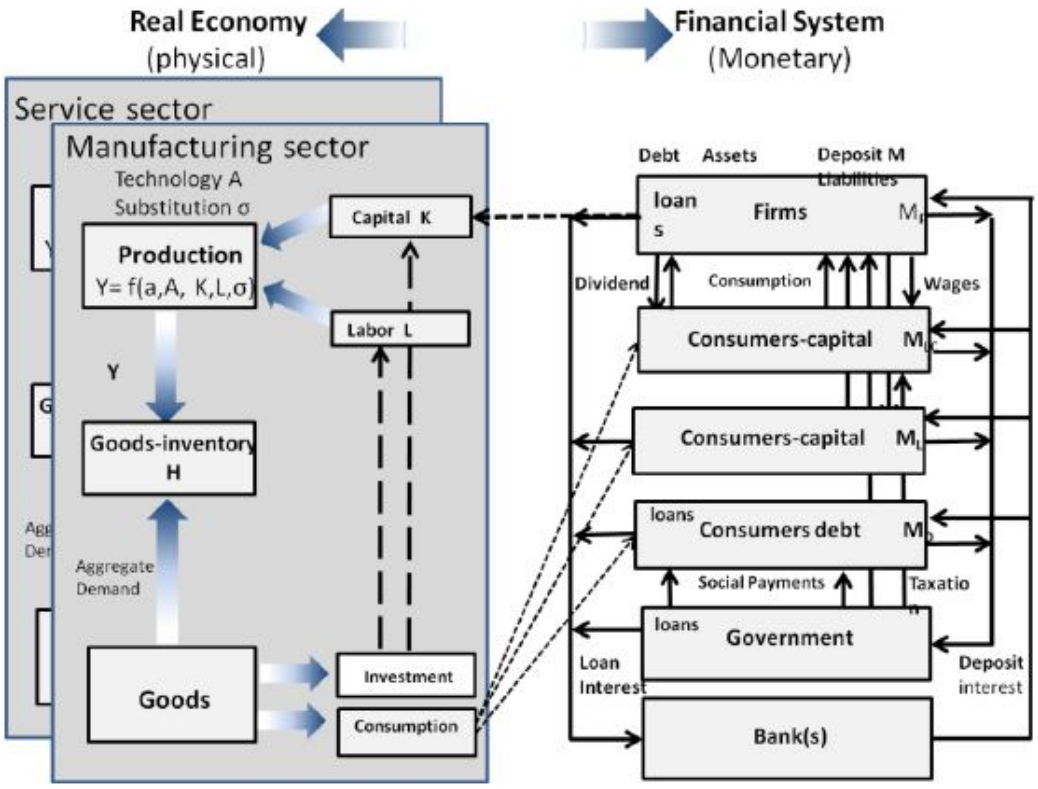

Fig 9. A representation of the two parts of the corporate finance model: the (real physical) economy (left) and the financial system (right) and their interconnections. Reprinted from "Monetary Reform: dynamics of a sustainable financial-economic system", by N. D. van Egmond and B. J. M. de Vries, 2016.

Firm production and wage

In the Fig 9, the real economy is presented in the left side. Production (output) is denoted with Y_i

[10] A closed economy is one that has no trade activity with other countries. A closed economy is self-sufficient within the domestic market. In a closed economy, no imports come into the country and no exports leave the country (n.d., 2018).

[11] Van Egmond and De Vries have mentioned about dividing the industry to two parts, manufacturing and services as following: "We distinguish the manufacturing and the services sector, because of the empirical evidence that the labor-capital ratio, the substitution mechanisms and productivity growth features are rather different, also over time, although the rapid growth in ICT may be depreciate such evidence."

and demand for the respective goods (manufacturing) and services (service) D_i, i=1,2[12]. In general, the production of goods and services Y does not match the actual demand D because the producers (firms) are not able to predict the exact demand and produce only that amount. This discrepancy is simulated as an inventory H which is an accumulated difference between supply and demand[13]. In formula: dH/dt = Y – D (Hallegatte et al. 2008).

In the model the inventory H tends towards zero because of the feedbacks via prices and employment. If more goods are produced than sold (Y > D), the inventory H will increase. As a result, the price will decline so that consumers can purchase more goods and services with the same wages. If demand is higher than production (D >Y), the inventory H will decrease or become negative and the reverse will happen. Therefore, the discrepancy between actual output ('supply') and aggregate demand determines the price p.

The actual employment and desired employment are decided in the similar mechanism as the price. In the model, the wage level w is a variable that represents the discrepancy between the actual employment rate and maximum employment rate. This is based on the assumption that wages rise when labor demand from the firm increases and they fall when labor demand from the firm decreases (Hallegatte et al. 2008). The resulting price p and wage level w influence the Labor force L through adjustments in the hiring/firing rate dL/dt. When the price of goods and services is low relative to the wage level (not profitable), the firms do not hire more people or even reduce the employees. However, when the price of goods and services is high relative to the wage level (profitable), the firms hire more people.

As shown in the real economy part of the Fig 9, the production of goods and services are decided by a combination of labor and capital. The resulting capital stock K (equipments, plants..etc) and labor force L determine output Y, with a technology factor[14]. The product of the labor force L and wage level w equals wage sum W. The consumers purchase firm shares and government bond, pay taxes, repay loans and consume C with their wage sum W and leave the remainder for (not indicated in figure 9) savings. Via the price p, monetary consumption C is translated into physical consumption C/p, which forms aggregate demand. Aggregate demand consists of consumers' consumptions, government consumption and firm investment. The firms decide investments based on profitability. In the later chapters, the calculation of investments and aggregate demand will be explained in more detail.

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[12] As is explained later on, the symbol $D = D_{mon}/p$ (p: price) is used to denote demand in physical units and D_{mon} is the demand in monetary units (billion euro).

[13] It represents stored goods and services when H>0 or unmet demand for goods and services when H<0.

[14] In the model, a technology is one of the production factors as a multiplier to the labor's productivity. The technology multiplier is not calculated within the model but it is put from an empirical data. The empirical data shows that the technology level gradually increases by time. When the technology level is high, the labors' production level goes up.

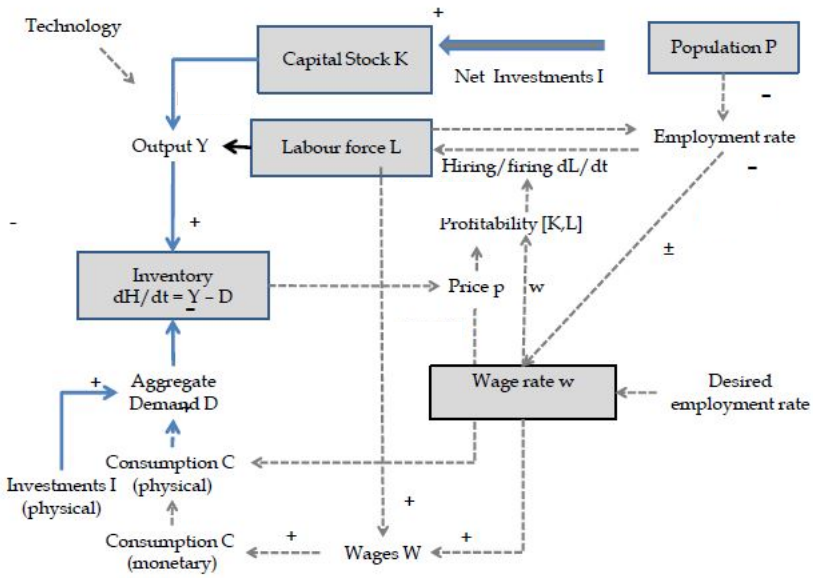

Fig 10. A scheme of the real economy model. Grey boxes indicate stocks that are governed by differential equations. Solid arrows indicate physical flows; dashed arrows indicate informational flows. Reprinted from "Monetary Reform: dynamics of a sustainable financial-economic system", by N. D. van Egmond and B. J. M. de Vries, 2016.

Production

In economic models, the goods and services are produced by means of a combination of labor, capital and technology. It is formulated in the form of a production function. A simple form of $Y \approx K^{\alpha} L^{(1-\alpha)}$, so-called Cobb-Douglas (CD) production function is the most commonly known. This formulation implies unitary substitution elasticity between capital and labor. It does not reflect the changing levels of substitution elasticity but it only assumes a linear production growth by the growth of labor and capital.

Therefore, in this study, a Constant Elasticity of Substitution (CES) production function is used as it allows higher and/or changing levels of the substitution elasticity. Its mathematical form is (Arrow et al. 1961; Jackson and Victor 2014):

$$Y(K,L,\sigma) = [aK^{(\sigma-1/\sigma)} + (1-a)AL^{(\sigma-1/\sigma)}]^{(\sigma/\sigma-1)} \quad [G/year][15] \quad (1)$$

σ is the capital-labor substitution elasticity. **a** is the parameter which distributes production (initially) to capital K and labor L. **A** is technology multiplier in labor productivity and is assumed to follow an exogenous exponential trend. Higher levels of σ (σ > 1) imply easy substitution between capital and labor. The parameters a and A have different values in the manufacture and the service sector. The technology's contribution to the labors' productivity is assumed to be bigger in the service sector

[15] The physical units were indicated with the capital letter G and monetary units with the capital letter M.

than in the manufacturing sector. In this study, $\boldsymbol{\sigma}$ is set to 1.01.

The total physical output (sum of products of manufacturing and service sectors) Y is expressed in physical units of goods and services. A monetary value of the output (pY) is calculated by multiplying an aggregate price p (weighted average of the price of goods and services) to the physical output. L is in million person and is converted into monetary value through the wage rate w. K is in physical units too, i.e. machinery, equipment, buildings, infrastructure etc. and is converted into monetary values through the price of capital $p_K K$. The capital stock K wears out with a depreciation rate δ, which is set to 0.15. Hence, the capital depreciation equals δ K.

In order to produce the total output Y, investment goods such as machinery, equipment, buildings and infrastructure, and labor are required. Therefore, for the firms, the wages, interest and depreciation are cost for producing goods and services. The profitability of the capital and labor are decided by the firms' sales profit relative to the cost of the goods and services production.

In the model simulation, investment in the production capital takes only place as long as additional profits from higher output sales exceed the cost of the additional investment i.e. as long as the net marginal capital productivity is positive. Similarly, additional labor is hired when the marginal labor productivity exceeds net revenues. Therefore, both the desired levels of capital and labor are driven by their respective marginal productivities.

Labor input: (un)employment

For an increase in the labor force dL, the marginal production in each sector will increase at a rate of p dY in monetary terms, with p the price of goods and services respectively and Y the physical production in the respective sectors.

The cost of the additional labor is w dL with w the wages in monetary units. The marginal profit rate (profitability) per additional labor can thus be written as:

$$\pi_L = \frac{p\,dY - w\,dL}{w\,dL} = \frac{p\,dY}{w\,dL} - 1 \qquad [\text{Dmnl}^{16}] \qquad (2)$$

This indicates the marginal level of employment for the firm. If p dY is bigger than w dL the firms would like to increase the employees in order to increase the profit. If p dY is smaller than w dL the firms would like to reduce the employees as having so much employees is not profitable.
In this study, a simplifying assumption is made that the firm's labor demand is linear with the labor profitability:

$$\frac{dL}{dt} = (\pi_L / \tau_L)L = (1/\tau_L)\left(\frac{p}{w}\frac{\partial Y}{\partial L} - 1\right)L \qquad [\text{person}^{17}/\text{year}] \qquad (3)$$

τ_L is a relaxation time that represents labor market frictions and inertia. Using that ∂Y/∂L (eqn. 3),

[16] Dmnl is a abbreviation of "Dimensionless". It is also known as a bare number or pure number or a quantity of dimension one (n.d., 2018).

[17] In the model, this unit is million people based on the historical population data.

this equation says that as long as an additional unit of labor yields an (expected) net gain, that is, p dY > w dL, more labor will be hired, at a rate proportional to the marginal labor productivity expressed in wage units: p (∂Y/∂L) /w.

Capital input: investment

The rule of thumb of the capital investment is that the firms replace the depreciated capital to new ones. This expense always occurs as long as there is a capital that is depreciated. δ (0 < δ < 1) is a depreciation rate, which is the proportion of the capitals that are depreciated every year. The investment, therefore, always includes δ K, the depreciated amount of capital to replace.

The second rule of investment is that, similar to labor, the firms demand additional capital when they consider it to be profitable. As with labor, it is assumed that investors increase the capital stock with an amount dK. The firms demand additional capital when the profitability of the capital is bigger than the cost of the capital. The cost of the capital is the cost of depreciation and interest payment. The interest payment is the cost of the capital if they are bought with bank loans. The additional costs of dK are p_K (ρ dK + δ dK), with p_K the price of one unit of capital and ρ the interest rate (Mankiw, 2006).

The marginal profit rate per additional capital expressed in capital cost units can now be expressed as:

$$\pi_K = \frac{p\,dY - pk\,(\rho+\delta)\,d_K}{pk\,(\rho+\delta)\,d_K} = \frac{p}{pk}\,\frac{\partial Y}{\partial K}\,\frac{1}{(\rho+\delta)} - 1 \qquad \text{[Dmnl]} \qquad (4)$$

For convenience it is assumed that the price of capital coincides with the aggregate price p of goods and services; $p/p_K \sim 1$. Therefore, investments for additional capitals will be made when the marginal capital productivity $\frac{\partial Y}{\partial K}$ is bigger than (ρ+δ).

Again, the simplifying assumption is made that the investment in the new capital stock is linear to the profitability of the capitals:

$$I_{gross} = \frac{dK}{dt} = (\pi_K/\tau_K)K = (1/\tau_K)\left(\frac{\partial Y}{\partial K}\,\frac{1}{(\rho+\delta)} - 1\right)K + \delta K \qquad \text{[G/year]} \qquad (5)$$

τ_K is a relaxation time over which firms react to the return of the investment. This equation states that firms will invest in new production opportunities as long as the (expected) profits are positive, that is, dY > (ρ+δ) dK. As with labor, additional capital input will result in decreasing marginal capital productivity and the marginal profit rate will tend towards zero.

Prices: supply demand adjustment

The price p drives supply and demand towards equilibrium. There are consumers who demand goods and services D_C and there are investors who have a demand for investment goods D_I. The aggregate demand D_{mon} consists of $D_C + D_I$. Under the assumption of equilibrium, economic output Y over the time period equals aggregate demand D in physical units, i.e. $Y = D_{mon}/p$. However, in reality and in our model formulation, output Y will differ from demand D, and there will be a surplus (inventory) or a shortage (unmet demand), indicated by dH/dt = Y – D. Following Hallegatte et al. (2007) we postulate that this feedback mechanism is via the ratio of the level of the inventory H and the demand D:

$$\frac{dp}{dt} = -\frac{dp}{\tau p}\frac{H}{D} \qquad [M/G/year] \qquad (6)$$

with τp a relaxation parameter that represents the inertia in the system. Note that the price p is constant if H = 0 and dH/dt = 0. In case of a low price rigidity (τp is small), fluctuations in H are quickly accommodated by price adaptation. Increasing demand means higher prices and increasing production will result in lower prices. In case of a high price rigidity (τp is large), fluctuations in H are only slowly absorbed through price adjustments.

Wages: labor market adjustment

In a capitalist economy, a shortage of labor will drive up wages whereas a surplus will decrease wages. Hence, a third differential equation is introduced concerning wages. The wage level w is assumed to change depending on the employment level, following Hallegatte (2008):

$$\frac{dw}{dt} = w\left(\frac{E - E_{full}}{\tau w}\right) \qquad [M/person/year[18]] \qquad (7)$$

with E the actual employment level which equals L_{Demand} / L_{Supply}, τ_w is the characteristic period during which the wage level changes as a result of the changing employment level; E_{full} the maximum employment rate which is set to 0.95 in this model[19].

The wage rate w is constant when actual employment equals desired employment level, L_{Demand} = L_{Supply}. If the employment rate E = L_{Demand} / L_{Supply} differs from a desired level of employment E_{full}, an equilibrating process starts through a delayed wage change. If E is still above E_{full} and the employment level E starts falling, the rate of change dw/dt is still positive and wages increase but at a declining rate; once E falls below E_{full}, dw/dt turns negative and wages will start falling.

Firm financing

In the original model, the firms always fund their investment with external funding such as bank debts and share sales[20].

$b * I_{gross} = BL_f$

$(1-b) * I_{gross} = S$

$I_{gross} = BL_f + S \qquad [M/year] \qquad (8)$

[18] In this equation, the unit is actually k euro/(persons*Year)/Year. This complicated unit is due to that the wage is calculated as a gross wage per employee per year (k euro/person/year). The wage change rate per year

[19] This relationship is in known as the Phillips curve. The assumption of a linear feedback is probably incorrect but made for simplicity reasons (Hallegatte et al. 2008).

[20] In this model, the corporate bonds sold to the consumers and other financial institutes than banks are not included.

With b the parameter which distributes investment funding to firm's bank loan BL_f and share sales S. It is also called as a "firm loan ratio" in this model. I_{mon} is the monetary value of I_{gross}. Therefore, it can be equated as $I_{mon} = p_k I_{gross}$ and $p/p_k \sim 1$.

Firms take loans from banks and repay them with interest over repayment period. They sell shares to the consumers (who become shareholders after purchasing the shares) and pay them dividends. The firms can sell as much share as the consumers can afford with their savings (deposit)[21]. In the original model, it is assumed that the consumers are willing to buy shares as much as available with their income and savings.

The shareholders receive dividends from firms and the dividends are given from the firm's profit. In the original model, the firms give away their entire net income from last year as dividends. The firms empty their vault every time when there is a new income. This means that firms give shareholders 100% of yearly net income as dividend as illustrated in Fig 11. The detailed principle of the net income calculation is introduced in the appendix A.

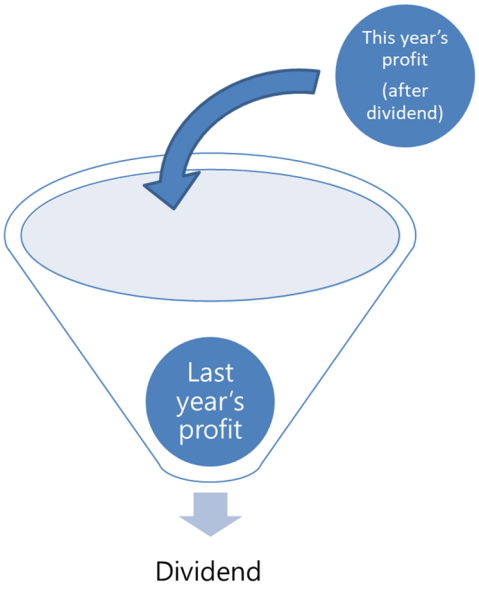

Fig 11. An illustration of Dividend payment

Therefore, firms' mutual transactions can be arranged as below table:

[21] In this study, the consumers are divided into three groups: Consumers who don't have any bank debt and buy government bonds and firm shares, consumers who don't have any bank debt and buy only government bonds and consumer who have bank debts and buy neither shares nor bonds. Therefore, consumers here represent only the first group of consumers.

Table 1. A matrix of the mutual transactions of the firm.

Transaction matrix of firms						
	Consumers			Firms	Government	Banks
	Indebted consumers with no capability to buy bonds or shares (D consumers)	Non-indebted consumers with capability to buy only bonds (LB consumers)	Non-indebted consumers with capability to buy both bonds and shares (LBC consumers)			
Consumption	$-C_D$	$-C_L$	$-C_{LC}$	$+C$		
Government Consumption				$+C_{gov}$	$-C_{gov}$	
Shares			$-S$	$+S$		
Investment				$+S + BL_{firm}$		
Dividend			$+Div$	$-Div$		
Wages	$+W_D$	$+W_L$	$+W_{LC}$	$-W$		
Loans				$+BL_{firm}$		$-BL$
Repay of loans				$-Repay\ BL_{firm}$		$+Repay\ BL_{firm}$
Interest on loans				$-rd * BL_{firm}$		$+r * BL_{firm}$
Interest on deposits				$+rl* BL_{firm}$		$-rl* BL_{firm}$
Income Tax				$-T_{firm}$	$+T_{firm}$	

3.1.2 Consumers (Households)

The consumers are divided into two big categories: Indebted consumers and non-indebted consumers. For the sake of simplicity, it is assumed that the non-indebted consumers do not borrow money from the bank. They own houses and sell them to the indebted consumers. They also trade houses within themselves. The non-indebted consumers are again divided into two categories; the consumers who buy both government bonds and firm shares and the consumers who buy only government bonds. Therefore, consumers are divided to three sub groups:

- First group of consumers is indebted consumers (D consumers). They have a negative net deposit (their deposit (saving) minus debts is negative) and no lending capability. They purchase houses from the non-indebted consumers with bank loans. They do not buy government bonds or firm shares. Their main income is labor wages and social payments from the government.

- Second group is called LB consumers and they have a positive net deposit and a lending capability. They do not take any bank debts. They purchase the government bonds and they are paid with the bonds repayments by the government. They also own houses and sell them to the indebted consumers. These consumers obtain their income from labor wages, interest on savings and bonds repayment.

- Third group is LBC consumers. They have a positive net deposit and a lending capability as LB consumers. A difference between LB consumers is that, together with the government bonds, LBC consumers also buy firm shares and are paid with the dividends. These consumers obtain their income from labor wages, interest on savings, bonds repayment and dividends from shares.

For the simplicity, the model did not count the houses as a part of the consumers' wealth. In this model, the wealth is strictly limited to the cash savings.

Consumer's cash flow and Consumptions

Consumption mechanism differs in each group of consumers. Firstly, the D consumers consume with whatever amount of income left after they pay tax, debt repayment and interest. Therefore, the D consumers do not have an actual control over their consumptions. Their consumption is decided by their income, tax and debt repayment.

Their income includes the labor wage, social payment and interest over deposit. There is one more income for them, which is debt. In the model, when D consumers take loans for purchasing the houses, they use only 80% of the loan to purchasing the houses and use 20% for other expenses such as consumption or debt repayments. Therefore the D consumer's income is:

$$INC_D = W_D + SP + \rho_d * M_D + (1-h)BL_D \quad [M/year] \quad (9)$$

INC_D is an income of D consumers and W_D is the labor wage. SP is social payment from the government which is assumed that only D consumers receive. ρ_d is interest rate over deposit[22]. M_D is the deposit of D consumers. h is the house purchasing ratio in the bank loan which is set to be 0.8 in this model. BL_D is that the D consumers' bank loans. Therefore, h BL_D goes to LB and LBC consumers' deposit as a house sales income and the rest, (1-h)BL_D is used by D consumers.

The D consumer's consumption can be expressed as below:

$$C_D = INC_D - T_D - \text{repay } BL_D \quad [M/year] \quad (10)$$

with C_D D consumers' consumptions, T_D the D consumers' income tax plus VAT. The repay BL_D is the debt principal plus interest repayment.

Unlike D consumers, LB and LBC consumers decide their level of consumptions depending on their income level and wealth. The model adopts a few consumption functions that were proposed by other scholars. Firstly, consumption level is decided by the income level. A part of consumption is proportional to disposable income[23]. According to Keynes (1936), men are disposed, as a rule and on the average, to increase their consumption as their income increases, but not as much as the

[22] The principle of interest rate calculation is explained in Appendix C.

[23] Disposable income is the income remaining after deduction of taxes, available to be spent or saved as one wishes ("31 CFR 285.11," n.d.).

increase in their income.

In this model, a consumption modeling approach of Godley and Lavoie (2007) is considered as well. Godley and Lavoie (2007) have proposed that the consumption might not only depend on the level of income but also level of wealth. The underlying assumption is that a certain, small fraction of the wealth is consumed. Wealth is defined here as the bank deposit (saving), M.

$$C = b_i\ DI + b_w\ M \quad [M/year] \quad (11)$$

b_i and b_w are a proportion of the disposable income and the wealth that LB and LBC consumers use for consumptions. DI is a disposable income and b is the proportionality constant. In general, b is smaller than one. In the model, b_i and b_w are set to respectively 0.8 and 0.03.

In this model the disposable income, DI, is calculated as income minus taxes and bonds or shares purchases. Therefore, the equation 11 is reformulated as below:

$$C_{LBC} = b\ (TI_{LBC} - T_{LBC} - B_{LBC} - S) + b_w\ M_{LBC} \quad [M/year] \quad (12)$$

$$C_{LB} = b\ (TI_{LB} - T_{LB} - B_{LB}) + b_w\ M_{LB} \quad [M/year] \quad (13)$$

with TI Total income which include not only labor salary but also other incomes such as government bonds repayment, share dividends in case of LBC consumers and interest on the deposits[24]. The total income of LB and LBC consumers is described in details in appendix B.

LB and LBC consumers purchase the bonds as much as they can afford with their saving deposit. But for LBC consumers, they put priority on the share purchases and buy bonds with what is left after purchase of firm shares:

$$B_{LBC} = MIN(m\ B_{total}\ ,\ M_{LBC} - S) \quad [M/year] \quad (14)$$

$$B_{LB} = MIN((1\text{-}m)\ B_{total}\ ,\ M_{LB}) \quad [M/year] \quad (15)$$

with B_{total} the total amount of government bonds that the government issues and M saving deposit. m stands for the ratio of LBC consumers and LB consumers in a bond purchasing. In the model, it is set to 0.5, which means that LB and LBC consumers buy half of total bonds issued each.

S in equation 16 stands for the share purchase of LBC consumers. LBC consumers buy as much shares as they can afford with their saving deposits:

$$S = MIN(S_{total}\ ,\ M_{LBC}) \quad [M/year] \quad (16)$$

Consumer cash flow

[24] FRB debt repayment from the D consumers in DFM system is also included in the total income of LB and LBC consumers. This will be explained in chapter, 3.2 MaD – DFM systems in the original model.

Therefore, the consumers' mutual transaction can be arranged as below matrix:

Table 2. A matrix of the mutual transactions of the consumers.

Transaction matrix of firms						
	Consumers			Firms	Government	Banks
	D consumers	LB consumers	LBC consumers			
Consumption	$-C_D$,	$-C_L$	$-C_{LC}$	+C		
Social payment	+SP				-SP	
Shares			- S	+ S		
Bonds		$-B_{LB}$	$-B_{LBC}$		+B	
Dividend			+ Div	- Div		
Wages	$+W_D$,	$+W_L$	$+W_{LC}$	- W	-W	-W
Loans	$+BL_D$					- BL
Repay of loans	- repay BL_D					+ Repay BL_D
Repay of bonds		+repay B_{LB}	+repay B_{LBC}		- repay B	
Interest on loans	$-\rho_l * BL_D$					$+\rho_l * BL_D$
Interest on deposits	$+\rho_d * M_D$	$+\rho_d * M_{LB}$	$+\rho_d * M_{LBC}$			$-\rho_d * M$
Income Tax	$-T_D$	$-T_{LB}$	$-T_{LBC}$		+ T	

3.1.3 Government

The government's role in the model is comparatively passive in MaD system and active in DFM system. This is because in MaD system, most money is created by banks through credit creation. In the model, the government collects taxes, borrows from banks and through bonds and expends the budget on physical (in this study, represented as government consumptions) and social infrastructure (in this study, represented as social payment) in MaD system. The government is represented explicitly by a flow of revenues from taxes and expenditures in the form of wages paid to government employees, investments in infrastructure (government consumptions) and social payments. In the model, the government does not create money under MaD system but only under DFM system.

Taxation

Tax T is decided by the tax rate tr. Tax rate applies to different kinds of incomes and consumptions:

- firms' net income

- consumers' / workers' gross wages

- consumption as value added tax (VAT) on the consumption of goods and services

Therefore, the government's tax collection can be formatted as below:

$$T = tr * (NP + W_D + W_{LB} + W_{LBC} + Div) + tr_{VAT} * (C_D + C_{LB} + C_{LBC}) \quad [M/year] \quad (17)$$

NP is firms' net profit and tr_{VAT} is VAT tax rate.

Tax Rate and Government Expenditure Level

The tax rate and government expenditure level are decided by the amount of government debt. If the government has too much debt comparing to the GDP (pY), they tend to increase the tax rate and decrease the government expenditure. If the government debt level is low enough, the reverse happens.

The government debt threshold hold is 60% of GDP which is recommended by the EU directive (COUNCIL DIRECTIVE, 2017). As soon as the government debt level exceeds the threshold, the level of taxation will increase and the level of government expenditure (social payments and consumptions) will decrease, in order to decrease the debt below 60 % of GDP[25].

$$G_{Dexcess} = \left(\frac{G_D}{f_{EU} * pY} - 1 \right) * e^{\left(-0.5 * \left(\frac{\frac{G_D}{f_{EU} * pY} - 1}{f_{Dexcess}}\right)^2\right)} \quad [Year] \quad (18)$$

$G_{Dexcess}$ is the excessive government debt, if the government debt exceeds the limit (60% of the GDP) it becomes a positive value and if it does not exceeds the limit it becomes a negative value. f_{EU} is the EU regulated government debt target rate to the GDP which is 0.6. pY is GDP and G_D is the government debt. $f_{Dexcess}$ is the government debt level factor. In this model it is set to 0.35[26].

Even if the government debt exceeds the 60% of GDP, the government can still maintain its expenditure and tax rate if it has enough revenues. Therefore, the tax rate and government expenditure level are a function of government debt and government revenues.

In the model, the level of government expenditure and tax rate are calculated into a multiplier. For instance, the basic tax rate with multiplier 1 is 0.25 (25%). But when the government debt increases the tax rate multiplier increases higher than 1, and it increases the tax rate. The government expenditure and tax rate change when the government debt level and government revenue as

[25] In the model, however, it is assumed that as long as the government debt level does not reach to the maximum level, the increased government debt increases the government expenditures. For example, as long as the government manages their debt level below 60% of GDP, the increasing amount of debt means increasing amount of funds that the government can utilize.

[26] This means that the government expenditure increases more when the government debt is more than 35% * 60% = 22.75% of GDP than when it smaller than the 22.75% of GDP. The government expenditure is larger when the government takes some debt then when government does not take any debt. This logic is only applied as long as the government debt does not exceed 60% of the GDP.

below:

$$\frac{dGE}{dt} = \frac{1}{\tau_{GI}} \frac{GI_{NET}}{pY} - \frac{1}{\tau_{gd}} G_{Dexcess} \quad [Dmnl] \quad (19)$$

$$\frac{dtr}{dt} = 2 - \left(\frac{1}{\tau_{GI}} \frac{GI_{NET}}{pY} - \frac{1}{\tau_{gd}} G_{Dexcess}\right) \quad [Dmnl] \quad (20)$$

GE stands for the government expenditure multiplier[27] and τ_{GI} and τ_{gd} are relaxation factors. GI_{NET} indicates the net revenue of the government which is the tax revenue minus social payment, government consumptions, wage payment to the government employees and debt repayment for the bank debts and bonds. The initial value of tr and GE are 1. With GE, the social payment is decided as below:

$$SP = W_D * f_{sp} * GE * \tau_{SP} \quad [M/year] \quad (21)$$

SP is the monetary value of the social payment. W_D is the D consumer's wage and f_{sp} is a constant factor of social payment. In this model, it is set to 0.7. τ_{SP} is a calibration[28] factor and it is 2 in the model. As shown in the above equation, the social payment is decided both by the government expenditure multiplier (GE) and the D consumer wage (w_D).

In summary, the government increases expenditures and decreases tax rate either when they do not have much debt or they have enough revenue to afford the debt repayment. The government decreases expenditures and increases tax rate either when they have too much debt or they do not have enough revenue to afford the debt.

Bank recapitalization

In MaD system[29], it is assumed that, when the households default over the debt, a certain amount of debts that the indebted consumers were supposed to repay are written off against the bank equity. This shortens the bank balance sheet and the banks become insolvent. In order to prevent the big banks become insolvent, the government supplies them money to restore the banks' equity. This is called bail out.

This then results in increased government debt, which, given the EU-constraint on maximum

[27] It does not stand for a physical monetary value of the government's capacity to spend. The government's expenditure capacity in monetary value is calculated by multiplying this multiplier to the certain amount of the monetary value.

[28] The model calibration is estimating the values of various constants and parameters in the model structure (Meyer & Institute of Transportation Engineers., n.d.). The purpose of the model calibration is, in large part, for the model to generate realistic behavior.

[29] In DFM system, the loan is given not from the credit creation but from the existing deposits of LB and LBC consumers. Therefore, the debts are not written off against the bank equity but against LB and LBC consumers' deposits.

national debt < 60 % of GDP, translates into increased taxation and/or reduced expenditures, which subsequently adds to the already existing stress on the system and intensifies the downward economic spiral.

Household defaults and bank runs in the model will be explained in the next chapter.

Government bonds

When expenditures exceed revenues, the government fills the deficit by selling government bonds in the financial markets and/or borrowing money from the banks. In MAD system[30], 70% of the government money is assumed to be funded by bonds which are bought by both LB and LBC consumers and 30% is obtained from bank loans. Government policies are expected to balance expenditures and revenues within the constraints of its annual budget and its accumulated debt.

Same with firm shares, the bonds are also sold only as much as consumers can afford with their saving deposit. As mentioned in chapter 3.1.2 Consumers, the original model assumes that consumers are willing to buy as much bonds as issued.

3.1.4 Banks

Loan

In the present model, the fundamental role of commercial banks is understood as money creation, in which money is created when banks give loans and disappears in the process when the loan is repaid (Werner 2014). The loans given by the aggregate banks (AB)[31] to the borrowers appear on the left hand asset side of the balance sheet. At the same time this increase in assets is balanced by the same increase in liabilities on the right hand side, in the form of new deposits.

In this model, it is assumed that only 3 types of loans are given:

1. Mortgage loans given to the D consumers: Due to its characteristic, the amount of debt is decided by house prices. The consumers take more or less equivalent amount of loans to house prices.

2. Firm loans for the investment and a budget deficit: As discussed in chapter 3.1.1, the firms take bank loans to invest in their capitals. They also take loans to fill the sales deficit caused by low sales profit or excessive expenses.

3. Government loans

[30] In DFM system, the government does not take bank loans anymore. They fund their expenses with bond sales and money creation.

[31] It means that banks in the model are not a single bank but an aggregation of multiple banks (same as firms).

Bank Equity

Bank described above, the banks' main income is a spread between the interest over debt that the borrowers pay and the interest over deposits that the banks pay to the depositors. The interest rate calculation is suggested in details in appendix C. Bank equity BE is calculated in below equation:

$$BE = \rho_l * BL_{total} - \rho_D * Dep_{total} \quad [M/year] \quad (22)$$

with BE bank equity. BL_{total} is the total outstanding bank loans of consumers, firms and government. However, it does not include the loans given under DFM system.[32] Dep_{total} is the total outstanding bank deposits of consumers, firms and government. The bank equity is banks' own capital and the bank can use it for the banks' expenses such as giving wages to the employees. Banks also have to hold a certain amount of bank equity in order to meet the bank capital requirement. The bank has to hold equivalent bank equity to a proportion of outstanding loans (van Dixhoorn, 2013).

$$Cr = f_{cr} * BL_{total} \quad [M/year] \quad (23)$$

with Cr capital requirement and f_{cr} the capital requirement ratio. f_{cr} is set to 0.05 (5%) in the model. A bank is considered to be insolvent when it cannot meet the capital requirement and the government then rescues the bank.

Household default and debt write-off

When the households default over its debt, a certain amount of debt is written off against the bank equity. The defaulting households can no longer repay the debt, the default debt disappears from the bank's balance sheet and the bank has to use their equity to recover the loss. Banks thus lose significant amount of its equity when households default. As banks suddenly lose such significant amount of equity, they become insolvency (cannot meet the capital requirements). The government then injects money (bail out) for the banks to recover back to its equity level, in order to prevent "Too big to fail"[33]. A further description of the household default in the model will be explained in the following chapter.

3.1.5 Asset (house) market

Private Debt, House price and household default Dynamics

Private Debt

According to Minsky's financial instability hypothesis, bank loans ('credit') play an important role in

[32] It is explained in the later chapter 3.2.

[33] The "too big to fail" theory asserts that certain corporations, particularly financial institutions, are so large and so interconnected that their failure would be disastrous to the greater economic system, and that they therefore must be supported by government when they face potential failure (Lin, 2012).

forming a relationship between house prices and inflation. Bezemer an Zhang (2014) found that house prices are a good predictor of a credit boom. There is a mutual relationship between house prices and credit supply that the credit increases when house prices increase and vice versa.

Furthermore, Goodhart et al. (2008) have revealed an evidence of a significant mutual relationship between house prices, the amount of money, private credit, and the macro-economy. Money growth has a significant effect on house prices and credit and the credit influences to the money and house prices and house prices influence to credit and money.

Also Fitzpatrick et al. (2007) found evidence of a long-run mutually reinforcing relationship between domestic bank credit and (Irish) house prices. When house prices increase, the households take more bank loans to buy houses. When the households take more loans, more money flows in the housing market and house prices go up.

Based on the suggested house prices and bank credit dynamics, Van Egmond and De Vries modeled the mutual interactions between house prices and bank credit.

In their model, D consumers take mortgages to buy houses and the money is paid to LB and LBC consumers who own and sell the houses. Furthermore, the model adopts the assumptions that the D consumers' only use 80% of their mortgage to purchasing houses and rest is used for their other expenses. Therefore, the increase in the credit creation increases the disposable income and wealth for D consumers, LB and LBC consumers. With the increased income and wealth, the consumers consume more and it stimulates the price and wage.

Given these strong indications for a multi-directional link between asset (house) prices and credit, the total amount of bank lending to the D consumers is modelled as the product of the house price, the loan to value ratio and number of transactions (of mortgages).

$$BL_D = n_{trans} * ltv * p_{ass} \qquad [M/year/year] \qquad (24)$$

BL_D is a bank loan for the D consumers, therefore, a mortgage and n_{trans} is the number of transaction. p_{ass} is house price. ltv is loan to value ratio. The loan to value ratio indicates the ratio of a loan to the value of asset purchased. In the model, this ratio was put based on the historical data. In the Netherlands, the ltv ratio was about 75 % in the 1970's and increased to 120 % just before the 2007 / 2008 crisis. It is maintained to be around 113% until 2013 and then gradually decreases to 90%. The number of transaction indicates the fraction of entire households who actually buy houses in given time period. For instance, if all the D consumers take loans to buy houses in the given time period, $n_{trans} = 1$ and if only half of the D consumers take loans to buy houses, $n_{trans} = 0.5$. The detailed calculation of n_{trans} is given in appendix D.

House price

The change in house price is derived from (the change in) D consumers' net income, the (change of the) total amount of mortgages issued and (the change in) LB and LBC consumers' deposit.

$$\frac{dP_{ass}}{P_{ass}} = \frac{1}{\tau_{DI}} \frac{d\,DI_D}{DI_D} + \frac{1}{\tau_{Dspec}} \frac{dBL_D}{BL_D} + \frac{1}{\tau_{spec}} \frac{dDep_{LBLBC}}{Dep_{LBLBC}} \quad \text{[Dmnl]} \quad (25)$$

DI_D here is D consumers' disposable income and it indicates the D consumers' wage minus tax. τ_{Dspec}, τ_{DI} and τ_{spec} are constant relaxation factors. And Dep_{LBLBC} is LB and LBC consumers' deposit. As indicated earlier, a major part of these bank loans ends up on the deposits of LB and LBC consumers, from where it will be used to a large extent for buying houses in the higher price segment. In this case, the physical money flow does not happen as LB and LBC consumers are the sellers and at the same time, the buyers. Their deposit (wealth) level, therefore contributes to the house price.

The above process shows that the increase in the D consumers' bank loans and LB, LBC consumers' deposit increases the house price, and increase in the house price increases the D consumers' bank loans and LB, LBC consumers' deposit.

Higher house prices result in higher bank loans, which also generate an increase in (at least monetary) GDP and, subsequently, in net income. The higher net income in turn allows higher house prices and higher bank loans. The overall result is an accelerated increase in house prices, GDP and debt:

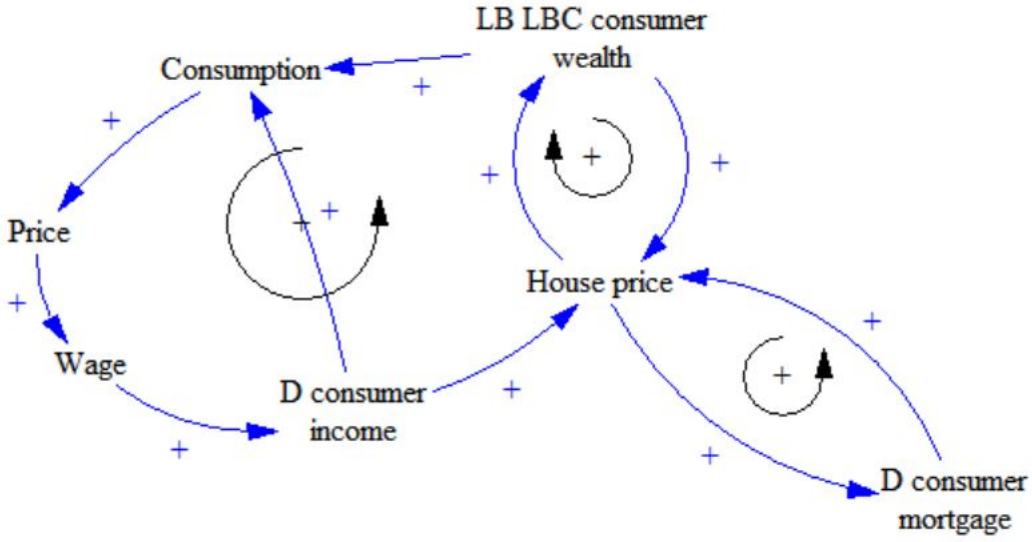

Fig 12. The positive loop between the D consumers' income, LB LBC consumers' wealth (bank deposits) and D consumers' bank loan (mortgage).

In this 'euphoric economy', growth is expected to continue forever and increasing debt is expected to be serviced by the increasing income. But house prices cannot go up forever. Minsky (1982) pointed out, in an analysis of stock market bubbles, that at a given, psychologically determined ('Minsky') moment, trust in ever rising price levels is lost, after which the level of the pressure on the debt repayment becomes heavier.

Therefore, the model includes the Minsky moment as when the households start losing their ability to repay the debt due to the high house prices or low income or both. When the house price

increases continuously, the ratio between the debt servicing (interest plus repayment) and the D consumers' net income, also called the 'residential quote', reaches the level where an increasing number of households can no longer repay the principal and the interest. In calculation of residential quote, instead of using actually bank loans issued, the house price is used to calculate the debt servicing:

$$RQ = \frac{\left(\frac{P_{ass}}{t_{repay}} + \rho_l * P_{ass}\right) ltv}{DI_D} \qquad [Dmnl] \qquad (26)$$

RQ stands for the residential quote and t_{repay} is repay term of the mortgage. This is set as a constant number of years, 30. DI_D is D consumers' income minus tax (disposable income). In the model, the RQ threshold is 0.5. This means if RQ exceeds 0.5, the households start defaulting. The equation indicates that the mortgage repayment plus interest (the numerator) should not exceed half of the D consumers' net income. When the debt repayment increases too much, the D consumers have to reduce their consumptions and therefore, the price level goes down.

Once RQ exceeds its threshold, the households start defaulting and the banks have to write off the outstanding loans. In the model, the banks are assumed to lose 100 billion euro when the households default. In this case, the banks are in the risk to be insolvent. The banks are then recapitalized by the government, being injected with the equivalent amount of money that the banks lost.

The government recapitalize the banks when the following two events happen together in 6 years: Ⅰ) The households default Ⅱ) The banks cannot meet the capital requirements. When the first event happens, the banks write off the loans against their equity, therefore the event 2 happens immediately as well. The government does not recapitalize the banks if the RQ exceeds the threshold but the banks can still meet the capital requirement.

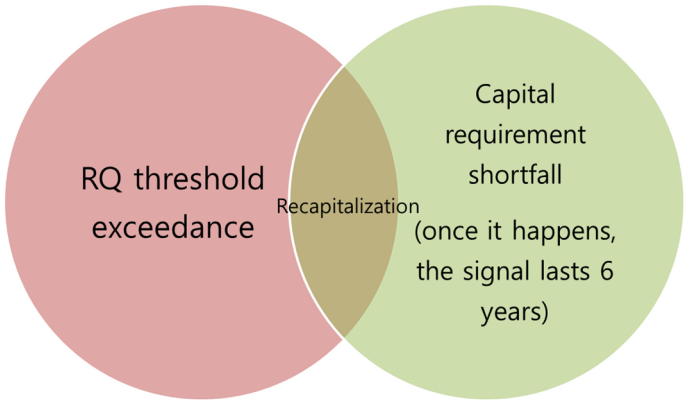

Fig 13. Recapitalization diagram

When the government recapitalizes the banks it issues the bonds to fund the recapitalization. As explained above, LB and LBC consumers buy bonds as much they are issued with their income and deposit. Therefore, when the D consumers default LB and LBC consumers' consumptions also

decrease. The vicious downward spiral is then created when the households default and the economy is put in the recession:

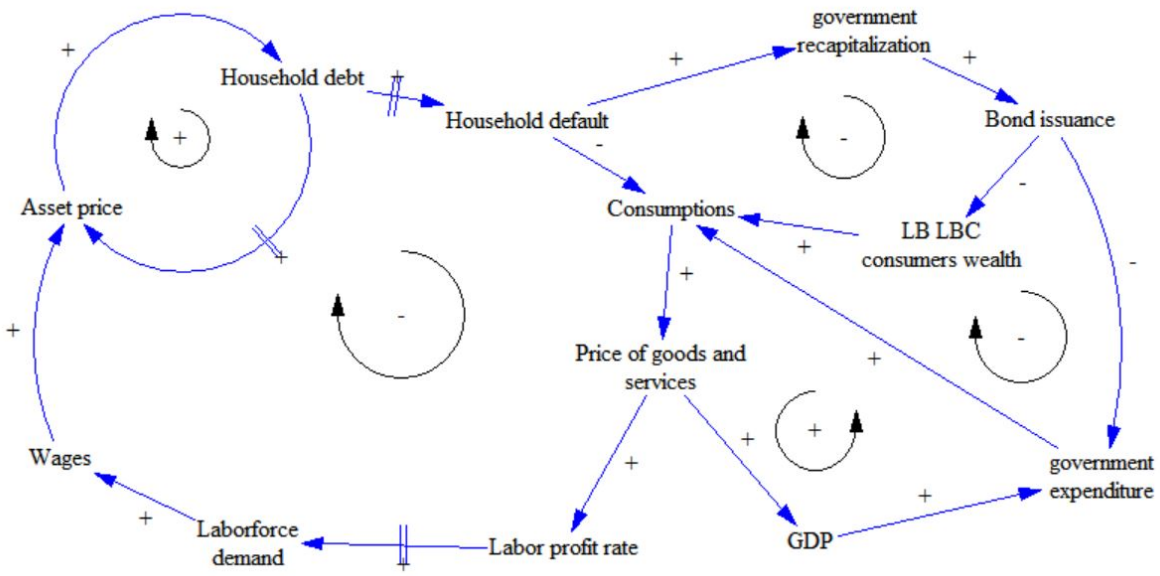

Fig 14. The household default loops.

As shown in the fig 14, when the RQ exceeds its threshold, therefore the households default, the negative loops become dominant. Consumption level decreases and therefore, the price decreases when the households default. Furthermore, the government will reduce its expenditure and raise tax rate and that contributes to lowering consumption level even further. Therefore, the economy is put in recession when the households default.

As described by Biggs et al. (2010), the households default implies a (moderate) decrease in aggregate demand and hence consumption via both income and wealth. This will result in lower price levels (deflation) and in a lower GDP (≈ pY) level. The government has to reduce the consumption and increase the tax rate due to the lower GDP and high debt level. With the reduced consumption level of consumers and governments, the price is deflated.

Due to the decreased price level, the firms do not hire as much labor force as before. This reduces the income for the consumers, and that also contribute to the lower consumption level. The vicious downward spiral is created and it continues until the economy gains the confidence again.

3.2 MaD – DFM systems in the original model

The model description so far was about MAD system. In this chapter, the mechanism of DFM system in the model will be explained.

The model is specifically designed to test the effect of Debt Free Money (DFM) system. In the model, DFM system can be turned on and off with a switch. The following is the change in the model when the switch is on:

- DFM mode is triggered from the time when the first financial crisis breaks. The financial crisis is defined in the model as when both the GDP reduces and the banks cannot meet the capital requirements. Two events do not need to happen at the same time. At the time when the later event happens is when DFM mode is on. For instance, if the first bank default happens in 2008 and GDP decreases significantly in 2013, DFM mode is on in 2013.

- Under DFM system, loans are not given from money creation but from the existing deposit of non-indebted consumers (LB and LBC consumers). The loan repayment (principal and interest) goes to LB and LBC consumers' deposit:

$$Repay_{frb} = \frac{BL_{frb}}{t_{repay}} + \rho_{frbl} * BL_{frb} \quad [M/year] \quad (27)$$

  BL_{frb} is the bank loan that is given from LB and LBC consumers' deposit under DFM system. ρ_{frbl} is the interest rate over debt under DFM system. The ρ_{frbl} is set to 0.03 (3%) higher than the interest rate over debt ρ_l under MaD system.

- The D consumers who take BL_{frb} loans pay the principal repayment and interest directly to LB and LBC consumers. The bank does not serve as an intermediary anymore.

- The D consumers take mortgage that has been sourced from LB and LBC's saving deposit and use this mortgage to pay for the house. This money thus goes to LB and LBC consumers as they are the house sellers.

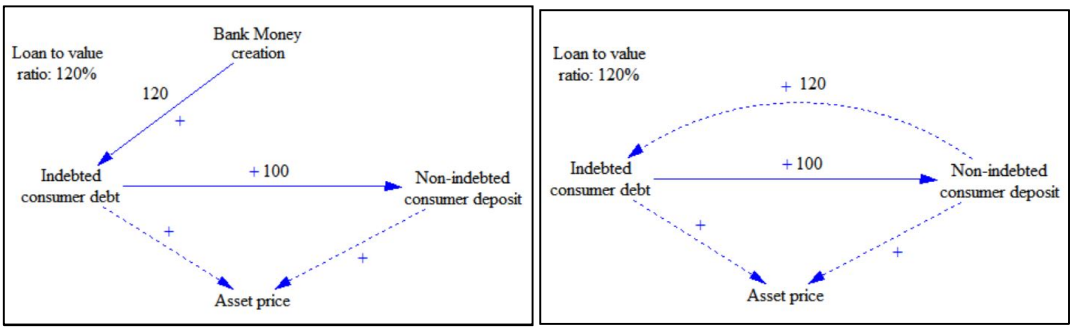

Fig 15. Loan flow in MaD system (left) and in DFM system (right). The line arrows are direct flow of money and the dotted lines are indirect flow of money. In DFM system, the loan is given from the non-indebted consumers' deposits. The level of non-indebted consumers' deposits[34] and mortgage

[34] Non-indebted consumers' deposit level is a determinant of the house price speculation. The assumption of the model is that the house owners (non-indebted consumers) speculate the house

has a positive relation with house price.

- Due to the characteristic of the bank loan under DFM system, it is assumed that the firms and government do not take bank loans anymore for the simplicity. This means that the firms fund their business 100% with sales of share or retained earnings and the government borrows money only through bond sales.

- As the money is not created by banks, it is created by the central bank and given to the government for government expenditures. Central bank creates money based on the price level. The objective of the money creation is to control the price level in the economy and therefore, to mitigate the boom-bust cycle. When the price level increases, the central bank reduces its money creation and the government puts higher tax rate and lower government expenditure. When the price level decreases, the central bank creates more money and the government stimulates demand in the economy by reducing the tax rate and increasing its expenditure.

  $$MC = -(dP + d^2P + \beta(P - P_t)) * aY \quad [M/year] \quad (28)$$

  MC is money creation and P is the price. β is a price change factor and P_t is a target price which is the price of the moment when DFM mode is on. a is a physical output factor and the Y is physical output. As shown in the equation, the money creation depends on the change in price level. If the price decreases so more money is created, the created money is used as an additional government income. The government then needs less tax, government bonds and bank debt and therefore, the government expenditures increase and the tax rate decreases.

  If the price increases, the central bank reduces the money creation and the government has to use tax, bonds and bank debt in order to fund their expenditure. In this case, the government expenditure would reduce and the tax rate increases.

- As the central bank creates money and the government can utilize the created money, the government bonds issuance will decreases significantly. As to be explained in the next bullet point, the government is no longer responsible for the bank recapitalization. And this eliminates the sudden increase in the government debt in case of the households default.

  The government bond is only issued when the government's net income becomes negative. If the price increases, the central bank reduces the money creation and the government income from the created money reduces. The government then has to use the debt to fund their expenditures and that increases the government debt and decreases the government net income (G_D and GI_{net} in equation 18, 19 and 20). Therefore, the government reduces its expenditure and raises the tax rate.

- When the households default and therefore, the banks lose its outstanding loans, the government does not bail out the banks under DFM system. Under DFM system, the loans

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price by continuous selling and buying.

are not written off against the bank equity but against LB and LBC consumers' deposit as the loans are given from their deposits.

Even though LB and LBC consumers will lose their money when D consumers default, they only lose a part of their money. The 80% of the loans that are given from LB and LBC consumers' deposit come back to them as D consumers use that money (loans) to purchase houses from LB and LBC consumers.

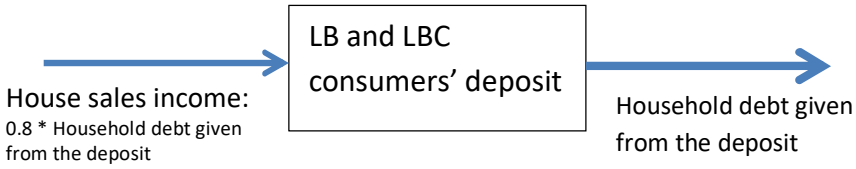

Fig 16. The debt and deposit flow within LB and LBC consumers' deposit

Therefore, the actual amount that is given to the D consumers as loans is 20% of the total amount of the loans.

$$Depout_{LB} = (1\text{-}h)BL_{frb} * f_{LB}$$

$$Depout_{LBC} = (1\text{-}h)BL_{frb} * f_{LBC} \quad [M/year] \quad (29)$$

The Depout is the deposit that outflows from LB and LBC consumers' deposit in giving the D consumers loans. h is the house purchasing ratio in BL_{frb} which is set to 0.8 in the model. This means that the D consumers use 80% of their loans to buy houses and keep the rest. f_{LB} and f_{LBC} are the fraction of LB and LBC consumers (the number of LB or LBC consumers/the total number of LB and LBC consumers).

When the D consumers default on loans, as mentioned in chapter 3.1.5, 100 billion euros are directly deducted from LB and LBC consumers' deposit in the model.

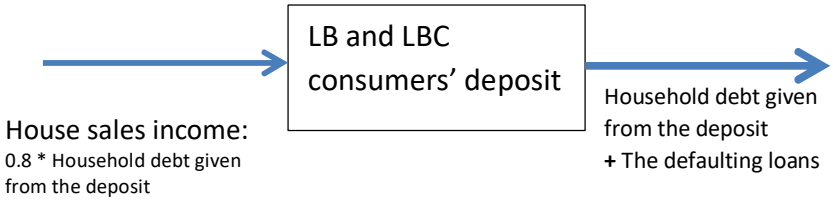

Fig 17. The debt and deposit flow within LB and LBC consumers' deposit with the households default.

In the original model, however, only 20% of the defaulted loans are deducted from LB and LBC consumers.

$$Depout_{LB} = (1\text{-}h)(BL_{frb} + Def_{frb}) * f_{LB}$$

$$Depout_{LBC} = (1\text{-}h)(BL_{frb} + Def_{frb}) * f_{LBC} \quad [M/year] \quad (30)$$

In the equation 30, it is shown that the (1-h) is also applied to the defaulting FRB loans[35], Def_{frb}.

- In DFM system, the households default mechanism is the same mechanism as the government recapitalization. This means that the households' loans are only written off when the banks cannot meet the capital requirement.

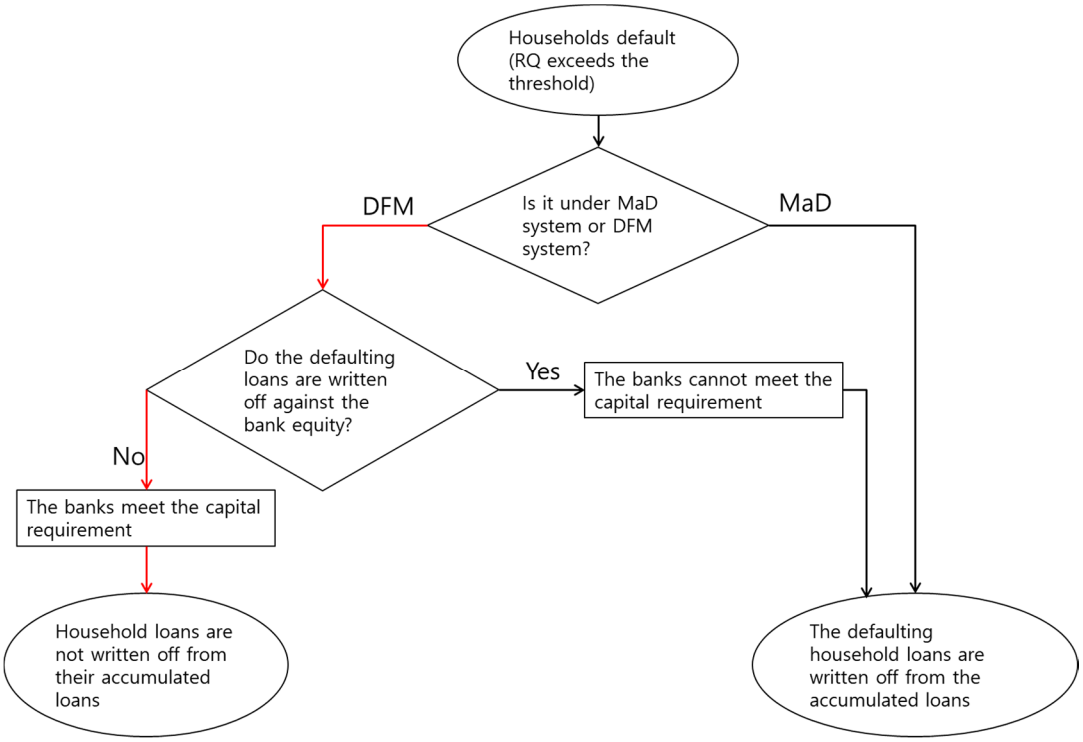

Fig 18. Process diagram of the households' default and loan write-off under DFM system.

As shown in the above diagram, the defaulting households' loans are only written off when the bank equity decreases significantly because loans are written off against the bank equity. However, the defaulted loans are not written off against the bank equity under DFM system. This causes the ironic mechanism that even though households cannot afford the debt payment and default, their loans are not written off.

[35] Loans that are given under DFM system are called FRB loans.

3.3 Model review for the analysis of the model problems

3.3.1 Model crashes in different condition

One of the biggest model problems is that the model keeps crashing in the circumstances that it must not crash. This reduces the reliability of the model results as it is not possible to examine if FRB system is also effective in different scenarios of economy.

Crashes in the smaller time step

In the system dynamics, the time step indicates how often the information or materials flow in and out of stocks. Assume a very simple stock-flow model that has a time unit of year. The stock increases by 1 every year and loses 0.5 every year.

Stock = inflow – outflow = 1 – 0.5

When the time step is 1, the stock shows the stock increasing by 0.5 every year. However, when the time step is 0.5, the in and outflow of the stock is reported every half year having an inflow of 0.5 and an outflow of 0.25[36]. Therefore, the stock increases by 0.25 every half year when the time step is 0.5.

In the Van Egmond and De Vries's model, the time step is set to 0.025. In principle, when the time step changes to smaller, it shows more accurate results which were generated by more frequently accessed input data (Vensim, 2018). And if the model's time step is appropriately chosen, the results should not be so different under the smaller time steps.

However, Van Egmond and De Vries's model crashes under the time step below 0.01. The model does not finish the run due to a crash at year 2040-2050.

Fig 19. The graph of the price from the original model. It is shown that the price level jumps to trillions at 2046.

[36] The SD model works in this way in the Euler integration method. The SD modeling software that is used for this research offer several different integration methods. Each integration method offers different ways to numerically integrate a set of differential equations.

In the fig 19, it is shown that the price jumps to infinity in year 2048. The model does not finish the run because of the internal crash. This shows that the model includes a flawed structure which makes the model instable in different time steps.

The model also crashes when certain variables change. The model could not finish the run when the firm loan ratio increases above 0.6.

Model review and desk research on the time step crash

In the system dynamics modeling manual, five rules for deciding the right time step are introduced. Among five rules, below two rules are emphasized as rules of thumb that can prevent (usually, but not always) model behavior to be significantly different in a smaller time step:

- Time step should be smaller than 1/3 of the shortest time constant in the model.
- Time step should be smaller than the shortest period for which a significant change in model behavior is at all likely.

The first rule implies that the delay time used in the model should not be smaller than the time step. In the SD modeling, the delay function[37] returns the input value delayed for delay time. For instance if a delay function is applied to the input which is a linear growth from 0 to 100 from year 0 to 100 with delay time 1, it returns a linear growth from 0 to 99 starting from year 1 to 100.

The first time step rule states that the delay times that are used in the different delay equations in the model have to be at least 3 times bigger than the time step. The second rule states that the time step has to be bigger than the shortest time period (delay time) that could significantly affect to the model's behavior.

Therefore, the original model is reviewed thoroughly in order to find the delay time that does not follow above two rules. Through a model review, below delay function is selected as the possible cause of the time step error:

Table 3. A delay variable that is considered to be the cause of the time step error.

Name of the variable	Delay time	The role of the delay
Firm deposit delay	0.025	As dividends, the firms give the shareholders their deposits that they had in the last time step (0.025 year before). Therefore, the shareholders receive the firms' existing deposit (which is their net income from last time step) as dividends (see chapter 3.1.1 firm finance). Furthermore, this variable is also used to calculate the extra bank loan that the firms need to fill the net income deficit. If the firm deposit delay (the deposits of the last time step) is below 0, the firms take an extra bank loan to fill the deficit.

[37] There are three different types of delay functions, Delay 1, Delay 3 and three of them returns a delay input in different mechanism. In this chapter, only a fixed delay is introduced as the model used only the fixed delay.

There are a few reasons that the above variable is chosen. Firstly, its delay time is 0.025 which is same as the time step itself. This is against the first rule. Secondly, as the model crashes when the firm loan ratio increases, it is considered that the firm finance part significantly affects to the model behavior. In order to prove this, the firm deposit delay time is changed from 0.025 to 0.1. With the delay time 0.1, the model did not crash under the time step below 0.01. Therefore, the chosen delay time is considered that it affects to the model behavior significantly.

However, even after the delay time has been changed, the model still crashes when the firm loan ratio becomes bigger than 0.6. From this, it can be considered that the model crashes not only because of the time step error but also because of a structural flaw in the firm part.

Model review on the firm finance part

Through the model review, it is found that the firm finance part creates a critical feedback loop. The feedback loop is created mainly by the dividends given to LBC consumers:

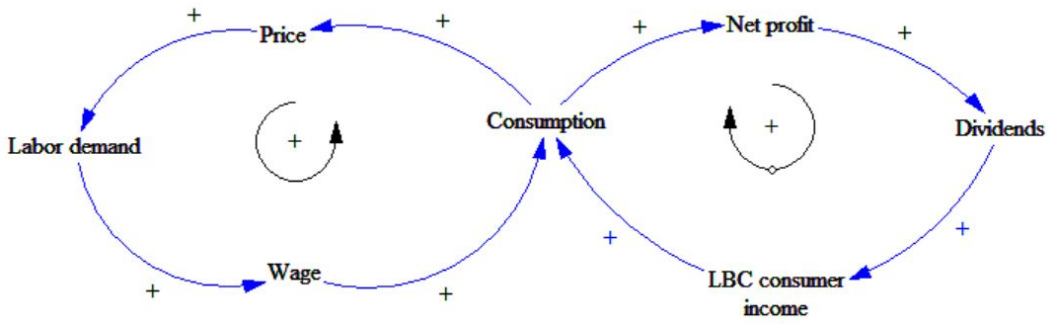

Fig 20. Positive feedback loop between dividend payment and consumption, consumption and wage.

As shown in the fig 20, a vicious positive feedback loop is created when LBC consumers receive “too much” dividend comparing to the money they spend on shares. When the firm loan ratio increases, the firms emit fewer shares for investment financing (see equation 8). However, they still give 100% of their net income to LBC consumers as dividends. As a result, LBC consumers spend less to purchasing the firm shares but receive a large amount of dividend.

This increases their income level and subsequently, the consumption. Increased consumption increases firm’s net income and this increases the dividend again (positive feedback loop in the right side). Furthermore, the increase in the consumption increases demand on goods and services. This thus increases the price level. Since price increases, firms demand more labors for more production. This increases the wage level which increases consumptions again (positive feedback loop in the left side).

From this review, it is shown that this positive causal loop can be a reason that the model crashes.

3.3.2 The critical assumptions in the model

The second model problem is that it contains unrealistic or illogical model assumtions.

Firm finance structure

One of the major problematic assumptions lies in its dividend payout rule as shown above. The given dividend payout rule not only causes technical instability in the model but it is also conceptually incorrect. According to O'Sullivan & Sheffrin (2003), dividend is a payment made by a corporation to its shareholders, usually as a distribution of profits. In order to calculate the dividend, the net income calculated from an income statement is used. Therefore, an income statement has to be made first to calculate the dividend.

Berk & Demarzo (2013) explained the income statement as following:

"The income statement or statement of financial performance lists the firm's revenues and expenses over a period of time. The last or "bottom" line of the income statement shows the firm's net income, which is a measure of its profitability during the period."

Income statement is the way to calculate the firm's earnings from the net revenue. The income statement consists of the below elements:

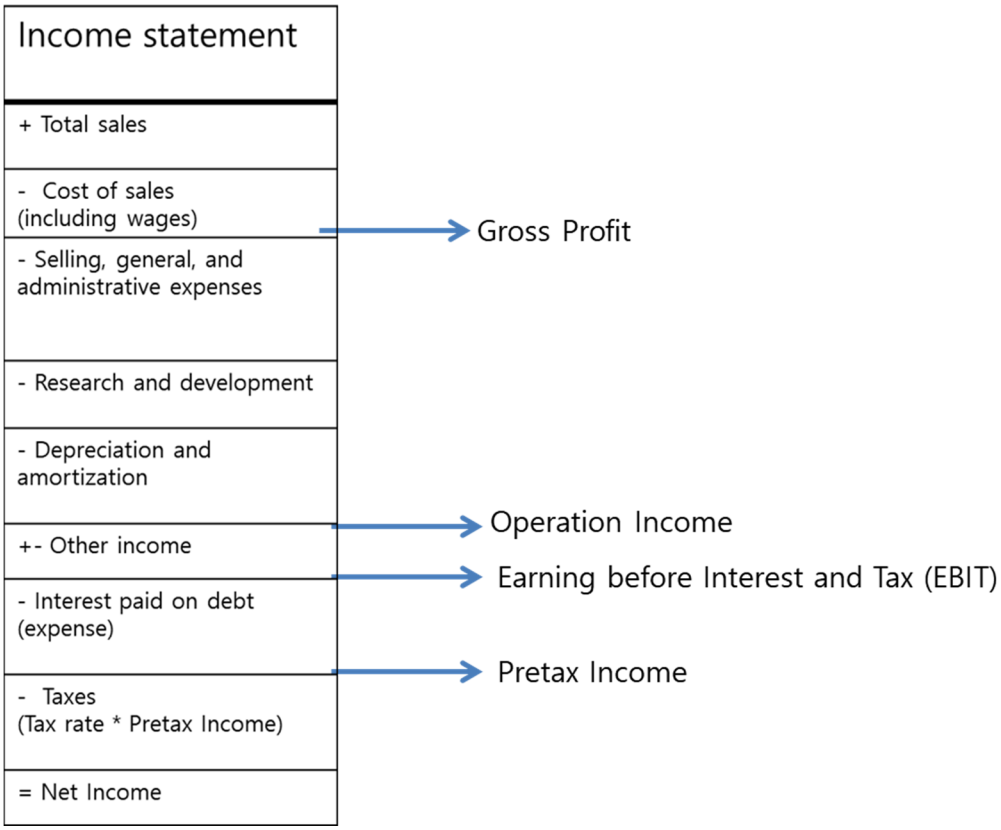

Fig 21. Income statement

What is notable is that repayment of principal of debt is not included in the income statement but only interest payment is included in the income statement. And also, the depreciation and

amortization of the firm's capital is counted as an expense in the income statement.

In principle, dividend is calculated from net income (Berk & Demarzo, 2013). As dividend is not an obligation for a firm to give, firms can choose how much of net income they want to pay out to the shareholders.

The dividend is thus calculated as below[38]:

$$Div = r_{Div} * NI \quad [M/year] \quad (31)$$

Div is the dividend and NI is Net income. r_{Div} is the ratio of the net income which the firms are willing to give the shareholder as the dividends.

In the model, however, the dividend has been calculated as below:

Dividend calculation in the model
+ Total sales (including company's investment input, see chapter 3.1.1 firm finance)
- Wage
+ Interest over deposit
- Interest payment over debt
- Debt repayment (the principal)
- Tax
= Net income
Dividend = Net income (r_{Div} = 1)

Fig 22. The dividend calculation in the model

The main differences between the proper income statement and the one used in the model are the depreciation and debt repayment. In the income statement, the depreciation and amortization are considered as operation expenses, therefore it must be included. On the other hand, the debt principal repayment is not included in the income statement. However, the depreciation is not included in the net income calculation in the original model but the debt principal repayment is included.

Furthermore, dividend equals the net income in the model as the firms give the shareholders 100% of their net income as dividends. Although dividend depends on the firms' decision on how much

[38] In principle, the dividend is given against each share emitted. The firms issue the shares as a financial product putting a certain value to each share. However, in this model, the number of shares emitted was not specified but the shares were calculated only in its monetary value.

they are willing to pay out, it is unlikely to assume that every firm in the country pays out their entire net income. According to empirical data, dividend payout ratio of S&P[39] 500 is around 40% in 2017 (Damodaran, 2018).

Consumer consumption mechanism

In the model, the consumption consists of the following elements:

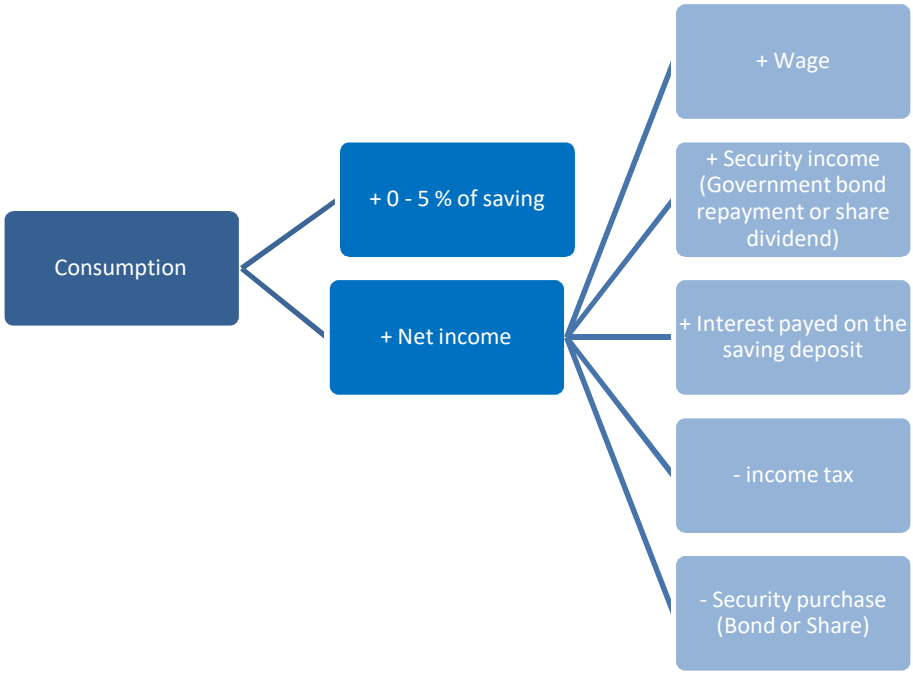

Fig 23. The households cash flow for the consumptions

As shown in figure 23 and the equation 11, the consumer's consumption consists of a small fraction of saving deposits plus net income. However, this assumption contains critical misunderstandings:

- In the model, LB and LBC consumers first allocate their disposable income (sum of wage, share dividends, bond repayment and other incomes minus tax) to purchasing firm shares and bonds. After purchasing the shares and bonds, the rest of disposable income is allocated for the consumptions.

▪ **LB and LBC consumers' net income for consumptions**
+ Wage + Security Yield (share dividend and bond yields) + Interest over saving deposit - Income tax - Purchase of security (share and bonds)
= Net income left for the consumption

[39] The Standard & Poor's 500, often abbreviated as the S&P 500, or just the S&P, is an American stock market index based on the market capitalizations of 500 large companies having common stock listed on the NYSE or NASDAQ.

Fig 24. Calculation of net income before consumption

- The original model includes an assumption that the consumers are willing to buy as much shares and bonds as possible. They buy as much they can afford with their wealth (saving deposits). This means that when a lot of shares and bonds are issued, they would purchase them sacrificing their consumptions. Therefore, the consumption level highly depends on the amount of shares and bonds issued.

This assumption is quite unrealistic in terms that all LB and LBC consumers put their priorities on bonds and shares purchases rather than the consumptions. The assumptions that the consumers would buy as much shares and bonds is not plausible.

According to Keynes (1936), the households first decide how much of their income they will save (by deciding how much they spend). After that, they decide how to allocate and save their wealth. The main flaw in the consumption mechanism is that this order is reversed.

This assumption is not only unrealistic but also can cause instability in the model. As discussed in the previous chapter, when the amount of shares issued decreases significantly, the consumption will increase significantly. This can cause acceleration in the positive feedback loop presented in fig 20. Furthermore, consumptions decrease significantly when a lot of shares or bonds are issued and subsequently, a deflation can be caused.

Household default mechanism

In the model, households default when RQ exceeds its threshold. However, RQ mechanism does not include the actual debt repayment of the D consumers. According to O'Sullivan & Sheffrin (2003), households default when they fail to meet the legal obligations (or conditions) of a loan. This means that the households default when they cannot afford the amount of debt repayment with their income.

The current RQ calculation is always based on the “current” household price. It does not reflect the previous house prices at which the borrowers took bank loans to buy houses. For instance, assume a D consumer A takes a mortgage to buy a house when the house price was high. He has a confidence to pay back the mortgage since he could afford the mortgage with his income at that time. However if house prices decrease to half and his wage also falls due to the economic recession, he is left with huge debt repayment that he promised in the past.

In the original model, households do not default when the “current” house price is low enough so RQ does not exceed the threshold. This means that the households would not default even when they are not able to repay their loan with their income. Moreover, the model can falsely behave as if the households cannot afford the repayment when they can. This is because RQ is calculated with the current house prices not with loan repayment.

With this default mechanism, the banks would not have to write off any debt even when the D consumers cannot afford the debt repayment. In the case, the households cannot get their debt written off but have to keep repaying the mortgage with money that they do not have. The banks

therefore have a large interest income over the loans.

According to Campbell & Cocco (2015), a mortgage default is triggered by negative home equity, which results from declining house prices in a low inflation environment with large mortgage balances outstanding. Therefore, the assumption has to be that the households default when they cannot afford the debt repayment with their income.

DFM system

DFM system in the model contains a few structural problems. Under DFM system, the borrowers directly pay the interest over FRB loans to the lenders. This process is possible in the situation that the loan is given by LB and LBC consumers to the D consumers without any intermediary such as the banks.

As mentioned in the chapter 3.2, in the model, the banks do not function as an intermediary between the depositors and the borrowers. They do not give the interest over the deposit and also do not receive any interest over FRB loans. Their equity therefore, decreases rapidly toward 0 under DFM system. In the paper of Van Egmond and De Vries, they did not mention that their model assumes such peer-to-peer[40] banking system.

The banks' role will be still important under DFM system as they have to decide how to allocate the existing deposits. Therefore, they would still need to receive the fee for their intermediary services through the interest spread.

Another problematic structure in the model is that the households default mechanism under DFM system. Under MAD system, the households default when the RQ exceeds its threshold. In the case of households default, banks lose their equity rapidly and the government recapitalizes the banks following two rules of the recapitalization (see the chapter 3.1.5).

In DFM system, the banks do not lose their equity against the defaulting household loans. The defaulted loans are instead written-off against LB and LBC consumers' deposit. The problem is that the loans are only written off when the banks cannot meet the capital requirements due to its loan loss. But this does not make sense as the banks do not lose its equity when the households default.

Furthermore, as FRB loans are not included in BL_{total} in the capital requirement calculation (equation 22 and 23), the banks' capital requirement decreases significantly. This means, it is easier for banks to meet the capital requirement and that makes it even harder for the FRB loans to be written off.

Therefore, the banks always meet the capital requirement under DFM system. The D consumers cannot get their loans written off even when they cannot afford the repayment.

Another problem is that only 20% of loans are written off when households default under DFM system. In the equation 30, the outflow of deposit of LB and LBC consumers are expressed as below:

[40] Peer-to-peer banking system here means that the depositors and borrowers directly trade the loans without a banking intermediator.

$Depout_{LB} = (1-h)(BL_{frb} + Def_{frb}) * f_{LB}$

$Depout_{LBC} = (1-h)(BL_{frb} + Def_{frb}) * f_{LBC}$ [M/year] (30)

The Depout is the deposit that outflows from LB and LBC consumers' deposit in giving the D consumers loans. h is the house purchasing ratio in BL_{frb} which is set to 0.8 in the model. f_{LB} and f_{LBC} are the fraction of LB and LBC consumers. Def_{frb} is defaulted loans under DFM system.

The equation presents that (1-h) is also applied to Def_{frb}. This means that only 20% of loans are written off when households default under DFM system. This is an unrealistic assumption as when the households default, they cannot repay whatever they owe at that moment.

3.3.3 The unit specifications

In the SD model, a measurement unit has to be specified for each variable. For instance, the unit of LB consumers' saving deposit is billion euros. And the unit of a change in the saving deposit is billion euros per year and this indicates the amount of money that goes in and out from the saving deposit every year.

There are 480 unit errors in the original model. The absolute majority of the errors are caused because the units are not specified for variables. Specifying the units does not change the model behavior or results. However, the model that does not specify its units is less reliable because the model results can change significantly depending on the units.

For instance, the unit of wages per person is not specified in the model. This wage input is multiplied with the total number of employees which has a unit of million persons to calculate a total wage that the entire employees receive per year. The W_{total} is given to be "billion euro/year".

$W_{total} = W_{pp} * L$ [billion euro/year)]

W_{total} is the total wages for the entire employees in the economy and W_{pp} is a wage per person. L is total employed labor force.

This causes a great confusion because depending on the unit of the wage per person, the total wages can change dramatically. If the unit of the W_{pp} is K euro per person per year, the unit calculation would be:

[billion euro/year] = [K euro/(person*year)] * [Million person]

However, if the unit of the W_{pp} is [euro/(person*hour)]:

[billion euro/year] =/= [euro/(person*hour)] * [Million person]

Therefore, a new unit calibration factor has to be multiplied to match the units:

[billion euro/year] = [euro/(person*hour)] * [Million person] * [hour/year] * [billion euro/million euro]

Therefore, the new equation has to be:

$W_{total} = W_{pp} * L * 8765.81277 * 0.001$

Therefore, if W_{pp} is given to be 5 and the employees are 6 million people, the W_{total} can be either 30 billion or 262.9743831 billion per year. In conclusion, the model units can change the model results significantly and also can affect calibration of the model to the real-economy.

04 Model Improvement

4. Model Improvement

The model has been improved in three different aspects: a technical improvement for the model crash, the model assumption specifications and a model unit specification. This study does not cover the model calibration which is for the model to generate realistic number that is comprehensible in the real world.

4.1 Elimination of model crashes and Model assumption specification

4.1.1 Firm financing

In the chapter 3.3.1, the model crash problem has been analyzed that the cause of the crashes is probably due to the flaw in the firm financing model design. Therefore, the entire firm finance part including the delay time and the positive feedback loop created by the dividends is improved.

Improving firm finance part is important in this thesis as the part contains not only assumptions that are less realistic but also a cause of the model crash. Therefore, the firm finance part has been changed based on the information that is gathered through a thorough desk research.

Restructure the Income statement and Dividend

Based on what is suggested in chapter 3.3.2, the dividend calculation in the model has been modified to follow a proper income statement. The net income of the firms is now calculated as shown in the below chart:

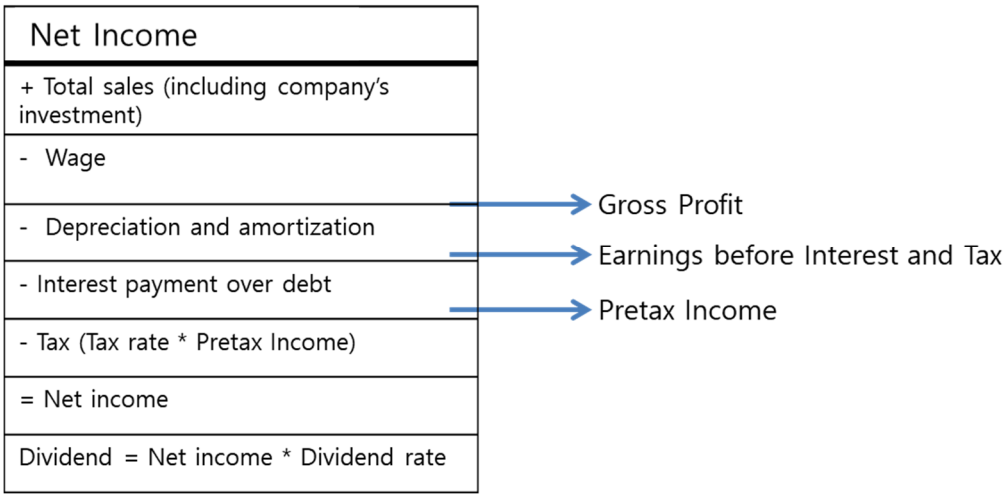

Fig 25. Net income and dividend calculation.

The dividend is given from the properly calculated net income in the improved model. Although dividend payout ratio (Dividend rate) is a subject to uncertainties, dividend payout ratio is set to 0.75 in the improved model[41].

[41] Devidend payout ratio 0.75 is still bigger than the empirical average dividend payout ratio of 0.3 – 0.4. However, the devidend payout ratio is one of the most sensitive variables in the model and it determines the model's behavior significantly. In the later chapter 7 and 8, the further analysis on dividend payout ratio in the

Even though the income statement measures the firm's profit during certain time period, it does not provide the information of the actual cash that the firm earns over the same time period. The statement of cash flow is to determine how much cash the firm has earned and spent during a certain period. Berk & Demarzo (2013) said in their corporate finance book that *"The statement of cash flows reports the sources and uses of the firm's cash during a given time period, and can be derived from the firm's income statement and the changes in the firm's balance sheet. The statement of cash flows shows the cash used (or provided) from operating, investing, and financing activities."*

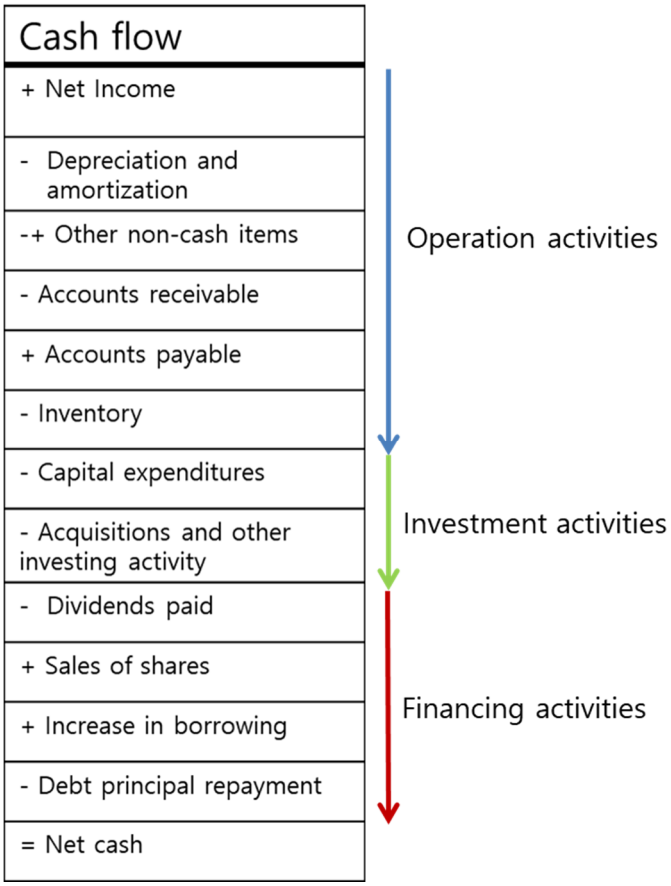

Fig 26. The principle to make a statement of cash flow

As shown in the above figure, the statement of cash flow starts from net income which is derived from the income statement. Unlike the income statement, the statement of cash flow measures strictly the cash that has come and gone from the firm's cash holdings. Therefore, the items like depreciation and amortization, account receivable, account payable and inventory are converted to the cash flow[42]. As those items usually do not feature actual cash flows but promises, they are retraced from the net income in the statement of cash flow.

The cash that has been used to pay for the investment, such as for a new plant, machineries or other

model and the recommendation for the possible future improvement will be suggested.

[42] Account receivable is a payment for goods supplied and/or services rendered that customers/clients have ordered but not paid for. And account payable is a liability of the money owed by the firm to the suppliers.

materials, is deducted in the investment activities. In the financing activities, the dividend payment, fund raised by sales of shares and borrowings and debt principal repayment are included. One thing to be clear is that the debt interest payment is not deducted in the statement of cash flow because it is already adjusted in the net income (from the income statement).

The firm's deposit in the model has to be determined by this physical cash flow. In the original model, the net income from its flawed income statement is considered to be a cash flow into the firms' deposit. In the improved model, the actual cash flow is calculated starting from the net income which is derived from the income statement.

Following above principles, the net cash flow that goes into the firms' deposit in the model is changed as below:

Cash flow
+ Net income
+ Depreciation and amortization
- Production Capital purchase (equipment, plants..)
- Dividend payment
+ Sales of share
+ increase in borrowings
- Debt principal repayment
= Net cash flow

Fig 27. Cash flow chart

One thing to be clear in income statement is that the capital investment was added in the "Total sales" category in the income statement and then deducted again in the cash flow statement. In the model, the firm is heterogeneous, firm's purchase and sales of goods and services are offset.

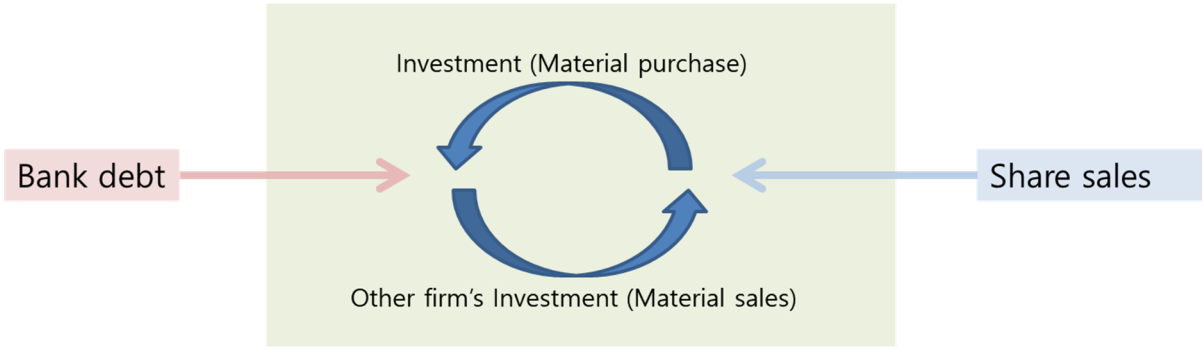

Fig 28. Firm investment diagram

As shown in the above diagram, the purchases and sales of goods and services between firms are offset while the money for the purchases is brought from external borrowings (bank debt) and share

sales.

Furthermore, the depreciation which has been deducted as an expense in the income statement is added back again in the statement of cash flow as it is not physical cash outflow. The net cash flow can be either positive (profit) or negative (loss). If the net cash flow is positive it goes into the firm's deposit. But if it is negative and the existing firms' deposit will become negative due to this cash flow deficit, the firms make up the deficit with share sales and bank debts.

Accumulated cash flow – Firm deposit

In the improved model, the firm's deposit is an accumulated net cash flow. The initial level of the firm deposit is 10 billion euros in 1950. The firms' deposit changes by the net cash flow:

$$\frac{dDep_f}{dt} = cf \qquad [M/year] \qquad (32)$$

Dep_f is the firms' deposit and cf is net cash flow. When cf is negative, a firm first sees if it can afford the negative cash flow with their cash holdings (deposit). If the firm has enough deposit to mitigate the loss, the firm endures the negative cash flow. However, if the firm does not have enough deposit, the firm seeks a way to make up the loss. The firm issues shares or take bank loans as much as the deficit:

$$\begin{cases} b * -cf = BL_{extra} \\ (1-b) * -cf = S_{extra} \end{cases} \qquad (cf < 0,\ Dep_f + cf < 0) \qquad [M/year] \qquad (33)$$

BL_{extra} and S_{extra} are the extra[43] bank loan and extra shares that the firm takes and sells to cover the sales deficit. b is the firm loan ratio.

Furthermore, the firms retain their earnings for investment in the improved model. In the original model, the firms always take bank loans or sell shares in order to fund investments (see equation 8). However, since the firms do not give the shareholders all of their net income in the improved model, they can save some of their earnings. The firms can utilize the retained earnings to funding the investment.

When an investment is required, the firm first checks if it holds enough cash to pay for the required investment. If the deposit is enough for the investment, the firm pays for the investment with their deposit. In this case, the firm does not have to take any external funding such as through bank debts or share sales. This means that the firm in the model does not have any cash flow regarding the investment as they are heterogamous in the model. When they take external funding from the banks and shareholders, they have a positive cash flow. However, when the firms can afford the investment with their own cash holdings the money does not flow in and out, as shown in the below figure 29.

[43] Other than for an investment.

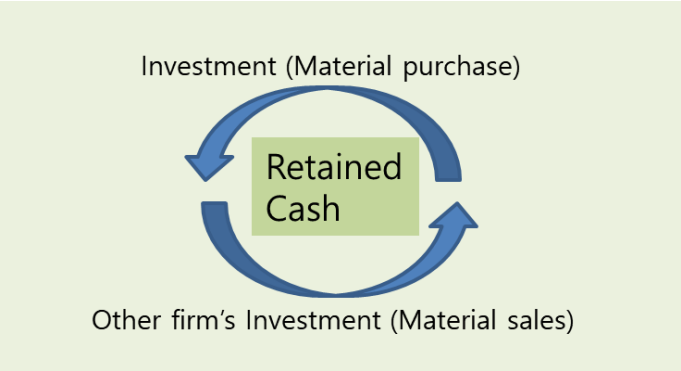

Fig 29. Retained cash funding. The firms do not need any external fund raise for their investment.

Comparing to fig 28, fig 29 shows that the firms do not need any external cash flow to fund their investments if can they have enough cash.

If the firm cash is not enough to afford the investment, the firm first funds the investment with existing deposit as much as possible and it funds the remaining investment with the share sales and bank loan. The firms, however, do not use all of their deposit in order to fund the investment. The minimum deposit level to keep in case of a sales deficit (negative net cash flow) is set to 10 billion euro[44] in the model.

$$\begin{cases} b * (I_{gross} - (Dep_f - MI_f)) = BL_f \\ (1-b) * (I_{gross} - (Dep_f - MI_f)) = S \end{cases} \quad (I_{gross} > (Dep_f - MI_f)) \quad [M/year] \quad (34)$$

$$\begin{cases} b * I_{gross} = BL_f \\ (1-b) * I_{gross} = S \end{cases} \quad ((Dep_f - MI_f) <= 0) \quad [M/year] \quad (35)$$

b is the firm loan ratio and it is a subject of uncertainty. It is set to 0.25 in this model. As the sales of shares depends on the deposit level of LBC consumers, the firm first checks if LBC consumers have enough deposit to buy the shares issued[45]. If LBC consumers do not have enough deposit to buy all the shares issued, the firms sell only the amount that LBC consumers can afford and transferred the rest to be funded by a bank debt.

$$BL_{fnew} = BL_f + (S - Dep_{LBC}) \quad (Dep_{LBC} < S) \quad [M/year] \quad (36)$$

$$b_{new} = \frac{BL_{new}}{I_{gross}} \quad [Dmnl] \quad (37)$$

BL_{new} is a new firm bank loan also including the unfulfilled amount of investment from the share sales. b_{new} is the new firm loan ratio with BL_{new}.

[44] This number is arbitrarily chosen as there is no available data of the average minimum cash holdings for the entire domestic firms.

[45] In real corporate financing, the firms strategically choose between bank debt and share issuance considering the interest payment, taxation and their management preferences (Berk & Demarzo, 2013). However, this strategic decision making has been excluded in this model for the simplicity.

Therefore, when a firm does not have enough deposit (cash) the firms have to raise the fund from the external source (shares and bonds). When the firm has to fund both the sales deficit and the investment with sales of shares and the deposit of LBC consumers is limited, the firm has to make a decision on which expense it will fund first. In this model, the firms first fund the investment with available LBC deposit and then fund the sales deficit[46].

In the improved model, the calculation of the firm production capital (equipment) profitability has been also modified. In the original model, the capital profitability is calculated as below:

$$\pi_K = \frac{p\,dY - pk\,(\rho+\delta)\,d_K}{pk\,(\rho+\delta)\,d_K} = \frac{p}{pk}\,\frac{\partial Y}{\partial K}\,\frac{1}{(\rho+\delta)} - 1 \qquad \text{[Dmnl]} \qquad (4)$$

The cost of the capital is represented depreciation rate δ and interest rate ρ. However, the firms use bank loans only partially to fund their investment in the capital. Therefore, the cost of the capital has to be calculated:

$$\pi_K = \frac{p\,dY - pk\,(\rho * b_{new}+\delta)\,d_K}{pk\,(\rho * b_{new}+\delta)\,d_K} = \frac{p}{pk}\,\frac{\partial Y}{\partial K}\,\frac{1}{(\rho * b_{new}+\delta)} - 1 \qquad \text{[Dmnl]} \qquad (4)$$

In the improved model, the cost of the capital is depreciation and interest on the part of capital that the firms bought with bank loans. In this way, the firms' investment cost is lower if the firms use more of their own cash and it is higher if the firms take more bank loans.

Improvement of the model crash

As result of this change, the model crash is eliminated because the positive feedback loop with dividend and the problematic delay time are eliminated. The stability of the model increases significantly and it does not crash in the smaller time steps and also in different conditions.

It is thus possible to examine the effectiveness of FRB system in different economic scenarios. The examination will be executed with uncertainty analysis and policy robustness test in chapter 7.

4.1.2 Consumption mechanism

As described in chapter 3.3.2 Consumer consumption mechanism, LB and LBC consumers first decide how much income they would like to allocate to purchasing bonds and shares in the original model. However, in the improved model, they allocate income to consumptions first[47]. They allocate the rest of income to shares and bonds or to saving deposit.

[46] This is however, not a corporate behavior that is backed up by literature. Such corporate behavior is arbitrarily assumed. A thorough literature research is required to determine the corporate decision making process in such circumstances.

[47] This consumption mechanism is not applied to the D consumers as D consumers always consume with the rest of the income after debt repayment.

In the improved model, the consumers consume first with their income and then buy bonds and shares with the rest. Therefore, the equation 12 and 13 are reformulated as below:

$C_{LBC} = b_{DI} * DI_{LBC} + b_w * Dep_{LBC}$ [M/year] (12)

$C_{LB} = b_{DI} * DI_{LB} + b_w * Dep_{LB}$ [M/year] (13)

C is consumption and b_{DI} is a fraction of disposable income that the consumers use for consumption. DI is disposable income. b_w is a fraction of wealth that the consumers use for consumption. The b_{DI} is set to 0.8 in the model. b_w is set to 0.03.

$DI_{LBC} = W_{LBC} + repay\ B_{LBC} + Div + \rho_d * M_{LBC} - T_{LBC}$ [M/year]

$DI_{LB} = W_{LB} + repay\ B_{LB} + \rho_d * M_{LB} - T_{LB}$ [M/year] (38)

The difference between the disposable income of LBC consumers and LB consumers is that LBC consumers receive dividends from the firms and also pay tax on the dividend.

After deducting consumptions and Value Added Tax (VAT[48]) from the disposable income, LB and LBC consumers can use both remaining income and savings to investing in the government bonds and firm shares.

The remaining income is calculated as below:

$Ri_{LBC} = DI_{LBC} - C_{LBC} - tr_{VAT} * C_{LBC}$ [M/year]

$Ri_{LB} = DI_{LB} - C_{LB} - tr_{VAT} * C_{LB}$ [M/year] (39)

Ri is remained income and $tr_{VAT} * C$ is VAT. The equation resents that LB and LBC consumers consume first with their disposable income and then use the rest for other purposes.

For LB consumers who only buy the government bonds, there is no need to divide the savings to invest both in shares and bonds. However, for LBC consumers who purchase both bonds and shares, the savings have to be allocated to the bonds and shares each.

Unlike in the original model, LB and LBC consumers do not buy government bonds and firm shares as much as they can afford with their deposit. LB and LBC consumers set a limitation in their deposit for buying shares and bonds.

$S_{LBC} = f_s * (Ri_{LBC} + HI_{LBC}) + f_{sw} * Dep_{LBC}$ [M/year] (40)

$G_{DLBC} = (1-f_s) * (Ri_{LBC} + HI_{LBC}) + f_{bwLBC} * Dep_{LBC}$ [M/year]

$G_{DLB} = (Ri_{LB} + HI_{LB}) + f_{bwLB} * Dep_{LB}$ [M/year] (41)

S_{LBC} is share purchases of LBC consumers with income and savings. f_s is a fraction of LBC consumers' income which is allocated to buying shares. It is 0.5 in the model. HI is the income from the house

[48] Consumption tax.

sales. HI occurs when the D consumers purchase houses from LB and LBC consumers. f_{sw} is a fraction of wealth (deposit) with which LBC consumers would buy firm shares. It is set to 0.4. G_{DLBC} is the government bond purchase of LBC consumers. f_{bwLBC} is a limit fraction of the deposit with which LBC consumers would buy government bonds. It is set to 0.3 in the model. G_{DLB} is the government bond purchase of LB consumers. f_{bwLB} is a limit fraction of deposit that LB consumers are willing to buy bonds with. It is 0.5 in the model.

In this way, LB and LBC consumers buy bonds and shares only with the limited wealth (deposit) with which they are willing to buy bonds and shares.

4.1.3 Household default

According to Arthur & Sheffrin (2003), households default when they are not able to meet the legal obligation of loan repayment. This means that they default when they fail to repay loans. As discussed in chapter 3.3.2 Household default mechanism, the current default mechanism does not reflect the fact that the households default not because of the current house price but because of accumulated debt repayments from the past.

Therefore, in the improved model, the households also default not only when RQ exceeds the threshold but also when their yearly debt repayment obligation exceeds their yearly income. The households default in below conditions:

$$RQ > RQ_{thres} \qquad \text{<condition 1>}$$

$$\left(\frac{BL_D}{t_{repay}} + \rho_l * BL_D\right) > DI_D \qquad \text{<condition 2>}$$

Households default in either condition 1 or 2. Condition 1 represents the RQ threshold exceedance. Condition 2 shows that the households default when the yearly debt repayment exceeds their yearly disposable income. DI_D is D consumers' disposable income and it consists of wage, social payment, the bank loan left after house purchase and the interest over deposit minus income tax and VAT on the previous consumptions. In this way, households default when they cannot afford the accumulated debt repayment.

Furthermore, the defaulting household loans that are written-off against the bank equity are always 100 billion euro in the original model (see 3.1.5 house price). This arbitrary number has been changed to adjust the actual amount that D consumers owe. In either condition 1 or 2, the defaulting household bank loans are:

$$BL_{def} = BL_D * f_{def}$$

BL_{def} is defaulting bank loans that are written-off and f_{def} is a fraction of the households bank loan that defaults. f_{def} represents how many households actually default when either condition 1 or 2 is fulfilled. Although this fraction is remained uncertain, it is set to 0.5 for the base case. This means, when either condition 1 or 2 is fulfilled, half of households default.

4.1.4 DFM loan mechanism

As discussed in chapter 3.3.2 DFM system, there are few misinterpreted concepts of DFM system. Firstly, an Egmond and De Vries did not specify what the role of banks is in DFM system. In the original model, the bank does not serve as an intermediary between borrowers and depositors. There is also no other intermediary institute introduced that manages the debt issuance.

Therefore, in the improved model, the new assumption is established, regarding the role of banks in DFM system. The banks still function as an intermediary between borrowers and depositors and take interest spread between interest on the debt and interest on the deposit. This is considered to be a reasonable assumption as the loans are given from the bank deposit and therefore, the banks will need to decide how to utilize the bank deposit.

The banks now serve as an intermediary facility between borrowers and depositors receiving the interest spread as a fee. Therefore, the BL_{total} in equation 22 and 23 are changed:

$$BE = \rho_l * BL_{total} - \rho_D * Dep_{total} \quad [M/year] \quad (22)$$

$$Cr = f_{cr} * BL_{total} \quad [M/year] \quad (23)$$

In the original model, the BL_{total} in the equation 22 and 23 includes only the loans given under MaD system. In the improved model, the BL_{total} includes loans given under DFM system as well.

The second problematic structure in DFM system is the households default mechanism. As discussed in chapter 3.3.2 DFM system, the households' loans are written off only when the bank equity cannot meet the capital requirement under DFM system. However as the loans are not written off against bank equity under DFM system, the households' loans are never written off under DFM system.

The solution for this mechanism is to establish the households default mechanism as same as the households default mechanism under MaD system. Under the MaD system, the households' loans are written off as soon as households default. This means that the households either when RQ exceeds the threshold or when the households cannot afford the loan repayment with their disposable income.

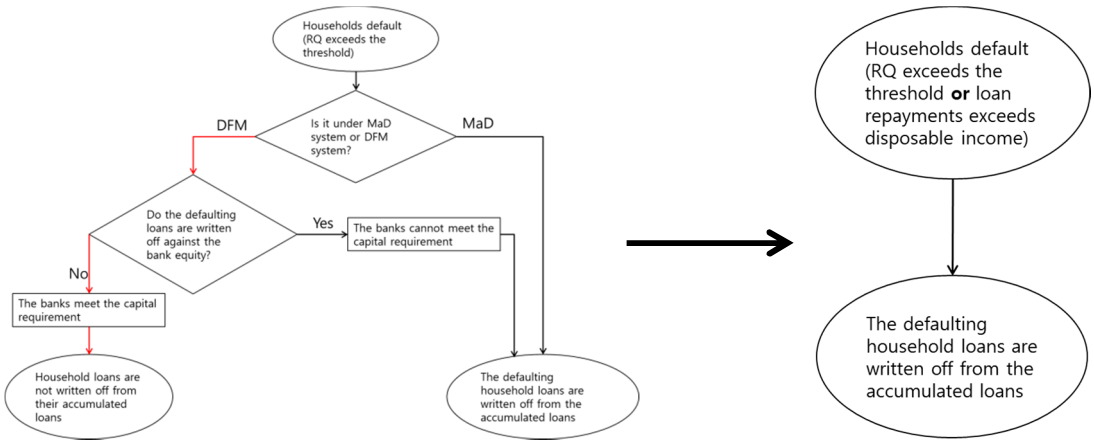

Fig 30. DFM loan write-off mechanism before (left) and after (right) improvement.

As shown in the above figure, the households default mechanism under DFM system has been changed to same as under MAD system. The defaulted loans are written off from the amount of the debt that the households have to repay (the households no longer have to repay the written off debt).

Under DFM system, the loans are not written-off against the bank equity but against LB and LBC consumers' deposit. A problem regarding writing off defaulted loans from LB and LBC deposit is that the amount of loans that are written off is only 20% of the actual defaulted loans.

$Depout_{LB} = (1-h)(BL_{frb} + Def_{frb}) * f_{LB}$

$Depout_{LBC} = (1-h)(BL_{frb} + Def_{frb}) * f_{LBC}$ [M/year] (30)

In the equation 30, it is shown that the (1-h) which is 0.2 is also applied to the defaulting FRB loans, Def_{frb}. Therefore, this equation has been changed as below:

$Depout_{LB} = ((1-h)*BL_{frb} + Def_{frb}) * f_{LB}$

$Depout_{LBC} = ((1-h)*BL_{frb} + Def_{frb}) * f_{LBC}$ [M/year] (44)

Now (1-h) is only applied to the BL_{frb} not to the Def_{frb}. In this way, the defaulted loans are written off properly against LB and LBC consumers'

4.2 Improvement of model units

The model unit specification was done following below rules:

1. The monetary unit of the model is always [billion euro] except for the price, house prices and the wage per person. The price unit is [euro/unit] which means a price per unit of goods and services. The house price unit is set to [k euro] per house. Wage unit is [k euro/(person*year)] which means wage that the each employ receive per year.

2. The rate of change is dimensionless.

3. The time unit in the model is year.

4. The unit of money stock variables such as consumers', firms' and government's deposit and bank equity is [billion euro] without time variables. However, the unit of the money flow into those stocks is [billion euro/year] which represents how much money comes in and goes out from the money stock per year.

5. The unit of the variables that is derived from the population, such as the number of LB, LBC and D consumers, the number of households and labors, is [million person].

6. The unit of fraction or rate such as depreciation rate or dividend payout ratio is dimensionless. However, if the rate changes every year or is applied every year, the unit [1/year] (=[dimensionless/year]) is used.

As presenting over 400 unit errors that were corrected is impractical, only a handful number of variables are selected in order to show the change:

Table 4. A short list of the unit changed.

Variable	Original unit	Changed unit
Physical output	-	billion unit (of goods and services)/Year
Capital stock	M	Billion unit (of capital)
Wage	€/person/hr	k euro/(person*Year)
Interest rate on debt	Dimensionless	1/year
Number of transaction	-	1/(household*Year)
Change rate of bank loan	-	1/year
Repay term	-	year

4.3 Introduction to the model performance indicators (MPIs)

In order to see the effect of DFM system and model improvement, a relevant variable was chosen to show the performance of the model. The variable is called model performance indicator (MPI) in this thesis. The MPI is chosen based on following rules:

- MPI represents economic performances in the modeled system.
- MPI shows differences between the original model's behavior and improved model's behavior.

Following above rules, price is chosen as a MPI in this thesis. The reason that price is chosen is because the price is a core variable which is resulted from various economic principles and mechanisms. Furthermore, it affects and is affected by many different variables being in the center of the model performance. In order to analyze its behavior, it is requited to thoroughly understand feedback loops in the model and other core variables such as physical production, unemployment and households default.

The price is one of determinants of the labor and capital profitability (see equation 2 and 4). The labor profitability decides the labor demand and therefore, the employment rate and the wage level. The wage level is one of the determinants of the households default because if the D consumers' wage becomes larger, house prices increase as well. Furthermore, the D consumers cannot afford the large amount of debt repayment if the wage becomes smaller. Price level also has an influence to the government expenditure as well. When the price increases, GDP increases as well and the government debt ratio (see equation 18) decreases. Therefore, the government expenditure increases and tax rate decreases.

Price is chosen to be a MPI not only because it is a core variable in the model but also it is one of the most commonly used economic indicators (Mankiw, 2009; OECD, 2018). In most of well-known data bases such as national data bases, World Bank, OECD and EU, price level or the change rate of price level (referred as inflation when price level increases and deflation when it decreases) is used as one of the core economic indicators.

05 Model Results

5. Model Results

5.1 Model results of the original and improved model

Under MaD system

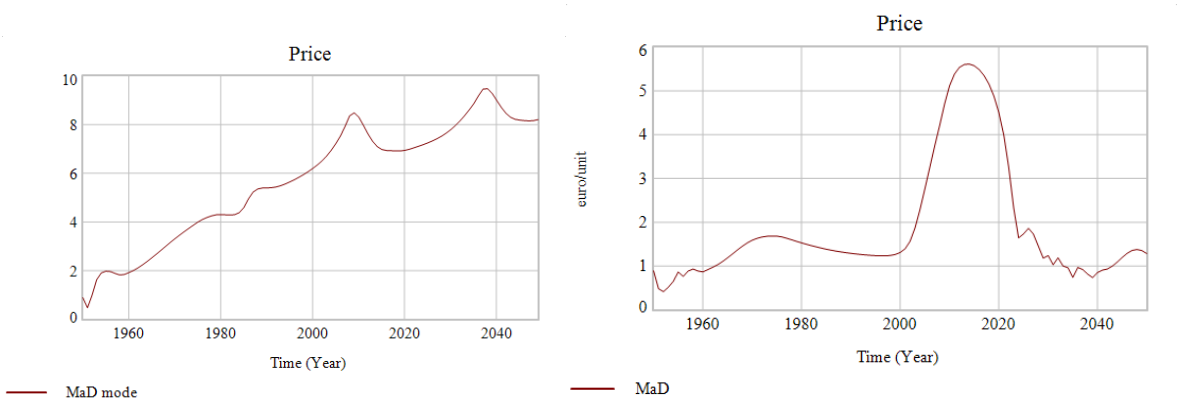

Fig 31. Price graph of MaD system in the original model (left) and in the improved model (right).

There are a few notable differences between the original model's result and the improved model's result. Firstly, the households defaults in 2007 does not affect to the price in the improved model.

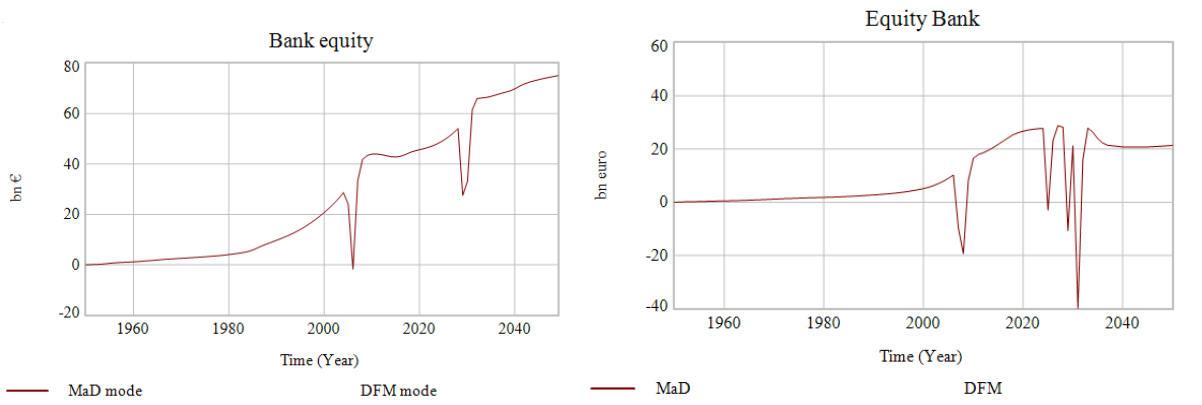

Fig 32. Bank equity under MaD system in the original model (left) and in the improved model (right)

The above graphs show when the households default and therefore, the debts are written off against the bank equity. In the original model, the households default two times around in 2005 and in 2029. In the same period of time, the price also drops. In the improved model, the households default in year 2007, and year 2025, 2029 and 2031. However, the households default in year 2007 does not affect to the price at all. But the price starts decreasing when there is no households default. This is considered because the reasons that the price drops are different in two models.

In the original model, the price drops when the RQ exceeds its threshold. When the households default, the banks lose their equity and the government bails out the banks. The government debt increases in this process and the social payment to the D consumers decreases. This reduces the D consumers' consumption level and price level.

However in the improved model, the price starts decreasing when wage grows too fast relative to

the price of goods and services. The firms then demand fewer labors due to the low profitability. In the employment rate graph, it is shown clearly that the employment started decreasing since 2004. However, that is not when the price drops. The wage does not decrease when the employment goes down because the accumulated labor demand of firms has increased so much until 2004. Since the labor demand has been increasing for a decade before 2004, the labor demand is still bigger than the labor supply when the labor demand starts decreasing.

Therefore, the employment growth is positive until 2013 when the labor demand becomes smaller than the supply. From that point, the employment growth becomes negative and the wage starts falling.

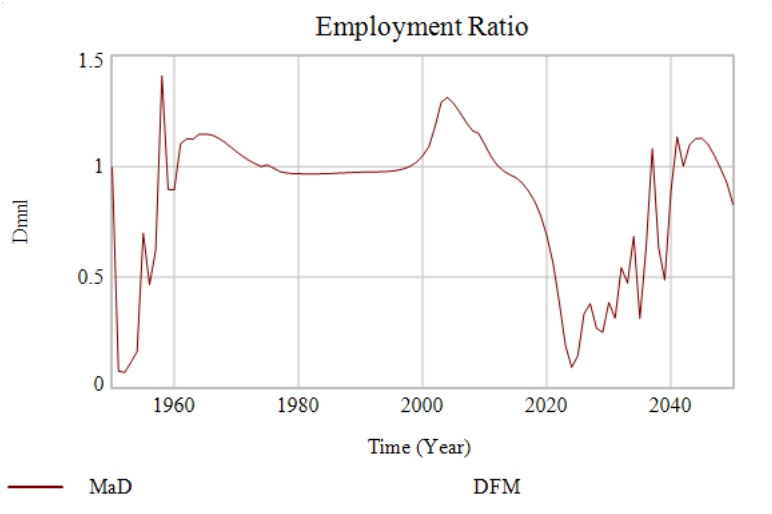

Fig 33. Employment rate under MaD system in the improved model

Then why does the households default in 2007 not affect to the price level in the improved model? The reason is because even when the demand for the goods and services falls 2007, the supply of goods and services is still lower than the demand. As mentioned above, the firms' labor demand was decreasing since 2004. This causes the production of the goods and services to decrease. In 2007, the accumulated supply deficit was significant. Therefore, even though the aggregate demand falls in 2007, the price does not decrease because the supply of goods and services is still lower than the demand.

Therefore, the reason behind that the price level is increasing being untouched during the first households default in 2007 is the production decline that keeps the price increasing. The accumulated production deficit maintains the price level increasing until the wage and the demand for the goods and services are actually falling so that the accumulated production deficit is disappearing.

Furthermore, the households default more often in the improved model when the price falls. This is due to the improved households default mechanism. Now the households default when they cannot afford the repayment of the accumulated household debts from the past. When the price level decreases, the wage and the social payment decrease as well. This puts the D consumers in a trouble to repay the debts that they made when the economy was still in the "boom" statement.

The households default in series from 2025 to 2031. They default until the debts are written off enough that they can afford the repayment. The recession lasts longer due to the defaults as the government has to keep bail out the banks and therefore, it has to increase the tax rate and decrease the expenditure. The economy thus falls in a state that it is hard to recover.

This result is in line with what Turner (2015) has argued in his book "Between Debt and the Devil: Money, Credit, and Fixing Global Finance". In his book, Turner addressed the danger of debt based economy. If the economic cycle highly depends on the housing market and private debt, a severe and long-lasting recession can result when something happens that can influence to the borrowers' solvency. In this model, that is the decreasing employment since 2014.

With the lower income, the D consumers (borrowers) reduce their consumption in order to repay the debt[49]. If the consumers consume less, the price level goes down and the firms' profit also decreases. Therefore, the firms do not hire people and the wage level is maintained low. Therefore, this positive feedback loop causes the long-lasting recession. With the low wage, the households can no longer afford the debt repayment that they made when the economy was in boom.

This effect is called debt overhang in his book. The debt overhang creates a long lasting recession after a financial crisis and it takes longer time for the economy to recover its performance.

In summary, the reason why the recession starts in the original model is because the house price went too high. Then the government decreases their expenditure in order to bail out the banks. The consumption and price level fall subsequently. The debt repayment does not directly affect to the consumers' consumption.

In the improved model, the reason why the recession starts is because the overheated economic boom is finished by a burst of wage bubble. The employment and wage grew too fast, which even hampers the firms' profit during the economic boom. Then the firms start demanding less labor. The wage bubble bursts when the labor demand of firms becomes less than the labor supply. The wage and price level starts decreasing from this point. With the lower wage, the consumers decrease their consumption in order to repay the debt. With the low consumption level, the employment and wage level cannot recover and the long lasting recession comes. During the recession, the households default on their debt as they cannot afford the repayment.

Therefore, the improved model shows that as long as the wage grows as fast as the house price or debt repayment, the households do not default. However, if the recession starts due to the low labor productivity or due to other reasons which bring the wage level down, the debt traps the economy in the long-lasting recession.

The result graphs of house prices, household debt, employment, GDP and physical output can be found in the appendix E.

[49] In the original model, however, the D consumers' consumption level decreases not because of the debt repayment but because the social payment decreases. The debt repayment does not directly influence the consumers' consumption.

Under DFM system

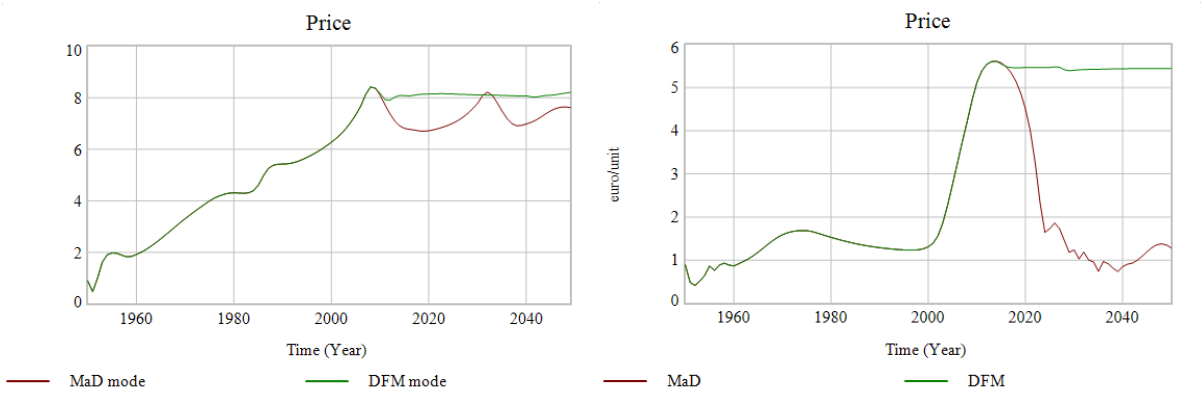

Fig 34. Price graph of MaD system (red) and DFM system (green) in the original model (left) and in the improved model (right).

As shown in the above graphs, the economic boom-bust cycle is eliminated from the time when DFM system is applied (when the red and green graphs are separated) both in the original model and in the improved model. Therefore, it can be said that DFM system functions well in the improved model.

Under DFM system, the central bank creates money following the price fluctuation and the government adjusts their consumptions, social payment and tax rate in order to keep the price level constant (see chapter 3.2).

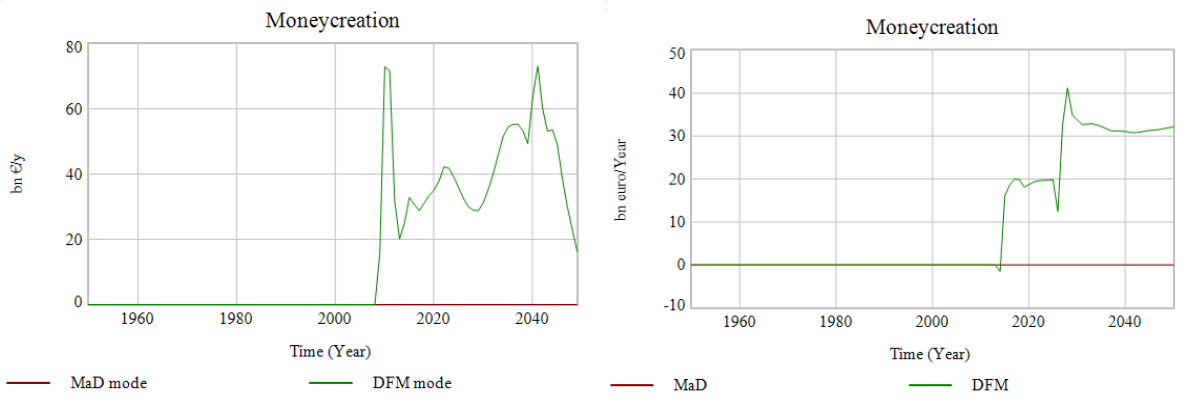

Fig 35. The money creation in the original model (left) and in the improved model (left). Since the central bank money creation only happens under DFM system, the graphs above show that the central bank money creation under MaD system is always 0.

As shown above, the central bank's money creation reacts sensitively to the price fluctuation. In the original model, DFM system is on in 2009 and until 2010 the system is in an adjustment. As the price level was decreasing at the time when DFM system is on, the central bank starts creating much money. In the 2041, the money creation increases again due to the price decrease. In 2040, the RQ exceeds its threshold and the D consumers face a large debt repayment. Even though the RQ

exceeds its threshold the households cannot get their debt written off. This is because in the original model, the household debts are written off only when the banks lose their equity for the debt write-off. However, the household debts are not written off against the bank equity under DFM system (see chapter 3.3.2 The critical assumptions in the model - DFM system).

Therefore, the D consumers cannot have their debt written off even when they are not able to afford the debt repayment. They have to decrease their consumption in order to repay the debt and this brings the price down. In the below figure, it is shown that there is a small bump in 2040 in the D consumers' consumption graph in left (the original model).

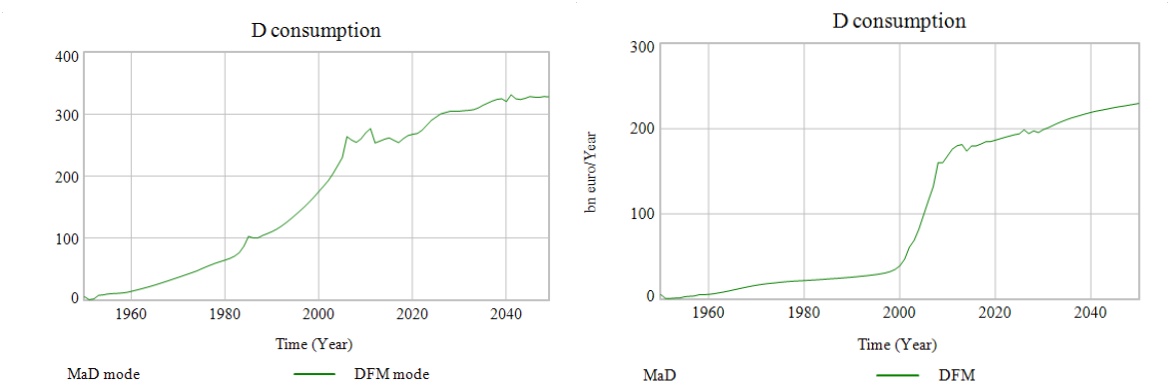

Fig 36. D consumers' consumption under DFM system in the original model (left) and in the improved model (right). In the original model, DFM system mode is on in 2009 and the system goes through adjustment period from 2009 to 2010. In the improved model, DFM system mode is on in 2014.

In the improved model, the money creation level falls in year 2025 and then it rises drastically from year 2026. In the price graph of the improved model, it is shown that the year 2025 is when the price increases slightly under DFM system and in the following year, it decreases slightly. This is due to the households default. In the improved model, the households can get their debt written off against LB and LBC consumers' deposit under DFM system (see chapter 4.2.4). This means that the households default under DFM system when the RQ exceeds its threshold or they cannot afford the debt repayment with their income.

When the households default, a certain amount of the outstanding debt is written off against LB and LBC consumers' deposit. This write-off decreases the debt outstanding for the D consumers and also decreases LB and LBC consumers' deposit. Therefore, the rising price in 2025 is explained by the D consumers' consumption increase due to the debt write-off. The D consumers consume more as the debts they have to repay decreases when the debts are written off. The falling price in the following year is explained by LB and LBC consumers' deposit decrease due to the debt write-off.

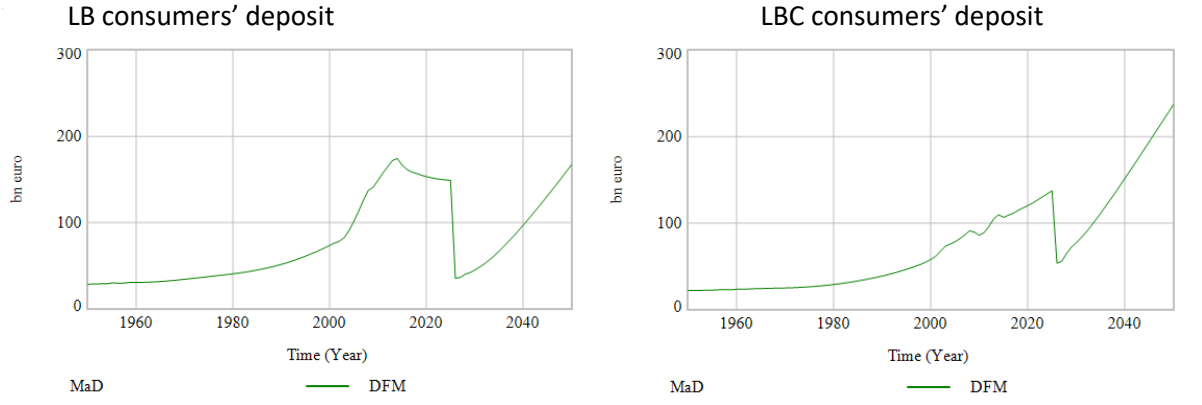

Fig 37. LB and LBC consumers' deposit under DFM system in the improved model.

The graphs above show that LB and LBC consumers' deposit decreases significantly due to the loan write-off. However, LB and LBC consumers' consumption level is not influenced as significantly because only 3% of their deposits are used for their consumptions (see the equation 16). As the wage does not change due to the constant price level, the consumption level of LB and LBC consumers is not affected significantly by the deposit decrease. After the loss, LB and LBC consumers gradually recover its deposit based on the stable income from wage and FRB loan repayment from the D consumers.

The created money by the central bank is distributed through the government expenditure such as a social payment and government consumption and tax reduction.

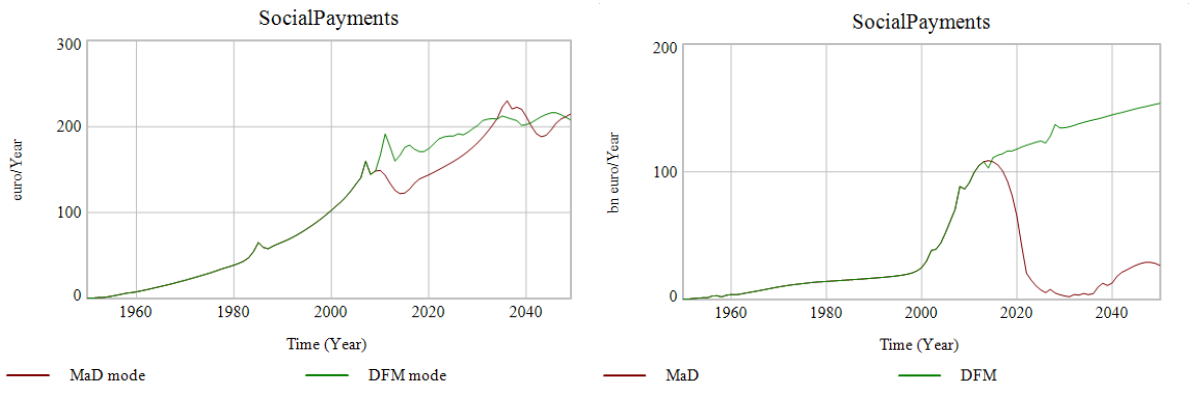

Fig 38. The social payment under DFM system (green) in the original model (left) and in the improved model (right).

As shown in the above graph, the social payment reacts sensitively to the price change both in the original and in the improved model. In the original model, the price decreases slightly right after DFM mode is on. The social payment then increase in order to raise the price level. In the improved model, the price decreases slightly in 2026 and the social payment increases in order to raise the price level.

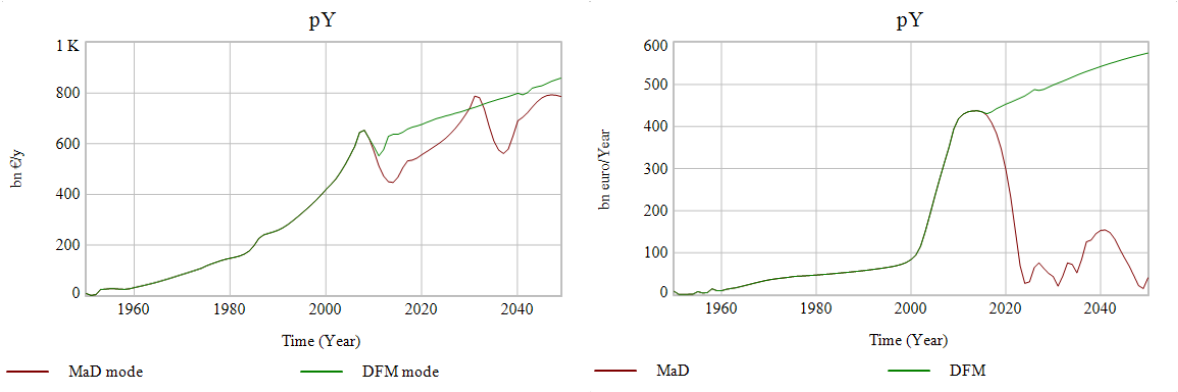

Fig 39. The GDP under DFM system (green) in the original model (left) and in the improved model (right)

It is shown in the above graphs that the GDP (price * physical output) steadily grows under DFM system in both original model and improved model. A steady GDP growth is possible under DFM system because the physical production grows steadily as well. Under DFM system, the labor and capital profitability is constant but the technology factor grows steadily (see equation 1). Therefore, the physical production increases steadily.

In conclusion, the original model and the improved model show the difference in how the recession starts. In the original model, the recession starts when house prices increase too much. In the original model, the recession starts when the wage increases too much and the damage of the recession becomes more severe and long lasting when the private debt level is high.

DFM system is effective to eliminating the recession in both models. It sustains the price level through government expenditures and tax rate adjustment. In both model, the GDP increases steadily under DFM system.

5.2 Model Result Interpretation

The improved model has its limitation in calibration. The model calibration is not included in this study's scope. Therefore, it is not appropriate to place much reliance on what happened or will happen in which year. In the improved model, year does not mean much.

The improved model is significant not because its results fit to the historical data but because it shows a complicated development of recession which is different than the one the original model shows. Furthermore, it shows the effect of FRB system in the economy. The development of recession in the improved model shows the debt overhang effect, which was not included in the original model. Therefore, instead interpreting the results as they are giving the exact values for the future state, the results have to be interpreted as they give a meaningful insight to understanding of the complex mechanism and development of recession (Ford, 1999).

The resulted behavior in the improved model shows that the combination of the decline in the labor profitability and a growing debt can cause a long-lasting recession. In Dutch economy, while the household debts increase significantly the labor profitability is maintained positive. In the Netherlands, the household debt increased 16% between 2009 and 2017. Comparing to the wage which increased only 11.2% and price which increased 12.5%, the household debt growth is significant. On the other hand, the physical production increased 11.3% and the aggregate demand increased 10.5% between 2009 and 2017.

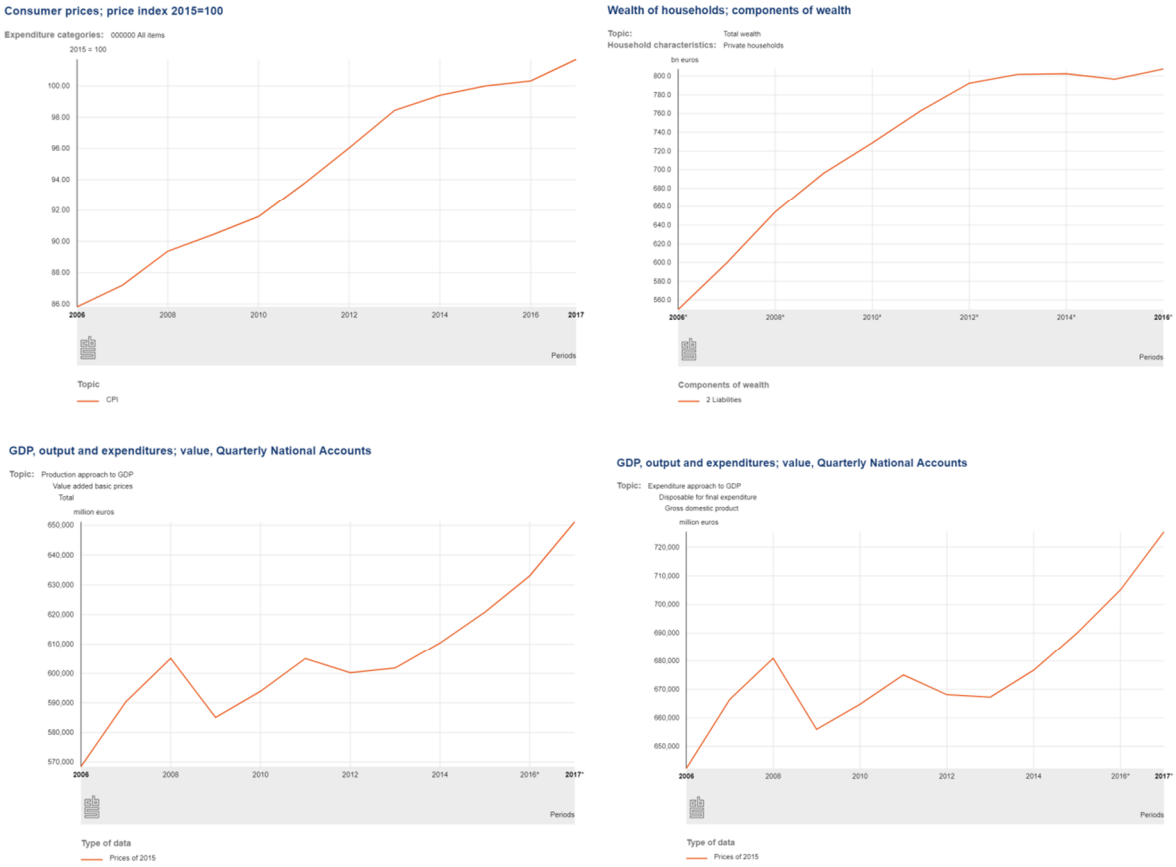

Fig 40. Price (upper left), household debt (upper right), aggregate demand (lower right) and GDP (lower left) in the Netherlands. Reprinted from GDP, output and expenditures; value, Quarterly National Accounts,

Consumer Price; Price Index 2015=100, Wealth of Households; components of wealth, by Statistics Netherlands, Retrieved October 29, 2018, from https://opendata.cbs.nl/statline/#/CBS/en/dataset/84105ENG/line?ts=1540731583984. Copyright 2018 by Statistics Netherlands. Reprinted with permission.

In the Dutch economy, the household debt increased significantly in last 9 year comparing to other economic indicators (GDP, price and wages). On the other hand, the labor productivity is positive as the price grows faster than the wage. However, there is a risk that the labor productivity becomes negative as the price decreases. In Dutch economy, the production grows faster than the consumption. This is assumed because of the high labor profitability the firms hire more people and therefore, the production increased. If production growth is maintained higher than consumption growth, there is a risk that the price declines and therefore, the labor profitability decreases. With the low labor profitability, the employment and wage will decrease and this can begin the recession in the Dutch economy.

As the accumulated debt level is high and the households have to pay back the debts, there is a high risk for households to default during the recession and this can last the recession long.

In summary, although the Dutch economy is experiencing an economic boom at the moment, there is a possibility of a long-lasting recession in future. DFM system could be a solution to prevent it in future.

5.3 Model Result Limitation

The first thing notable in the results of the improved model is that the value of almost every variable (GDP, price, social payment...etc.) is smaller than the original model. For instance, the highest price in the original model is around 8.5 euro/unit but the highest price in the improved model is only around 5.5 euro/unit. In GDP graph, the difference is bigger. The highest GDP is 800 billion euro/year in the original model but in the improved model, the highest GDP is only around 430 billion euro/year.

This is considered because that the price level in the model is highly influenced by dividend payout ratio. In the original model, dividend payout ratio is always 100% of the firms' net income. The LBC consumers receive a large amount of dividend and consume much. Therefore the price level is high. On the other hand, dividend payout ratio is 75% in the improved model and the price level is significantly lower than in the original model. In real world, the average dividend payout ratio in the real-world is around 40% (Damodaran, 2018). The model shows unrealistically low price level (below 1 euro/unit) with no growth or slump when dividend payout ratio is set to 40%. The further experiments on dividend payout ratio and analysis will follow in the chapter 7.

The second limitation in the model is that it does not show the historical values. This is because the model is not calibrated in this model. Although the purpose of this study is to understand what contributes to the recession and the effect of FRB system in the economy as mentioned in the chapter 5.2, the model calibration is still important as the model reliability is limited when the model does not show empirical results.

Furthermore, the real-world economy is more advanced than the modeled economy. For instance, the model does not include monetary or fiscal policies which have been executed in the Netherlands such as regulations on the mortgage, which would or would not have influenced to house prices and households debt level. The model also does not include importation and exportation which play important role in deciding price, wage and employment level.

06 Design of Uncertainty Analysis and Policy Robustness Test

6. Design of Uncertainty Analysis and policy robustness test

The uncertainty analysis and policy robustness test are conducted only with the improved model as the original model crashes in different scenarios. The uncertainty analysis has been conducted in order to see the model's behavior in various scenarios and to see if DFM system is effective to reducing the recessions in various circumstances. The policy robustness test has been conducted in order to analyze the circumstances in which DFM system is or is not effective.

6.1 Uncertainty Analysis

In this thesis, the uncertainty analysis is conducted in order to test if there is any case that the price is not maintained constant under DFM system.

In order to conduct the analysis, a research methodology called Exploratory Modeling and Analysis (EMA) has been used. EMA is a free distributed workbench which is run in a programming language, Python. This methodology uses computational experiments to analyze complex and uncertain systems (Bankes, 1993).

It is possible to connect the EMA workbench to the SD modeling software, Vensim, and the users can therefore conduct uncertainty analysis with the model built in the SD modeling software. Kwakkel (2012) explained that the main objective of the EMA connecting to Vensim "…is to gain insight into what kinds of surprising dynamics can occur given a variety of uncertainties and a basic understanding of the system."

The workbench conducts the experiments when the user puts the input data of the uncertain variables and the range, the outcomes that he/she wants to see, the number of scenarios and the policy levers. When the uncertain variables and its range in which the experiments will be conducted are put, the workbench uses Latin hypercube sampling[50] for both sampling over levers and sampling over uncertainties.

The workbench samples the scenarios based on the number of the scenarios that the user wishes to conduct the experiments. The policy of which the user wants to see the effectiveness in different scenarios is evaluated in each scenario. Therefore, if the user wants to test 2 policies and the number of scenarios in which the user wants to conduct the experiments is 100, the total 2* 100 = 200 times of experiments are conducted.

6.1.1 Scenarios

In this study, the EMA workbench has been used to conduct uncertainty analysis with 10 different uncertain variables.

[50] Latin hypercube sampling (LHS) is a statistical method for generating a near-random sample of parameter values from a multidimensional distribution (McKay, Beckman, & Conover, 1979). LHS divide the range of the values equally and take a sample out of each divided dimension.

Table 5. Uncertainty variables.

Name of the variable	Parameter type	Parameter range	Note
Firm loan ratio	Real Parameter	0.05 - 0.8	The ratio between two firm funding methods, bank debt and sales of shares. If the ratio is higher than 0.5, firm takes bank debt more than share sales.
RQ threshold	Real Parameter	0.5 – 1.0	RQ threshold is a determinant of household default. If the ratio of debt repayment and deposable income (wage) exceeds the threshold, the household defaults.
LB consumers' deposit fraction used for a bond purchase	Real Parameter	0.1 - 0.8	It is a fraction of saving deposit that LB consumers use to buying bonds.
LBC consumers' deposit fraction used for a share purchase	Real Parameter	0.1 - 0.7	It is a fraction of saving deposit that LBC consumers use to buying shares.
The ratio of the firms' net income given as dividend (Dividend payout ratio)	Real Parameter	0.1 - 0.8	It is a fraction of the firms' net income that the firms give shareholders as dividends. If the ratio is 0.5, the firm gives shareholders half of its net income as dividends.
The fraction of LBC consumers' income to buying share	Real Parameter	0.1 - 0.9	It is a fraction of net income that LBC consumers use to buying shares. If the ratio is 0.3, LBC consumers use 30 percent of their income minus consumption to buying shares.
The ratio between LB and LBC consumers to sell bonds	Real Parameter	0.1 - 0.5	When the government sells bonds, it decides how much to sell to each consumer group, LB and LBC. This variable is a fraction of bonds issued sell to LBC consumers. If it is 0.5, the equal amount of bonds is sold to LB and LBC consumers.
Depreciation rate in manufacturing sector	Real Parameter	0.1 - 0.3	Rate of the manufacturing production capital that is depreciated every year.
Depreciation rate in service sector	Real Parameter	0.1 - 0.3	Rate of the service production capital that is depreciated every year.
The ratio of the households debt that default when D consumers default	Real Parameter	0.5 - 1.0	A fraction of the household debt that default when the D consumers default. If it is 0.5, half of the outstanding household debt defaults and is written-off when D consumers default.

The above variables are chosen for the following reasons:

1. The selected variables are not known its exact value and contain possibility of the variation in real-world economy. For instance, the capital depreciation rate in manufacturing and service sector can vary depending on the type of industry and the equipment (n.d., 2004). A fraction of LBC consumers' income that is used to purchasing the firm shares are also unknown and can vary depending on the individuals.

However, the "Dividend payout ratio" or "RQ threshold" are clarified relative well by real-world data and some literatures. These variables, however, are chosen in order to see their impact in the model as the model is expected to be very sensitive to these variables.

2. The above 10 variables might have significant influence to the model results. "Depreciation rate in manufacturing sector", "Depreciation rate in service sector", "The fraction of LBC consumers' income to buying share", "Firm loan ratio" and "LBC consumers' deposit fraction used for a share purchase" have a direct relation with the firm investment. The variables "RQ threshold" and "The ratio of the household debt that default when D consumers default" affect directly to the households default, debt write-off and government bail-outs.

The variables "The ratio of the firms' net income given as dividend" also plays a significant role as it decides the income and the consumption level of LBC consumers. "The ratio between LB and LBC consumers to sell bonds", "LB consumers' deposit fraction used for a bond purchase" and "The fraction of LBC consumers' income to buying share" influence the bond sales.

3. Some of the variables are not possible to estimate the possible range. Most of the relaxation factors are not clarified by the real-world data and therefore, hard to estimate the possible range. In the model, the relaxation factors (expressed as τ in the equations in chapter 3) are mostly arbitrarily chosen for the model calibration. The original modeler, Van Egmond and De Vries have calibrated the model with these relaxation factors for the model to show historical values in year 1950 to 2016. As the scope of this thesis does not include the model calibration the relaxation factors were unchanged.

4. The model is too sensitive to some of the variables. Variables such as "a fraction of the net income that LB and LBC consumers use for consumptions" (b_i in equation 16) change the model significantly when they are changed very slightly. For instance when it changes from 0.7 to 0.8 the price level becomes more than 10 times bigger. When it changes to 0.6, the price level decreases to 10 times smaller. Due to this sensitivity, this variable was considered inappropriate for the experiments. However, it gave an insight for the analysis that the consumers' consumption level plays a core role in the model.

6.1.2 Outcomes, policy and number of scenarios

The MPI (the price) will be shown as an outcome in the uncertainty analysis. In this analysis, only one

policy was tested, DFM system[51]. The number of the scenarios was chosen to be 8000. The number was chosen because of the behavior of the model does not change much when the number increases more than 8000. Therefore, it was considered that the 8000 scenarios can present the variation of the results well.

[51] DFM system is a monetary policy framework.

6.2 Policy robustness test

The objective of the policy robustness[52] test is to analyze in which circumstances DFM system is of is not effective. In order to test this, EMA workbench is used with the same scenarios defined in the previous chapter 6.1.1. The policy robustness criteria are as below:

Criterion 1. The price level under DFM system should not change more than 5%.

Under DFM system, the central bank creates money in order to keep the price level constant. Therefore, the price level must not fluctuate much under a well-functioning DFM policy. This criterion is only triggered when DFM system mode is on. The price change when DFM system is off is not counted for this criterion.

Criterion 2. DFM system should be turned on in the model.

In the model, DFM system is turned on when the banks cannot meet its capital requirements and when the nominal GDP (price * physical output) decreases (see chapter 3.2). Therefore if the economy is stable with an increasing GDP and without a households default, DFM system is not turned on as it is not necessary.

The number of scenarios in which the experiments are conducted is 4000. As the test is only for DFM policy case, the policy number is one. In the policy robustness test, it is examined if there are any cases that fulfill one of the criteria or both. If there are such cases, the scenarios behind will be searched and analyzed.

[52] The policy is said to be robust when it is effective as it is intended.

07 Results of Uncertainty Analysis and Policy Robustness Test

7. Result of uncertainty analysis and policy robustness test

7.1 Uncertainty analysis

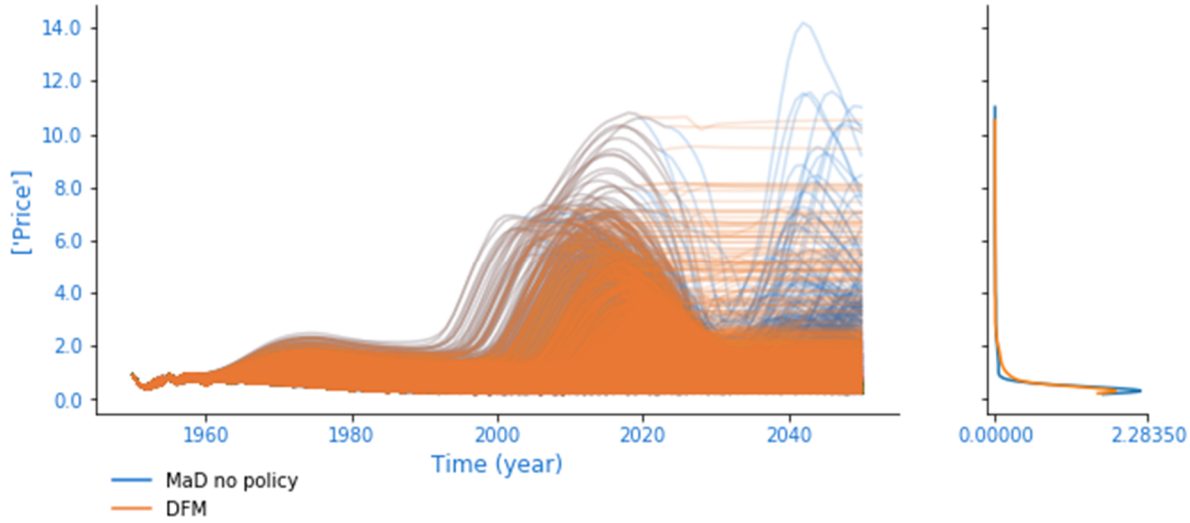

Fig 41. Price graph and the density of the results in the various scenarios

The left side graphs are the results of 8000 experiments in different scenarios and the right side graphs represent the density of the results. The density of the results shows at which level most of results are concentrated.

The density graphs of MaD system and DFM system are very similar. Moreover, the uncertainty graph on the left shows that the most of DFM results (orange) do not show constant price during the recession (when the price declines). Therefore, it is considered that there are a significant number of scenarios in which either DFM system is not effective or is not turned on (see chapter 3.2).

Furthermore, the price level is varied in different scenarios but it is mostly concentrated to the level near 2 to 0 euro/unit. Since the physical output shows a concentration around 80 billion unit/year[53], the nominal GDP (price * gross physical output) is mostly concentrated around 160 billion per year. This is significantly low comparing to the real-world nominal GDP of the Netherlands. According to the Het Centraal Bureau voor de Statistiek, the Statistics Netherlands, the nominal GDP in the Netherlands in 2016 and 2017 is 702 and 733 billion euro (CBS,2018).

[53] It is presented in Appendix F.

7.2 Policy robustness test

There are a few findings from the policy robustness test that could answer the odds found in the uncertainty analysis. Firstly, there are total 2778 scenarios in which DFM system was not turned (no DFM policy). This is a significant number considering the total number of the experiments in policy robustness test is 4000. This means that in 69.45% of chance, the policy is not necessary in the economy as the households do not default and the nominal GDP is maintained stable.

Secondly, there are total 382 cases that DFM system was on but the price level changed more than 5% (non-robust DFM). This is also a significant number considering that there are only 1222 cases that DFM system was invoked. By 31.26% of chance, DFM policy fails to stabilize the price level in the model.

The scenarios behind the "non-robust DFM" policy cases and the "no DFM policy" cases are analyzed as below:

Table 6. The mean value of each uncertain variable in the scenarios that DFM policy was invoked but the price changes more than 5%.

		Robust DFM	Non-robust DFM
The mean value of the uncertain variables	Firm loan fraction	0.42	0.44
	RQ threshold	0.75	0.74
	LBC consumers' deposit fraction used for a share purchase	0.4	0.41
	LB consumers' deposit fraction used for a bond purchase	0.45	0.45
	Dividend payout ratio	0.43	0.65
	The fraction of LBC consumers' income to buying share	0.5	0.48
	The ratio between LB and LBC consumers to sell bonds	0.3	0.3
	Depreciation rate in manufacturing sector	0.2	0.21
	Depreciation rate in service sector	0.2	0.19
	The ratio of the households debt that default when D consumers default	0.75	0.76

Table 7. The mean value of each uncertain variable in the scenarios that DFM policy was not invoked.

		DFM	No DFM
The mean value of the uncertain variables	Firm loan fraction	0.42	0.43
	RQ threshold	0.75	0.75
	LBC consumers' deposit fraction used for a share purchase	0.4	0.4
	LB consumers' deposit fraction used for a bond purchase	0.45	0.45

	Dividend payout ratio	0.67	0.35
	The fraction of LBC consumers' income to buying share	0.5	0.5
	The ratio between LB and LBC consumers to sell bonds	0.3	0.3
	Depreciation rate in manufacturing sector	0.18	0.21
	Depreciation rate in service sector	0.2	0.2
	The ratio of the households debt that default when D consumers default	0.75	0.75

As shown above, dividend payout ratio plays an important role in determining the functionality of DFM policy. The mean value of dividend payout ratio in the scenarios that DFM system is not robust (DFM system is on but price changes) is 0.65 and in the scenarios of robust DFM system, it is 0.43. The mean value of dividend payout ratio in the scenarios that DFM system is not invoked ("No DFM") is 0.35 and in the scenarios of DFM system is invoked, it is 0.67.

This result shows that when dividend payout ratio is high, DFM system is invoked but by high chance, DFM system is not effective to stabilize the price. However, DFM system is not invoked when dividend payout ratio is low. The reason that dividend payout ratio contributes so much to DFM functionality in the model is because the dividends determine the price level.

When only a small fraction of the net income is given to the shareholders, firms can keep more net income for themselves and utilize it for the investments. Therefore, firms do not take bank loan or sell shares in order to fund their investment. If the firm does not have to repay the debt, interest tsyr ρ becomes zero in equation 4 and therefore the profitability of production capital (equipment) increases. Due to the increases profitability of the production capital, firms can invest more in expanding the production capital (equipment). This leads to more production and the price level is maintained low.

With a low price level, the wage of D consumers and LB and LBC consumers deposit level are also maintained low and this contributes to low house prices. Since house prices are low, D consumers' debt level is maintained low as well and therefore, D consumers do not default. Since the banks do not lose their equity because households do not default, DFM system is not turned on.

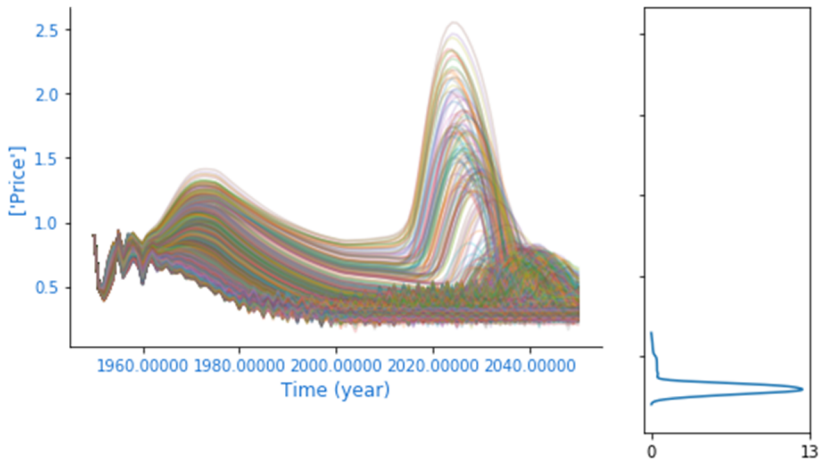

Fig 42. The price graph when DFM system is not turned on. The resulted prices are concentrated to less than 0.5. Comparing with the price graph in the uncertainty analysis, the price level when DFM system is not invoked is almost 6 times smaller than the average.

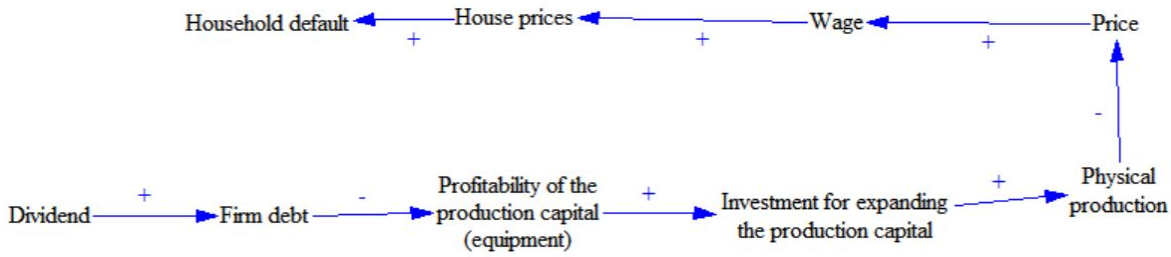

Fig 43. The mechanism of dividend influencing the price level and household default.

In figure 42, it is shown that resulted prices under scenarios that DFM system is not turned on are concentrated below 0.5 euro per unit. This is exceptionally and unrealistically small number.

However, when dividend payout ratio is high, the firms cannot utilize the sales income for their investment. Therefore the firms have to fund their investment with share sales and bank debt. The increasing bank debt brings down the profitability of the capital and firms do not see investments in the capital profitable. The firms therefore, do not invest in the capital as much as when dividend payout ratio is low. Since the firms do not invest in the new capital or even decrease the capital due to the low profitability, the production goes down. In this way, the price level increases. When the price level is high due to the high dividend payout ratio, there is more chance of price fluctuation under DFM system as well because of the increasing house prices and households default.

In conclusion, it is shown in the test results that the dividend determines the price level. When dividend payout ratio is decreased, the price level significantly decreases and vice versa. This also explains why the price level is concentrated on such low level, around 0 to 2 euro per unit. That is because the majority of the scenarios (2778 out of 4000) have low dividend payout ratio and therefore, DFM system is not turned on in these scenarios.

The average dividend payout ratio of S&P 500 companies[54] in the real world is around 40% (Damodaran, 2018). The reason that the model shows unrealistically low price level and no households default (it is an empirical fact that households defaulted in 2007) with dividend payout ratio around 30 – 40% is considered because that the model is not calibrated properly regarding dividend payout ratio.

Furthermore, even though it was not possible to conduct uncertainty analysis and policy robustness test with the original model, the original model has been only calibrated with dividend payout ratio of 100% and it shows drastically low level of price when the ratio is decreased. When dividend payout ratio is decreased to 75% it shows 10 times smaller nominal GDP and no households default.

Therefore, in order to raise the robustness (effective in different scenarios) of DFM policy, an elaborate calibration with dividend payout ratio is recommended in the future research.

[54] The Standard & Poor's 500, often abbreviated as the S&P 500 is an American stock market index based on the market capitalizations of 500 large companies which have common stock listed on the New York Stock Exchange or NASDAQ stock exchange (Obienugh, 2010).

08 Conclusions

8. Conclusion

8.1 Conclusion

In this thesis, a system dynamics model of FRB system from Van Egmond and De Vries has been improved and the improved model has been used to assess the effect of FRB system in the economy. This thesis answers the research question suggested at the beginning of the thesis:

"How to improve the System Dynamics model of FRB system from Van Egmond and De Vries (2016) in order to give more insight into the effect of FRB system in the economy? How does this improvement change the model results and how does FRB system work in different scenarios of the economy?"

Three problems in the model that decrease the model reliability have been improved in this thesis. The first problem was that the model crashes in different conditions. The model did not properly work in smaller time step or when the firm loan ratio increased above 60%. The second problem was the assumptions used in the model. Some parts of the model were based on the less realistic or less logical assumptions. The third problem was the model unit. The model units were not properly specified in the model. This made interpretation of the model results hard as the scale of the model is vague.

In this thesis the solutions for these model problems were sought through a model review and desk research. In this process the sub research question 1, "What causes the model problem?" and 2, "How the model problems can be solved?" were answered.

By reviewing the model, the cause of the model crash was found in the firm finance part. The firm finance part contained a time constant (delay time) which is same as the time step. According to the SD modeling manual, the time constant in the model has to be at least three times bigger than the chosen time step in order to avoid an error (n.d., 2018).

Furthermore, it was found that a positive feedback loop is created when firm loan ratio increases. In the original model, the firm finance part was designed for the firms to give the shareholders their entire net income as dividends. Therefore, when firms finance their investment more with loans emitting fewer shares, the shareholders receive total net income of firms buying only little shares. This increases the shareholders' income and consumption level significantly. Subsequently, the price level jumps high and based on the high price the firms demand more labor in order to produce more. This increases the wage and consumption and again, the firms' net income increases. Therefore, a positive feedback loop is created centering around dividends.

This positive feedback loop makes the model crash with the firms' net income (profit), dividend and LBC consumers' consumption increasing to infinity. This model crash problem is solved by restructuring the firm finance part.

The model problem caused by less realistic assumptions was solved by the desk research and model review. Through a model review, total 4 different parts are decided to be modified: Firm finance, Consumption, Households default and DFM system.

Firstly, the firm finances part, which is also a cause of the model crash problem, has been improved

by restructuring it to follow a proper corporate finance reporting rules such as income statement and cash flow statement. Furthermore, the firms' dividend payout ratio is modified to below 100%.

The production capital (equipment) profitability calculation has been changed as well. Since the firms fund only a part of their investment with bank loans, cost of capital has been modified to include only as much interest rate as firms take bank loans for investments.

Secondly, the consumers' consumption mechanism has been changed. In the original model, consumers first buy bonds and shares with their income and then use the rest for consumptions. In the improved model, consumers consume first with their income and then decide if they would like to purchase bonds or shares with the remaining income and wealth (saving deposit). Furthermore, in the original model the consumers buy the available bonds and shares as much as possible. In the improved model, consumers purchase bonds and share only as much as a part of their wealth (deposit) that they decided to buy bonds and shares with.

Thirdly, the households default mechanism has been changed. In the original model, the households defaulted when current house prices are too expensive for their income. In the improved model, the households default both when current house prices are too high and when the households cannot afford outstanding debt repayments with their current income.

Fourthly, the households default mechanism under DFM system has been modified. In the original model, banks do not play a role of intermediary between debtor and depositors under DFM system. Therefore, banks do not have any income from interest. In the improved model, it is assumed that the banks still play an important role of intermediary between debtors and depositors.

Furthermore, in the original model, household debts are only written off when banks cannot meet capital requirement under DFM system. In the improved model, loans are immediately written off against the deposit from which the loans were given, when households default.

The model units were also rightly defined for each variable in the improved model.

The improved model shows a different behavior than the original model. In the original model, the recession is initiated when households default. The households default when house prices are too high and this causes price drop.

However in the improved model, the recession is not initiated by households default. The recession is initiated by the economic slump. In the improved model, the wage level has been increased too fast during the economic boom. As wages increase too much, the labor profitability falls and the firms start hiring fewer employees. Price falls when the demand for labor falls short of the supply for labor. From that time on, wages start falling fast. Subsequently, the consumptions and price also fall fast causing the recession in the economy.

During the recession, households default in series. As house prices and household debts have increased enormously during the economic boom and the households still have to repay the debt when the economy is in the recession. The households then cannot afford large debt repayments with their shrunken wages and default in series until the debts are written off much enough that they can afford the repayments. Therefore, the recession starts because price is stagnated and it

lasts because of the high debt level.

Sub research question 3, “How the improvements of the model problems change the model results?” is thus answered; in the original model, price (and wage) decreases because households default and in the improved model, households default because price (and wage) decreases.

Under DFM system, both models show a stable price level. The demand level is sustained when households default, by the government expenditures and tax reduction. As money creation increases when price falls and decreases when price rises, aggregate demand and wages are maintained constant and therefore, the recession can be eliminated. Under DFM system, money creation is under control of a public body by separating the monetary and credit functions of the banking system. The sub research question 4 “Is FRB system effective to stabilize the price level and reduce the economic boom and bust in the improved model?” can be answered; FRB system is effective to stabilize price in the improved model.

According to the improved model, the Dutch economy is currently experiencing an economic boom but there is a possibility of a long-lasting recession in future. In the Dutch economy, household debts increased rapidly in last decade and there is a probability that price will fall. The recession will be initiated when price falls and the recession can last long due to high debt repayments. DFM system can be a solution to reduce the probability of the long-lasting recession to occur.

In the uncertainty analysis and policy robustness test, it is found that DFM system is not necessary and therefore, not turned on in 2778 scenarios out of 4000. Moreover, DFM system is turned on but price still fluctuates in 382 scenarios out of 1222. DFM system fails to stabilize the price by 31.3% chance. Therefore, DFM system in the model is considered to be not effective to stabilizing the price by high probability.

The reason that DFM system is not turned on and is not effective is because of dividend payout ratio. Dividend payout ratio is vital in the model as it highly affects the price level. The price level remains very low when dividend payout ratio is low (average 35%). As the price level is low, the wage and house prices also remain low and households do not default in such circumstance. Therefore, DFM system is not required when dividend scenarios. This is unrealistic as average dividend payout ratio in real world is around 40% and there was an empirical mass household default in 2007 (Damodaran, 2018). Furthermore, the nominal GDP remains too low comparing to the GDP in real world.

On the other hand, DFM system fails to stabilize the price level when dividend payout ratio is high (average 0.65). This is considered because the price level increases so much having more fluctuations when dividend payout ratio is high. Considering that the average dividend rate in the real world is 0.4 (Damodaran, 2018), it is concluded that the model is not appropriately calibrated with dividend payout ratio. It is assumed that the model was calibrated by the Van Egmond and De Vries not noticing the fact that dividends play such important role in the model. The model is only calibrated with dividend payout ratio of 100% which is empirically incorrect.

In conclusion, the policy robustness test results and analysis answer the sub research question 5, “Is FRB system effective in different scenarios? If not, what causes the ineffectiveness and how is it expected to be improved?”. DFM system is not effective to eliminating the price fluctuations in

different scenarios with high probability. The reason that DFM system is not robust in the model is because the model is not properly calibrated regarding dividend payout ratio. Therefore, the proper calibration regarding dividend payout ratio is required in order to increase the robustness of DFM system in the model and also the reliability of the model.

8.2 Research Limitation

The study includes a few limitations which could influence to its reliability. Firstly, the model has its limitation in calibration. The original model has been calibrated by the original modelers, Van Egmond and De Vries. They have calibrated the model with a dividend payout ratio of 100%. The original model shows relatively empirical result from year 1950 to 2016 with dividend payout ratio of 100%. In real world, however, the average dividend payout ratio is around 40% (Damodaran, 2018). In the original model, the price level remains unrealistically low when dividend payout ratio is set to 40%.

In the improved model, dividend payout ratio is set to 75% and the scale of the economy is much smaller than the original model. For instance, it is shown in the chapter 5 that the highest price in the improved model's result is around 5.5 euro per unit but the highest price in the original model's result is around 8.5 euro per unit. Therefore, it is considered that the model is calibrated inappropriately with incorrect dividend payout ratio.

In this study, the improved model is not calibrated to show empirical results. Therefore, it is not appropriate to place much reliance on what happened or will happen in which year. In the improved model, the year does not mean much.

However, the study focused more to show a development of recession which is different from what the original model shows. The development of recession in the improved model shows the debt overhang effect, which was not shown in the original model. Therefore, instead interpreting the results as they are giving the exact values for the future state, the results have to be interpreted as they give a meaningful insight to understanding of the complex mechanism and development of recession (Ford, 1999).

Furthermore, the study has a limitation that the model does not consider importation and exportation of goods and services. According to Turner (2015), the consumers can still maintain their consumption level with the stagnated wage because of the cheap imported goods and services from the developing countries. Furthermore, as only the domestic production is considered in calculating the price in the model, the price level is sensitive to the change in the domestic production. However, in real world, if the domestic production falls so the price increases, the imported goods and services can replace the domestically produced goods and services. The goods and services which are cheaper than the domestic goods and services are an important variable to the price level.

The fact that the real-world economy is more advanced than the modeled economy limits the model's reliability as well. For instance, the model does not include monetary or fiscal policies which have been executed in the Netherlands such as regulations on the mortgage, which would or would not have influenced to house prices and households debt level.

Finally, even though the time step error has been improved, the model still shows a slight different behavior in smaller time steps. The smallest time step at which the model behavior does not change was not found in this study.

8.3 Recommendation

Firstly, as mentioned in the previous chapter, the model needs to be calibrated with an empirical dividend payout ratio. In order to calibrate the model, the role that the dividend plays in the model has to be thoroughly analyzed.

Secondly, including importation and exportation in the model is considered to be necessary. The model now is a closed economic model and therefore, there is a limitation to calculate the price level accurately. The model is expected to be more insightful by including importation and exportation.

Thirdly, some of the model assumptions need to be more specified. Even though the thesis aimed to improve the model assumptions that were not specified enough, some of the model assumptions were left for the future improvement due to the constraint of time. For instance, the RQ is calculated with house prices, not with the actual bank loans that the households have to repay. Since not every D consumer households purchases the houses every year, the RQ should be calculated with the actual bank loans that the households have to repay, not with house prices.

Moreover, the way of interest rate calculation also needs to be more specified. The interest rate in the model is calculated with difference between the money demand (the investment of the firms and bonds issuance of the government) and the money supply (the consumers' and firms' deposit). However, the money demand does not include the money demand of households which is represented households loans.

In the model, firms are turned to be all-equity firms under DFM system. All equity firms fund their investment only with share sales or their own earnings. This means that the firms do not demand "money" that is supplied through the debt. Therefore, the firms' investment should be excluded from the money demand in calculating the interest rate under DFM system. It is also unrealistic that all firms in the model turn to be all-equity firms.

Furthermore, the model behavior still changes slightly in a smaller time step. It is recommended to find the smallest time step at which the model behavior does not change in the future research.

In conclusion, there is still has a room for improvement in the model. There are model assumptions that can be specified in the future research. A thorough calibration is highly recommended in the future research. It is also recommended to find a proper time step in which the model behavior does not change in the future research.

Bibliography

Bibliography

Andersen, A. L., Duus, C., & Jensen, T. L. (2016). Household debt and spending during the financial crisis: Evidence from Danish micro data. European Economic Review, 89, 96-115. doi:https://doi.org/10.1016/j.euroecorev.2016.06.006

Arrow, K. J. C., H. B.; Minhas, B. S.; Solow, R. M. (1961). Capital-labor substitution and economic efficiency. Review of Economics and Statistics, 43, 225–250. doi:10.2307/1927286

Benes, J., Kumhof, M., (2012). The Chicago Plan Revisited Retrieved from IMF Working Paper

Board of governors of the Federal Reserve System. FRB: Regulation D: Compliance Guide (2016).

CAMPBELL, J., & COCCO, J. (2015). A Model of Mortgage Default. The Journal Of Finance, 70(4), 1495-1554. doi: 10.1111/jofi.12252

CBS StatLine - GDP, output and expenditures; value, QNA, 1995-2017. (2018). Retrieved from http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLEN&PA=82601ENG&LA=EN

Ceicdata. (2018). Retrieved from https://www.ceicdata.com/en/countries

Charles P. Kindleberger and Robert Aliber (2005), Manias, Panics, and Crashes: A History of Financial Crises, 5th ed. Wiley, ISBN 0-471-46714-6.

Damodaran, A. (2018). S&P Earnings History. Retrieved from http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/spearn.htm

Dixhoorn, C. V. (2013). Full Reserve Banking: An analysis of four monetary reform plans. Retrieved from Utrecht: http://sustainablefinancelab.nl/wp-content/uploads/sites/232/2013/07/Full-Reserve-Banking-Dixhoorn-SFL.pdf

European commission. (2017). laying down provisions for strengthening fiscal responsibility and the medium-term budgetary orientation in the Member States. Brussels.

Fisher, I. (1936), “100% Money and the Public Debt”, Economic Forum, Spring Number, April-June 1936, 406-420.

Global Property Guide. (2017). Retrieved from https://www.globalpropertyguide.com/Europe/Netherlands/Price-History

Godley, W. and M, Lavoie. (2007). Monetary economics : an integrated approach to credit, money, income, production and wealth. Palgrave Macmillan, Basingstoke, UK.

Hallegatte, S., Ghil, M., Dumas , P., Hourcade, J.C. (2008). Business cycles, bifurcations and chaos in a neo-classical model with investment dynamics. Journal of Economic Behaviour & Organisation 67(2008)55-77.

Hallegatte, S., M. Ghil, P. Dumas, J.C. Hourcade (2008). Business cycles, bifurcations and chaos in a neo-classical model with investment dynamics. Journal of Economic Behaviour & Organisation 67(2008)55-77.

Heldane, A. (2012). On being the Right Size. Speech, the Institute of Economic Affairs.

Jackson, T. (2016). Beyond consumer capitalism – foundations for a sustainable prosperity. Retrieved from www.cusp.ac.uk/publications.

Jackson, T. and P. Victor. (2014). Does slow growth increase inequality? http://www.prosperitas.org.uk/assets/does-slow-growth-increase-inequality---paper.pdf.

Josh Ryan-Collins, T. G., Richard Werner, Andrew Jackson (2011). Where Does Money Come From? : Independently published.

Keen, S. (2011). Predicting the "Global Financial Crisis"—Post Keynesian Macroeconomics. Submitted paper.

Keynes, J. (1936). The general theory of employment, interest and money. London :Macmillan,

Keynes, J. (1936). The general theory of employment, interest, and money (p. 166).

Krugman, P. (2014, 26 April 2014). Is A Banking Ban The Answer?, Opinion page. The New York Times. Retrieved from Is A Banking Ban The Answer?

Kwakkel, J. (2017). The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. Environmental Modelling & Software, 96, 239-250. doi: 10.1016/j.envsoft.2017.06.054

Kwakkel, J., & Pruyt, E. (2013). Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. Technological Forecasting And Social Change, 80(3), 419-431. doi: 10.1016/j.techfore.2012.10.005

Lin, T. (2012). Too Big to Fail, Too Blind to See. 80 Mississippi Law Journal, 355. Retrieved from https://ssrn.com/abstract=2040921

Lovati, J. (1976). The Unemployment Rate as an Economic Indicator. Review, 58. doi: 10.20955/r.58.2-9.ewf

Mankiw, N. (2009). Macroeconomics. New York: Worth Publishers.

McKay, M., Beckman, R., & Conover, W. (1979). A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code. Technometrics, 21(2), 239. doi: 10.2307/1268522

Mellor, M. (2016). Debt or Democracy - PUBLIC MONEY FOR SUSTAINABILITY AND SOCIAL JUSTICE: The University of Chicago Press

Meyer, M. Transportation Planning Handbook (p. 1182).

Minsky, Hyman P. Ph.D., "Financial Instability Revisited: The Economics of Disaster" (1970). Hyman P. Minsky Archive. 80. https://digitalcommons.bard.edu/hm_archive/80

MIT SDEP: What is System Dynamics?. (2018). Retrieved from http://web.mit.edu/sysdyn/sd-intro/

n.d. (2018). 100% Money and Chicago-Plan: Full Reserve Banking | Monneta. Retrieved from https://monneta.org/en/100-money-and-chicago-plan-full-reserve-banking/

n.d. (2018). Minimum reserves. Retrieved from https://www.ecb.europa.eu/mopo/implement/mr/html/index.en.html

n.d. (2018). Netherlands House Prices Growth Rate | Real Estate | Economic Indicators. Retrieved from https://www.ceicdata.com/en/indicator/netherlands/house-prices-growth

n.d. (2018). Netherlands: mortgage debt 1995-2017 | Statistic. Retrieved from https://www.statista.com/statistics/590299/total-mortgage-debt-from-households-in-the-netherlands/

n.d. (2018). Retrieved from http://www.uphelp.org/sites/default/files/pdfs/Depreciation_CP.pdf

n.d. (2018). Vensim Help. Retrieved from https://www.vensim.com/documentation/index.html?fn_exp.htm

n.d. (n.d.). Closed Economy. Retrieved from https://www.investopedia.com/terms/c/closed-economy.asp

n.d. (n.d.). Definition of real economy. Retrieved from http://lexicon.ft.com/Term?term=real-economy

Netherlands, S. (2018). GDP, output and expenditures; value, Quarterly National Accounts. In. The Hague/Heerlen.

O'Sullivan, Arthur; Sheffrin, Steven M. (2003). Economics: Principles in Action. Upper Saddle River, New Jersey 07458: Pearson Prentice Hall. p. 273. ISBN 0-13-063085-3.

Obienugh, J. (2010). Jonbull's Stock Guide: How to Invest Profitably in a Volatile Stock Market (p. 156). Victoria, BC, Canada.

OECD https://stats.oecd.org/glossary/detail.asp?ID=1163

Paul H. Douglas, I. F., Frank D. Graham, Earl J. Hamilton, Wilford I. King, and Charles R. Whittlesey. (1939). A Program for Monetary Reform. Retrieved from https://web.archive.org/web/20110726013412/http://www.economicstability.org/wp/wp-content/uploads/2010/07/A-Program-for-Monetary-Reform-.pdf

Paul H. Douglas, I. F., Frank D. Graham, Earl J. Hamilton, Wilford I. King, and Charles R. Whittlesey. (1939). A Program for Monetary Reform. Retrieved from

Ross, S. (2018). Why do banks write off bad debt? Retrieved from https://www.investopedia.com/ask/answers/070815/why-do-banks-write-bad-debt.asp

Statistics Netherlands. (2018). Consumer Price; Price Index 2015=100. Retrieved from http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLEN&PA=83131ENG&LA=EN

Statistics Netherlands. (2018). GDP, output and expenditures; value, Quarterly National Accounts.

Retrieved from
https://opendata.cbs.nl/statline/#/CBS/en/dataset/84105ENG/line?ts=1540731583984

Statistics Netherlands. (2018). Wealth of Households; components of wealth. Retrieved from https://opendata.cbs.nl/statline/#/CBS/en/dataset/83834eng/table?ts=1540968917945

Turner, A. (2015). Between Debt and the Devil.

Van Egmond, K., & De Vries, B. (2016). Monetaire hervorming; de mogelijkheid van een gezond financieel-economisch bestel Dynamics of a sustainable financial-economic system, 1-58.

Yamaguchi, K. (2011). Workings of A Public Money System of Open Macroeconomies: Modeling the American Monetary Act Completed.

Zheng, M., Wang, H., Wang, C., & Wang, S. (2017). Speculative behavior in a housing market: Boom and bust. Economic Modelling, 61, 50-64. doi:https://doi.org/10.1016/j.econmod.2016.11.021

Appendix

Appendix A Firm Finance

Before calculating the firm's net income, a few of vital model assumptions have to be introduced:

- The firm in the model represents not a singular firm but heterogeneous firms. Therefore the firm deposit and cash flows in the model is for the entire domestic firms. When firms buy materials that are necessary for their investment, such as constructing a new plant or buying new machineries, they buy them from other firms. But since the firms share a single cash stock and flow in the model, it is considered that the cash flow within the firm deposit is 0 (Cash comes out from one company and goes in to another company within a same deposit).
- Therefore, for a single firm, the cash flow regarding the investment can be described as below:

Table 8. Heterogeneous firm cash flow.

+	-
▪ Fund raised for the investment from a bank debt and share sales ▪ Sales income from other firms (amount of fund raised both form a bank debt and sales of share)	▪ Expense of the raised fund on investment (amount of fund raised both form a bank debt and sales of share)

As "sales income from other firms" and "Expense of the raised fund on investment" offset, the investment funding is the only income from the outside of the endogenous circle.

- The firm's net income is calculated as below:

Table 9. Net income calculation in the model.

Net Income from net income
+ Sales Revenue (consumers' and government's Consumption) + Investment funding (bank debt and share sales) + Interest on deposit - Bank debt interest payment - Wage payment - Tax
Net income

The first dividend is given out of the net income

$Div_p = (1-b)\ NI$ [M/year]

with Div_p the dividend from the net income and NP the net income. b is a rate that the firms

fund their investment with share sales used in equation 10.

After giving the dividend, the rest of firms' net income goes to the firm's deposit as a cash income. If the net income is negative the firms do not give shareholders any dividend. The deficit amount is filled with the extra bank loans.

$BL_{extra} = - NI \quad (NP<0)$ [M/year]

Therefore, the total firm bank loan is $BL_f + BL_{extra}$.

Appendix B Total income of LB and LBC consumers

Total income of LB and LBC consumers consists of different elements.

$TI_{LBC} = W_{LBC} + repay\ B_{LBC} + Div + \rho_d * M_{LBC}$ [M/year] (18)

$TI_{LB} = W_{LB} + repay\ B_{LB} + \rho_d * M_{LB}$ [M/year] (19)

W is the wage and repayB is the government bond repayment. ρ_d is the interest rate on saving deposits and M is saving deposit. The difference between total income of LB consumers and LBC consumers is that LBC consumers have an extra income from share dividends.

Disposable income of LB and LBC consumers is total income minus taxes and bonds or shares purchases. In the below equations, T is taxes that LB and LBC consumers have to pay. For LBC consumers, the income tax rate is also applied to their share dividend income.

$T_{LBC} = tr * (W_{LBC} + Div)$ [M/year] (20)

$T_{LB} = tr * W_{LB}$ [M/year] (21)

with tr tax rate decided by the government.

Appendix C Interest rate

The bank's main source of income is the borrower's interest payment over bank debts. This income becomes the bank equity. The banks receive the interest payment from the borrowers and pay the interest back to the depositors over their deposits. The interest rate on deposits ρ_d is lower than the one on the loans, ρ_l, reflecting the 'spread' which generates the profit of the bank. This spread can be considered as 'bank fee'. The rate ρ_d is chosen such that the received total interest on loans equals the total interest paid on deposits, plus the spread.

$(\rho_l + spread) * (BL_{firm} + BL_D + BL_{Gov}) = \rho_d * (Dep_{firm} + Dep_D + Dep_{LB} + Dep_{LBC} + Dep_G + BE)$ [Dmnl] (33)

$$\rho_d = \frac{\rho_l * (BL_{firm} + BL_D + BL_{Gov})}{Dep_{firm} + Dep_D + Dep_{LB} + Dep_{LBC} + Dep_G + BE} - spread \quad [1/year] \quad (31)$$

BL is bank loan and Dep is deposit. BE is the bank equity. In the model, the spread is set to 0.01.

The mechanism that ρ_l is decided is more complicated. The relevant feedback mechanism is found in the relation between the money demand and supply. In the economy, the money demand is represented by the economic agents' needs to acquire funds. When the firms need to invest or the government needs to fund their expenses, the money demand in the economy increases. Money supply is the existing deposits of the consumers and firms that can be utilized to funding the firms' investment and the government expenditures (Mankiw 2007:61).

In the model, when the bonds and firm investments increase, but the non-indebted consumers'[55] and firms' deposit do not, the money demand becomes higher than supply. In this case, the interest rate ρ will increase in proportion with the ratio of the required investment and the available deposit. This is a well-known relationship between required investments and the cost of money i.e. real interest rate (Mankiw 2007:61):

$$\rho_l = \frac{1}{\tau_{MD}} \frac{dMD}{MS} - \frac{1}{\tau_{MS}} \frac{dMS}{MS} \quad [1/year] \quad (32)$$

MD is money demand which is the firm investment plus bonds. MS is money supply which is the bank deposits of LB and LBC consumers and firms. τ_{MD} and τ_{MS} are relaxation factors. According to the equation 13, when the MD increases more than MS, the interest rate over loan ρ_l increases.

In order to structure this, the interest rate in DFM system has to be calculated including FRB loans.

$(\rho_l + spread) * (BL_{firm} + BL_D + BL_{Gov} + BL_{frb}) = \rho_d * (Dep_{firm} + Dep_D + Dep_{LB} + Dep_{LBC} + Dep_G + BE)$ [Dmnl] (29)

$$Repay_{frb} = \frac{BL_{frb}}{t_{repay}} + \rho_l * BL_{frb} \quad [M/year] \quad (38)$$

As shown above, the calculation of the interest rate on the deposit now includes FRB loan which is the bank loan given to the D consumer under DFM system. Furthermore, the interest rate on the

[55] In the model, only non-indebted consumers can buy bonds or shares.

debt under DFM system is no longer ρ_{frbl} but normal ρ_l. The reason that the ρ_{frbl} is 0.03 higher than ρ_l in the original model is considered because the debt supply level is lower under DFM system as the debt is given only from the existing deposit. However, there is no need to arbitrarily modify the interest rate on the debt as the ρ_l calculation anyway includes the deposit level.

$$\rho_l = \frac{1}{\tau_{MD}} \frac{dMD}{MS} - \frac{1}{\tau_{MS}} \frac{dMS}{MS} \quad \text{[1/year]} \qquad (31)$$

MD is money demand which is the firm investment plus bonds. MS is money supply which is the bank deposits of LB and LBC consumers and firms. In DFM system, the MS decreases as the loans are given from their deposit. Therefore, the ρ_l increases even without arbitrary interest rate modification.

Appendix D Number of Transaction

The number of transactions per year n_{trans} is assumed to be a multiply of a fixed fraction f_{trans} and the number of D consumers' households plus the newly included D consumers' households.

$$n_{trans} = f_{trans} * n_{Dhh} + dn_{Dhh} \quad [1/year]^{56} \quad (37)$$

f_{trans} is a proportion of the D consumer households that make mortgage - house purchase transactions. And n_{Dhh} is the number of D consumer households. It is assumed that the newly added D consumer households, such as young households, must make a mortgage-house purchase transaction.

This means, a f_{trans} fraction of households make a mortgage-house purchase transaction every year. However, the actual number of transactions will also depend on house prices and the bank loan issued. Increasing house prices and decreasing bank loans reduce transactions, hence:

$$\frac{d\, f_{trans}}{f_{trans}} = \frac{1}{\tau_{BL}} \frac{dBL}{BL} - \frac{1}{\tau_{ass}} \frac{dP_{ass}}{P_{ass}} \quad [1/(household*year*year)]^{57} \quad (38)$$

τ_{BL} and τ_{ass} are time relaxation factors. This equation indicates that the transactions increase when there is enough money (loans) in the economy and the transactions decrease when house prices increase so fast that the loans are not issued enough yet.

[56] The actual unit is a million (times of transactions) per year.

[57] The unit indicates that the $\frac{d\, f_{trans}}{f_{trans}}$ is a changing rate of f_{trans} which is the number of transactions that a single household makes per year (1/(households*year)).

Appendix E Model Results

The result graphs of the original model (left) and improved model (right).

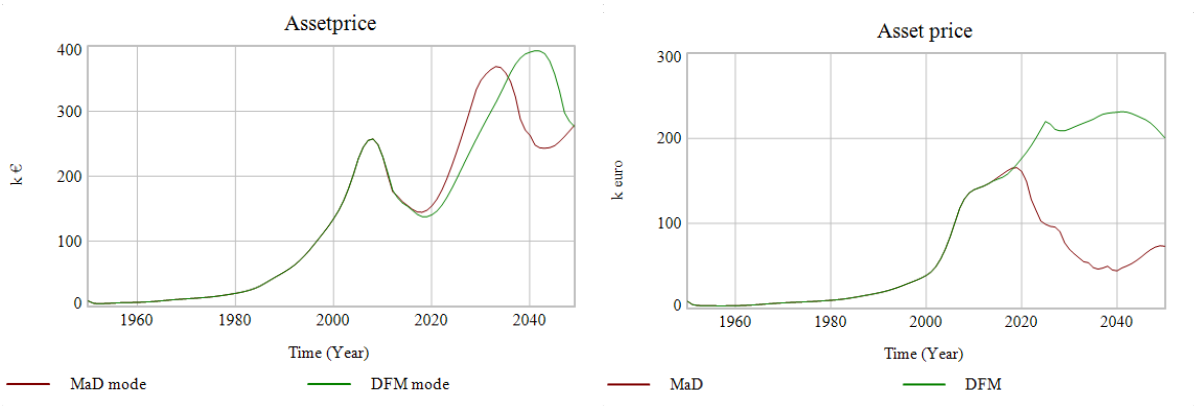

Fig 44. House prices graph of MaD system (red) and DFM system (green) in the original model (left) and in the improved model (right).

As shown in fig 44, house prices increase significantly both in the original and improved model. In the graph of the original model, house prices fluctuate as price fluctuates. House prices are the reason the recession is initiated. Under DFM system, house prices increase even higher but it does not affect households default anymore. In the improved model, growth of house prices is stagnated as price stagnated. High house prices cause the long-lasting recession but it also decreases rapidly during the recession as consumers cannot afford houses. Under DFM system, house prices do not fall but constantly increase.

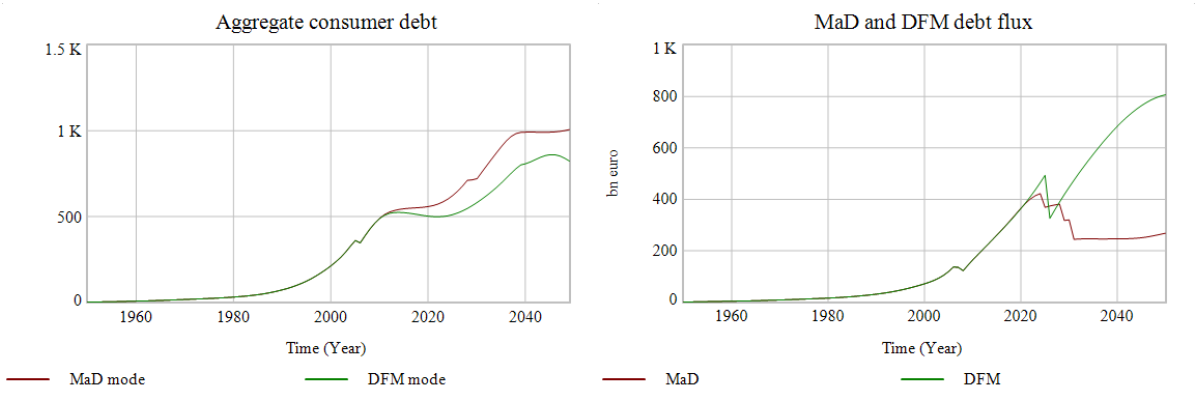

Fig 45. Household debt graph of MaD system (red) and DFM system (green) in the original model (left) and in the improved model (right).

In the original model, household debts growth is stagnated when house prices decrease. MaD graph shows small bumps when households default. As households do not default under DFM system in the original model, there is no bump in the DFM graph. In the improved model, household debts decrease and stagnated as house prices decrease under MaD system. Under DFM system, household debts increase as house prices increase but the graph shows bumps when households default.

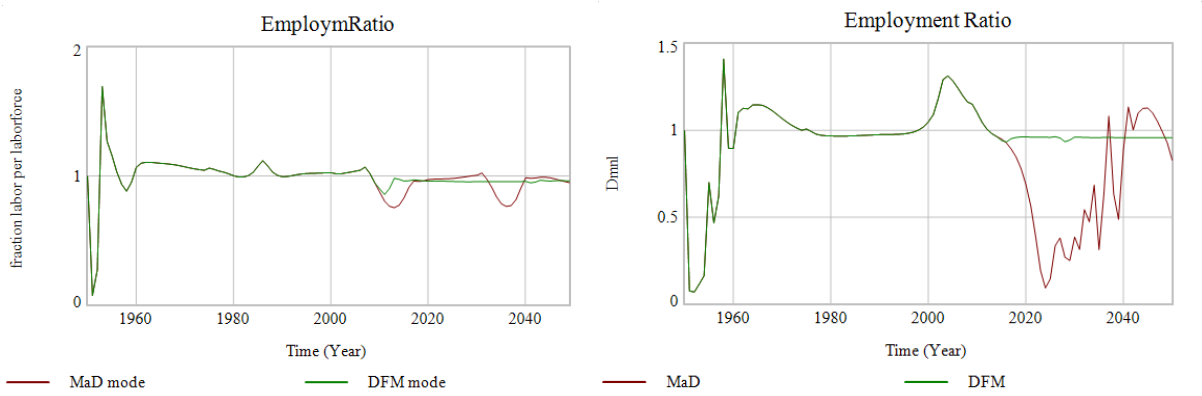

Fig 46. Employment (labor demand/labor supply) graph of MaD system (red) and DFM system (green) in the original model (left) and in the improved model (right).

Employment rate represents labor demand divided by labor supply. Employment rate in the original model shows a very similar behavior as price as it decreases below 1 under the recession. In the improved model, employment rate starts decreasing in 2004 but it still remains above 1. In 2014, it decreases below 1 and that is when the recession is initiated. After that, employment rate falls drastically.

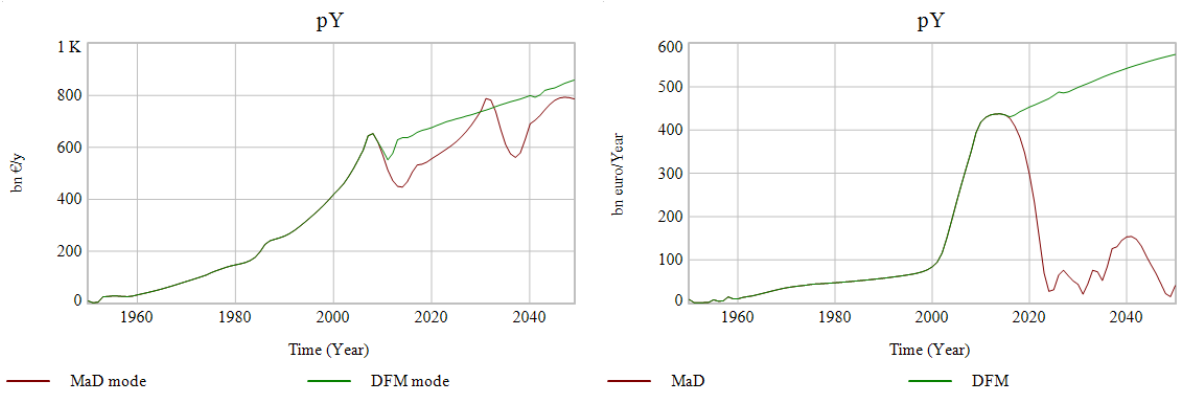

Fig 47. GDP (Price * physical output) graph of MaD system (red) and DFM system (green) in the original model (left) and in the improved model (right).

As GDP is a product of price and physical output, it shows almost same behavior as price. However, under DFM system, both model's graphs show GDP increases constantly unlike price which remains constant under DFM system. The reason is that the physical output increases constantly under DFM system.

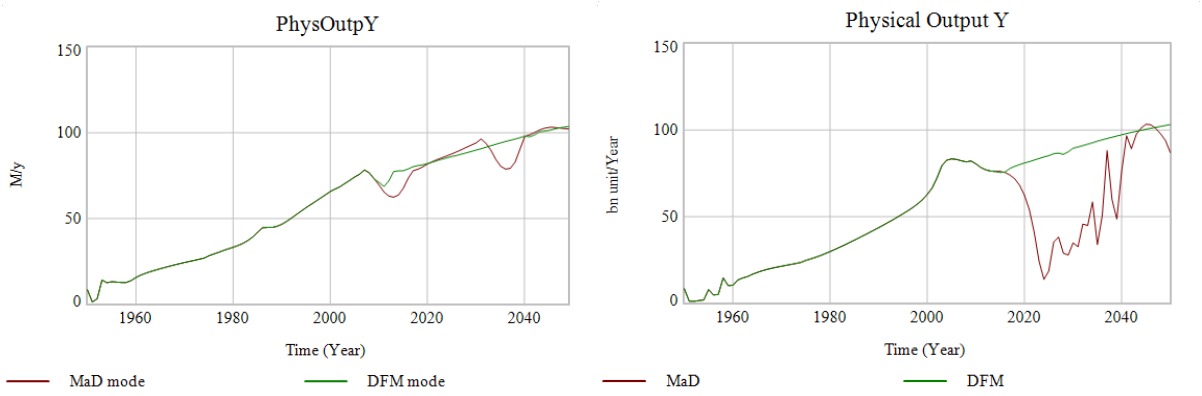

Fig 48. Physical output graph of MaD system (red) and DFM system (green) in the original model (left) and in the improved model (right).

In the original model, the physical output increases constantly except during recessions. In the improved model, the physical output starts decreasing in 2004 due to decreasing employment (labor demand). From 2014, it decreases drastically. However, under DFM system, the physical output increases constantly both in the original and improved models.

Appendix F Physical Output in 8000 different scenarios

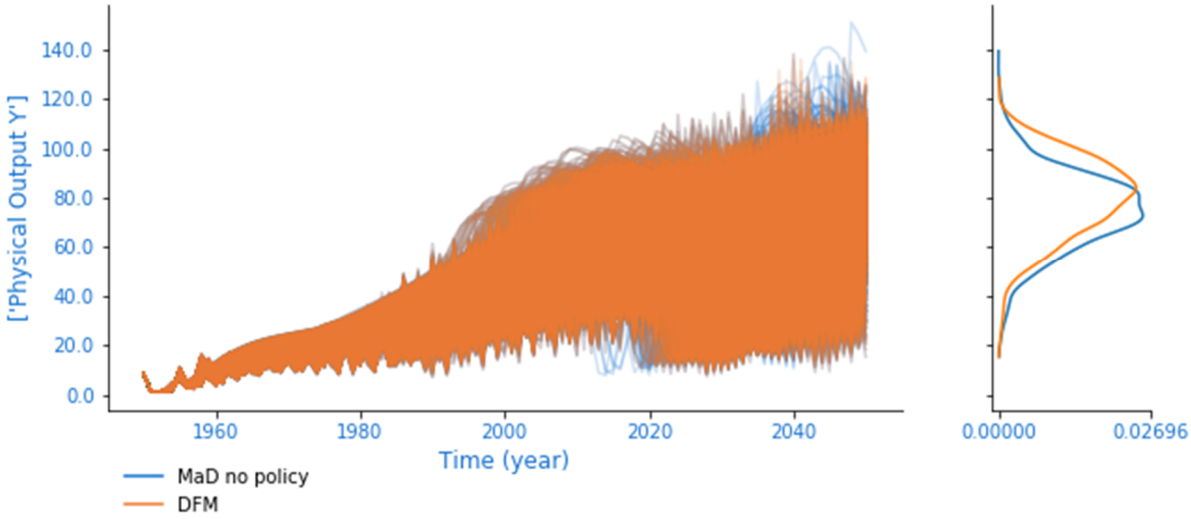

Fig 49. Uncertainty analysis physical output graph.

As shown in the above figure, physical output results in 8000 different scenarios concentrating around 80 billion units per year. This means, the average physical output in 8000 scenarios is 80 billion units per year.